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MARKET COUPLING IN THE POWER MARKETS

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Banca Examinadora:

____
Prof. Dr. Rafael Schiozer (Orientador)
EAESP - FGV

____
Prof. Dr. Lauro Emilio Gonzales Farias
EAESP - FGV

____
Prof. Dr. Ricardo Rochman
EESP - FGV

Preface

The author of this thesis participates in a Double Degree Program jointly organized by the University of St. Gallen (HSG) in St. Gallen, Switzerland and the Fundação Getúlio Vargas (FGV-EAESP) in São Paulo, Brazil. Therefore this master thesis is to be submitted to both of these institutions. The master thesis has therefore to meet the requirements of the Master in Banking and Finance (HSG) as well as the requirements of the Master in International Management program of FGV-EAESP.

The main supervisor of this thesis is Prof. Dr. Karl Frauendorfer from the Institute for Operations Research and Computational Finance of the University of St. Gallen.

At FGV, the thesis is handed in under the supervision of Prof. Dr. Rafael Schiozer.

ABSTRACT

The thesis analyses the European Unions' effort to create an integrated pan-European electricity market based on "market coupling" as the proposed allocation mechanism for interconnector transfer capacity. Thus, the thesis' main focus is if market coupling leads to a price convergence in interlinked markets and how it affects the behavior of electricity price data. The applied research methods are a qualitative, structured literature review and a quantitative analysis of electricity price data. The quantitative analysis relies on descriptive statistics of absolute price differentials and on a Cointegration analysis according to Engle & Granger (1987)'s two step approach. Main findings are that implicit auction mechanisms such as market coupling are more efficient than explicit auctions. Especially the method of price coupling leads to a price convergence in involved markets, to social welfare gains and reduces market power of producers, as shown on the example of the TLC market coupling. The market coupling initiative between Germany and Denmark, on the other hand, is evaluated as less successful and illustrates the complexity and difficulties of implementing market coupling initiatives. The cointegration analysis shows that the time series were already before the coupling date cointegrated, but the statistical significance increased. The thesis suggests that market coupling leads to a price convergence of involved markets and thus functions as method to create a single, integrated European electricity market.

KEYWORDS: Market coupling, Implicit auctions, Explicit auctions, Market integration, Cointegration

RESUMO

A dissertação analisa o esforço dos sindicatos europeus para criar um mercado pan-europeu de electricidade integrada baseada em "mercados combinados", como o mecanismo de alocação de capacidade de transferência de energia entre diferentes sistemas. Assim, o foco principal do estudo é se a integração do mercado leva a uma convergência de preços nos mercados interligados, e como isso afeta o comportamento dos preços de energia elétrica. Os métodos de investigação são uma revisão bibliográfica estruturada qualitativa e uma análise quantitativa de dados de preços de energia elétrica. A análise quantitativa se baseia em estatísticas descritivas das diferenças de preços absolutos e em uma análise de cointegração de acordo com a abordagem de Engle e Granger (1987). As principais conclusões são que os mecanismos de leilões implícitos, tais como a integração de mercado são mais eficientes que os leilões explícitos. Especialmente, o método de acoplamento de preços leva a uma convergência de preços nos mercados envolvidos, a ganhos de bem-estar social e reduz a o poder dos produtores no mercado, como mostra o exemplo da integração mercado TLC. A iniciativa mercados combinados entre a Alemanha ea Dinamarca, por outro lado, é avaliada como de menor sucesso e ilustra a complexidade e as dificuldades de implementação de iniciativas de integração de mercado. A análise de cointegração mostra que as séries temporais já estavam cointegradas antes da data de integração, mas a significância estatística aumentou. A tese sugere que a integração do mercado leva a uma convergência dos preços dos mercados envolvidos e, portanto, funciona como método para criar um mercado de eletricidade único e integrado na Europa.

PALAVRAS-CHAVE: integração de mercados, leilões implícitos, leilões explícitos, Cointegração

Content

Preface I
Abstract II
Resumo III
Content IV
List of Figures VI
List of Tables VIII
List of Abbreviations IX
1 Introduction 1
2 The Liberalization and Integration Process in European Electricity Markets 3
3 Relevant Stakeholders in European Electricity Markets 5
3.1 Regulators 5
3.2 Power Producers 6
3.3 Power Exchanges 8
3.4 Transmission System Operators 10
3.5 Auction Offices for Cross Border Capacity 13
4 Market Integration and Cross-Border Trade in Europe 15
4.1 Regional Electricity Markets 15
4.2 Analysis of Cross-Border Trade 18
5 Congestion Management 26
5.1 Capacity Calculation Methods 28
5.1.1 ATC Approach 28
5.1.2 Flow-Based Approach 30
5.2 Capacity Allocation Methods 30
5.2.1 Explicit Auctions 31
5.2.2 Implicit Auctions 32
5.2.3 Market Splitting 34
5.2.4 Market Coupling 35
5.2.5 Redispatching 37
5.2.6 Countertrade 37

6 Market Coupling in Practice 39
6.1 Market Coupling Initiatives 39
6.2 The EU Target Model 41
6.3 Market Coupling within Different Timeframes 43
7 Qualitative Evaluation of Market Coupling 48
7.1 Comparison of Different Capacity Allocation Methods 49
7.2 Impact of Market Coupling on Market Power 52
7.3 Welfare and Economic Effects 53
8 Descriptive Statistics of Market Coupling Initiatives 55
8.1 Data set 55
8.2 Price Convergence and Market Coupling 58
9 Cointegration Test 66
9.1 Methodology 66
9.2 Empirical Results Unit Root Test 68
9.3 Empirical Results Engle-Granger Cointegration Test 69
10 Conclusion and Outlook 72
References XI
Appendix XX
Declaration of Authorship XXVI

List of Figures

Figure 1: Power Generation Mix in European Countries in 2012 7
Figure 2: ELIX as theoretical future price of an integrated European power market...... 10
Figure 3: ELIX Price history 10.2010-11.2012 10
Figure 4: The creation of regional markets as interim steps towards an Internal Electricity Market.. 15
Figure 5: Seven Regional Electricity Markets 17
Figure 6: Net Export (Export minus Import) per country 18
Figure 7: Illustration of physical energy flows, production and consumption across the Baltic Region (and Finland) in 2012 20
Figure 8: Illustration of physical energy flows, production and consumption across CEE in 2012.. 21
Figure 9: Illustration of physical energy flows, production and consumption across CSE in 2012.. 22
Figure 10: Illustration of physical energy flows, production and consumption across CWE in 2012 23
Figure 11: Illustration of physical energy flows, production and consumption across the Northern Region in 2012.. 24
Figure 12: Illustration of physical energy flows, production and consumption across SWE and Marocco in 2012 24
Figure 13: Illustration of physical energy flows, production and consumption across FUI and Netherlands in 2012... 25
Figure 14: Commercial Flows versus Physical Flows 27
Figure 15: Derivation of ATC 29
Figure 16: ATC method 29
Figure 17: Order of Congestion Management Methods... 31
Figure 18: Implicit auctioning 33
Figure 19: Volume coupling based on Glachant (2010)... 36
Figure 20: Price coupling based on Glachant (2010).. 37
Figure 21: The EU Target Model 42
Figure 22: Implemented market coupling in the day-ahead market 44
Figure 23: Implemented market coupling in the intraday market 46

Figure 24: Long-term Transmission Rights 47
Figure 25: EEX (Germany) 57
Figure 26: EPEX (France) 57
Figure 27: Nord Pool Spot Copenhagen NPS (Denmark DK2)..................................... 58
Figure 28: APX (Netherlands)... 58
Figure 29: Frequency Distribution of Price Differentials for the TLC Coupling............... 60
Figure 30: Frequency Distribution of Price Differentials for the EMCC Coupling 62
Figure 31: Frequency Distribution of Price Differentials for the CWE Coupling 64

List of Tables

Table 1: European Transmission System Operators/ Member Companies of ENTSO-E 13
Table 2: Market Coupling Initiatives.. 39
Table 3: Authors focusing on the comparision of congestion management methods 48
Table 4: Authors focusing on the impact of market coupling on market power.............. 49
Table 5: Authors focusing on social welfare and economic effects................................ 49
Table 6: Advantages and disadvantages and summary of different congestion management methods.. 51
Table 7: Type and source of data 55
Table 8: Descriptive Statistics for daily spot prices €/MWh... 56
Table 9: Descriptive Statistics for daily log prices 57
Table 10: Descriptive Statistics TLC, in €/MWh.. 59
Table 11: Descriptive Statistics EMCC, in €/MWh 61
Table 12: Descriptive Statistics CWE MC, in €/MWh... 63
Table 13: Significance levels and lag length of ADF unit root tests before and after coupling 69
Table 14: ADF T-statistics for cointegration tests in the pre-coupling periods 70
Table 15: ADF T-statistics for cointegration tests in the post-coupling periods............. 71
Table 16: Energy Exchanges in Europe XXIII

List of Abbreviations

AAC	Already Allocated Capacity
ACER	Agency for the Cooperation of Energy Regulators
ATC	Available Transfer Capacity
BS	Baltic States
CACM	Capacity Allocation and Congestion Management
CEE	Central Eastern Europe
CEER	Council of European Energy Regulators
CRCC	Cross Regional Coordination Committee
CSE	Central Southern Europe
CWE	Central Western Europe
EEX	European Energy Exchange
ELIX	European Electricity Index
EMCC	European Market Coupling Company
ENTSO-E	European Network of Transmission System Operators for Electricity
ERI	Electricity Regional Initiatives
ERGEG	European Regulators' Group for Electricity and Gas
FUI	France, UK and Ireland
GWh	Gigawatt-hours
ICER	International Confederation of Energy Regulators
IEM	Internal Electricity Market
ITVC	Interim Tight Volume Coupling
NRA	National Regulation Agency
NTC	Net Transfer Capacity
NEW	North Western Europe (Cross Regional Market Coupling)
PCG	Project Coordination Group of Experts

PCR	Price Coupling of Regions
PTDF	Power Transmission Distribution Factors
PX	Power Exchange
SWE	South West Europe
TLC	Trilateral Market Coupling
TSO	Transmission System Operator
TWh	Terawatt-hours
TYNDP	Ten-Year Network Development Plan

1 Introduction

It is the declared goal of the European Union to create a single, integrated electricity market in Europe. That requires the linking of formerly separated national electricity markets. This process of integrating different markets is highly complex. It is necessary to involve a broad variety of stakeholders, to look at different national regulations and to combine different market structures. On top of that, the electricity transfer capacities between single countries are often insufficient and the linkages are not suited for a single, integrated market. Thus, congestion occurs. This scarce transfer capacity can be allocated through different methods. To ensure an efficient integrated market, the European Union proposes the use of implicit auction mechanisms and more precisely the use of market coupling. Market coupling is a congestion management mechanism that allows electricity traders to bid directly for electricity contracts without buying transfer capacity on a separate market. As such, market coupling allows the use of one single auction mechanism for cross-border electricity trade. Although this auction mechanism seems very promising, the implementation appears to be challenging and delays in the implementation of an integrated electricity market occur.

The aim of this master's thesis is to provide an overview of the European electricity market and its relevant stakeholders in order to describe the implementation process towards a single, integrated market. Based on these fundamentals, the thesis aims at analyzing market coupling as the proposed transfer capacity allocation mechanism. Thus, this paper explains the functioning of this mechanism and compares it with alternative allocation methods. The main contribution is an assessment of market coupling in terms of economic effects, impact on market power and price convergence. This assessment is based on a qualitative literature review as well as on a quantitative analysis measuring the degree of price convergence. Finally, it is investigated if the price behavior of electricity prices in linked markets changes significantly after the coupling. This investigation is based on cointegration, a statistical method introduced by Engle and Granger (1987).

In order to achieve these goals, the thesis is structured as follows: After the introduction, the second chapter provides an overview of the liberalization and integration process in European electricity markets. The third chapter introduces the relevant stakeholders, which are directly affected or involved by the creation of a single, internal European electricity market. The fourth chapter investigates the market integration process in detail. Thus, these chapters represent the first part of the thesis by providing an overview of the European electricity market framework and cross-border electricity trade within Europe. The second part of the thesis examines the functionality and efficiency of the "linking" of single countries through market coupling. Therefore, the fifth chapter offers a theoretical overview of different congestion management tools. The sixth chapter provides an analysis of implemented market coupling methods for both, different regions and different timeframes. The seventh chapter assesses different congestion mechanisms based on a literature review. The eighth chapter offers a descriptive analysis of market prices and a quantitative analysis of the degree of price convergence before and after introducing market coupling. Based on that, the ninth chapter finally provides a cointegration analysis of the market price behavior of different market coupling initiatives. The tenth chapter summarizes the whole thesis and provides the concluding remarks. The approach of the thesis is to provide a systematic and holistic analysis of market coupling in European electricity markets.

2 The Liberalization and Integration Process in European Electricity Markets

The following chapter aims at providing a short overview of the historical development towards a liberalized and integrated electricity market in Europe as well as of the underlying legal framework and the most important regulations.

The liberalization of energy markets in Europe began through national initiatives in England and Norway. On a broader European scale, countries have started a long process of liberalizing their national electricity markets in the second half of the 1990s. One objective of the liberalization of the electricity supply industries was to build a single European electricity market, also referred to as Internal Electricity Market (IEM). In turn, the IEM represents the long-term goal of an electricity market that fulfills the criteria of competitiveness, sustainability and security of supply as stated by the (European Union) EU. To achieve this goal, the liberalization reforms of the electricity sector have been implemented by several legislative packages and regulations. *Directive 96/92/EC,* also known as "*First Electricity Directive*", can be seen as starting point of European liberalization efforts. Within this first Electricity Directive, the main issue was to restructure the power sector in the European member states. Originally vertically and horizontally integrated companies should be transformed towards companies that are separated in production, transmission, distribution and retail activities. This separation of different activities is called *unbundling* and is regulated in Article 14, Directive 96/92/EC; "Integrated electricity undertakings shall [. . .] keep separate accounts for their generation, transmission and distribution activities [. . .]" (The European Parliament and The Council of the European Union, 1996). Production and retail were restructured with the goal to enforce market-based competition. Transmission and distribution, on the other side, have the characteristics of natural monopolies (the rebuilding of a parallel grid network does not make sense) and are thus regulated through different regulatory systems, as a competitive market is not efficient for natural monopolies. The main issue is therefore a *free* and a *non-discriminatory network access* for *third-parties*. Hand in hand with the market restructuring, electricity started to be treated as a commodity with a wholesale price based on supply and demand. In 2003 a second electricity market reform has been implemented with *Directive 2003/54/EC*, known as "*Second Electricity Directive*". The second Electricity Directive mainly repeals Directive 96/92/EC and establishes common rules for the generation, transmission and distribution of electricity. Its objective is to create conditions that improve the competition in the electricity market while increasing efforts for the creation of a single electricity market. In the first two Electricity Directives, the main focus was laid on the liberalization of the electricity market with special attention on increasing competition, unbundling and third party access to grid structures. The issue of cross-border trade was addressed in 2003 by Regulation 1228/2003/EC on conditions for access to the network for cross-border exchanges of electricity. The act also defines principles of cross-border congestion management. The regulation is of special relevance as it proposes *market-based solutions* for the allocation of cross-border capacities (The European Parliament and The Council of the European Union, 2003b). Although first regulations for congestion management are implemented by Regulation 1228/2003/ EC, congestion management became a main issue in the "*Third Legislative Package*". The third legislative Package was implemented in 2009 and contains different directives and regulations handling cross-border trade of electricity. Many of them are repealing directives from 2003. The main issues regulated in the *Third Legislative Package* are definitions of common rules for the internal market of electricity (Directive 2009/72/EC repealing Directive 2003/54/EC), common rules for the internal market in natural gas (Directive 2009/73/EC repealing Directive 2003/55/EC), and for the establishment of an Agency for the Cooperation between national Energy Regulators (Regulation (EC) No 713/2009). Based on this article is the foundation of the *Agency for the Cooperation of Energy Regulators* (ACER) as the successor organization of the *European Regulators' Group for Electricity and Gas* (ERGEG). Furthermore, the Third Legislative Package also provides conditions for the access to the network for cross-border exchanges in electricity (Regulation (EC) No 714/2009 repealing Regulation (EC) No 1228/2003) and conditions for the access to the natural gas transmission network (Regulation (EC) No 715/2009 repealing Regulation (EC) No 1775/2005). Since the enactment of the described legal framework at the EU level, the liberalization reforms have not been implemented uniformly within the EU member states. As a result, alternative market designs across Europe emerged. This is why in 2006 the European Regulator's Group for Electricity and Gas (ERGEG; the forerunner organization of ACER, see Chapter 3.1) has launched the Electricity Regional Initiatives (ERI) project. The ERI project aims at setting up seven electricity regions across Europe as an interim step towards complete market integration. Through these regional initiatives, which emerged from a bottom-up approach, progress could be made concerning an improved management of cross-border congestions and concerning an optimized use of the available interconnection capacity. To avoid a divergence of developments across Europe, ERGEG established a working group in 2008 (called Project Coordination Group of experts, PCG) with the objective to create a *EU-wide target model* of congestion management methods. This model is meanwhile included in the *Framework Guidelines on Capacity Allocation and Congestion Management (CACM)*, issued by ACER, and provides a model on how to handle cross-border capacity issues. The main contribution of this model is the proposition to replace explicit auction mechanism with implicit auction mechanisms for the allocation of day-ahead cross-border interconnection capacity. (Agency for the Cooperation of Energy Regulators (ACER), 2011b; Pellini, 2012; Scheepers, Wals, & Rijkers, 2003; The European Parliament and The Council of the European Union, 1996, 2003a, 2003b, 2009a, 2009b, 2009c, 2009d, 2009e)

3 Relevant Stakeholders in European Electricity Markets

This chapter aims at providing an overview of the most important stakeholders that are involved or affected by cross-border trade issues and the previously described change in the legal framework. Section 3.1 briefly describes the most important regulators in Europe. Not covered are the legal bodies of the European Union as this would by far exceed the extent of this work. Section 3.2 provides an overview of the electricity production mix in European countries. Section 3.3 addresses European power exchanges (PXs). PXs are of special relevance because they are often directly involved in market coupling initiatives. Section 3.4 covers Transmission System Operators (TSOs), which often are directly involved in the creation of market coupling initiatives, too. Furthermore, TSOs represent the party most affected by cross-border trade, as it is their responsibility to hold the grid stable. Section *3.5 Auction Offices for Cross Border Capacity* introduces stakeholders over whose platform cross-border capacity can be traded.

3.1 Regulators

The regulators set the legal framework in which other stakeholders operate. Furthermore, many market coupling initiatives have their origin in changing regulatory frameworks. The most important ones are the following institutions:

CEER The *Council of European Energy Regulators* (CEER) is a non-profit organization based in Brussels. The organization was established in 2009 and serves as the voice of Europe's national regulators of electricity and gas at the EU and international level. The council enforces the cooperation and exchange of best practices between the independent energy regulators in Europe by providing a common platform. The declared goal of the organization is to "[. . .] facilitate the creation of a single, competitive, efficient and sustainable EU internal energy market that works in the public interest." (CEER). The organization also aims at promoting regulatory best practice worldwide through its membership in the International Confederation of Energy Regulators (ICER). Currently, CEER has 29 national energy regulators as members (27 EU-member states, Norway, Iceland) and two "observers", namely Switzerland and Macedonia. The council is closely linked to the Agency for the Cooperation of Energy Regulators ACER and both organization share similar objectives. (CEER)

ACER ACER stands for *Agency for the Cooperation of Energy Regulators* and is a European Union body created to further progress the development towards an internal energy market for both, electricity and natural gas. The organization was created by the "Third Energy Package"[1] and launched in 2011 with its headquarter in Ljubljana. The main purpose of the organization is to ensure that market integration and harmonization of

[1] The third Energy Package consists of different Regulations dated of 13 July 2009 (see also the previous chapter).

regulatory frameworks are done in respect of the EU's energy policy objectives. These goals are a more competitive, integrated market, an efficient energy infrastructure and a monitored and transparent energy market guaranteeing fair and cost-reflective prices. ACER is the successor of the forerunner organization **ERGEG** (European Regulators' Group for Electricity and Gas). CEER is a non-profit organization, whereas ACER is a formal EU Agency. (ACER, 2012; CEER)

ICER The *International Confederation of Energy Regulators* ICER is a voluntary framework for a better cooperation of energy regulators worldwide. The goal of the organization is to improve the awareness and the understanding of energy regulation and its impact to socio-economic, environmental and market issues for both, public and policy-makers. As such, the organization supports regulators in the exchange of information and best practices. (International Confederation of Energy Regulators ICER)

National regulations Beside the described regulators on a European and International level each country still has its own national regulation, referred to as National Regulation Agencies (**NRAs**), which are not further characterized.

3.2 Power Producers

The supply chain of electricity starts with its production. The methods of the electricity production heavily depend on a country's geographical shape as well as on the political framework and the political support of certain energy resources. Broadly, generation sources can be distinguished between *fossil fuels* (coal, oil, gas), *nuclear power*, *hydro power* (run-of-river, pumped storage plants, reservoir), *renewables ex. hydro power* (wind, photovoltaic, solar thermal) and some others like geothermal or tidal power plants, which are less important in terms of generation capacity. Figure 1 shows the share of each type of source by country in 2012. In Norway, Switzerland and Austria with its mountains, water reservoir and pumped storage power plants play a more important role than in flat countries. In countries with sea access such as (North-) Germany and Denmark, off-shore wind power plants account for a rising share in the production mix in recent years. Whereas Germany and Switzerland decided a nuclear phase-out after the nuclear power melt-down in Fukushima, in France nuclear power is still accounting for a substantial amount in the generation mix. The unique generation mix in each country is relevant for the topic of market coupling, as market coupling allows a more efficient and complement use of the different power generation methods. If, for example, in North Germany during night time (when the electricity consumption is very low) a heavy storm occurs and much power is produced, this power can be "stored" in pumped storage plants in the Alps (CH, AT) or in Norway if the relevant countries are connected over an efficient interconnection capacity allocation tool and sufficient interconnection capacity is available.

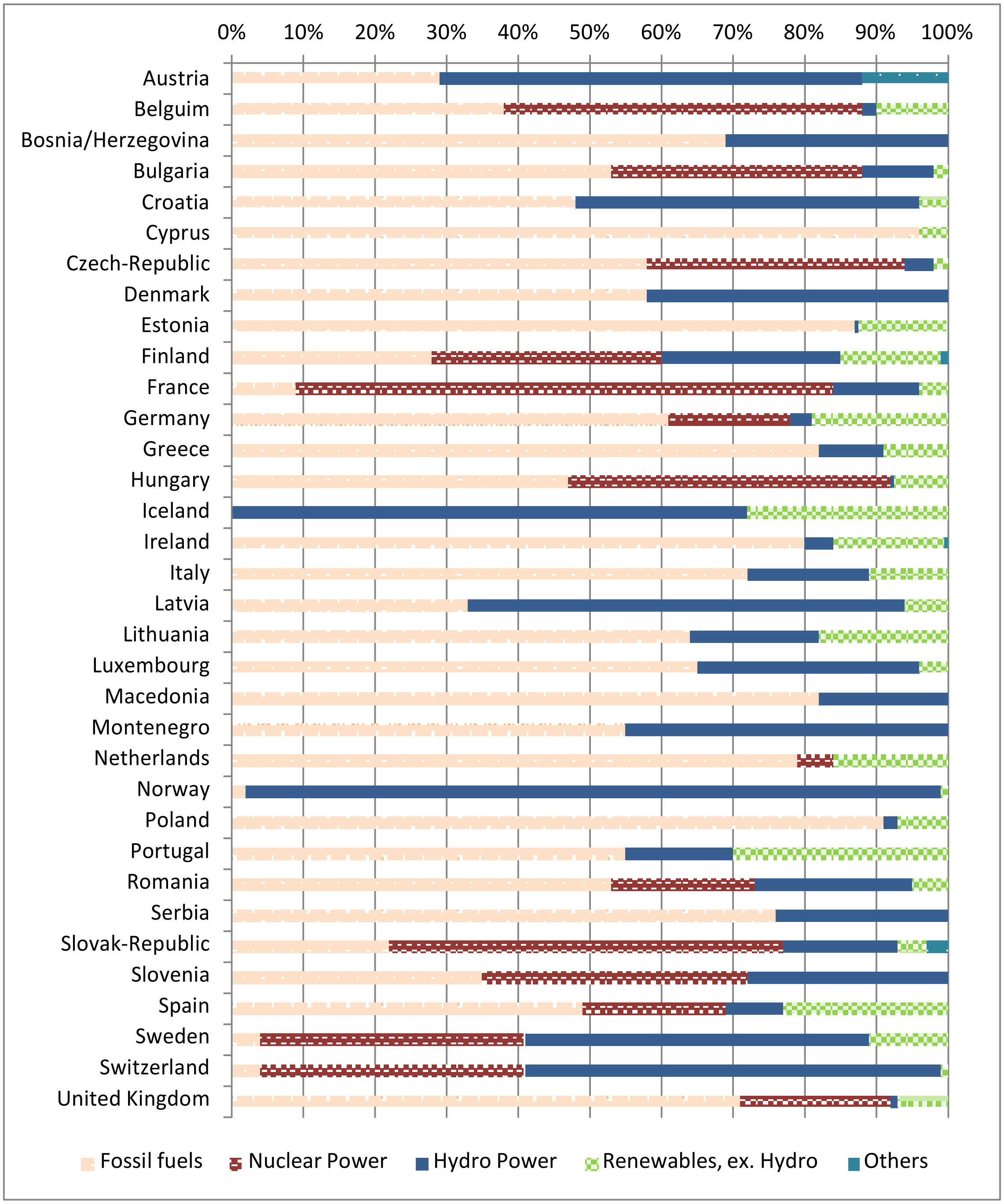


Figure 1: Power Generation Mix in European Countries in 2012
Source: (European Network of Transmission System Operators for Electricity ENTSO-E, 2012)

In most of the countries power is produced by a broad variety of companies with different sizes. Market coupling and the development towards an IEM is affecting producers in a way that market competition may increase and therefore market power decrease, as proposed by Mirza & Bergland (2012). The research paper provides evidence that producers exercise more often their market power during hours when transmission constraints occur (Mirza & Bergland, 2012). The most important producers in terms of power generation (measured in TWh) in Europe are listed in Appendix A.

3.3 Power Exchanges

Power Exchanges (PXs) are the market places for electricity and play an important role for the development towards a European internal energy market as they provide liquidity, reduce transaction costs and increase price transparency. Additionally, PXs provide key risk mitigation tools which market participants can use to hedge their exposure. The participants are electricity producers and consumers (physical side) or non-physical traders (intermediaries). (Association of European Energy Exchanges EUROPEX, 2013a; Scheepers et al., 2003)

Electricity can be traded on the spot market and on derivative markets. The spot market can be further divided into day-ahead auctions and intraday trade. In day-ahead auctions, hourly contracts that lead to power delivery for a certain hour on the following day are auctioned. Often, these hourly contracts can be bundled in block contracts. The most common block contracts are *base load contracts*, which contain electricity delivery for the hours 01 to 24 (24 hour delivery) and *peak load contracts* that contain power delivery for the hours 09 to 20 (08.00 am to 08.00 pm). Based on these block offers, many exchanges build indexes quantifying base load and peak load deliveries. In addition to the day-ahead auctions, many exchanges offer intraday trading for some market areas. In intraday auctions power can be bought and sold at a very short notice with delivery on the same day.

On the derivative markets, many exchanges offer futures with certain maturities like *day futures*, *weekend futures*, *week futures*, *month futures*, *quarter futures* and *year futures*. Mostly, futures are offered as base load (Mo-Su, 24 hours), peak load (Mo-Fr, 08.00 am to 08.00 pm) and off-peak (difference between base load and peak load: Mo-Fr from 00.00 am to 08.00 am and 08.00 pm to 12.00 pm and on Sa to Su from 12.00 am to 12.00 pm) contracts. The delivery rate for a future is usually 1 MW. By multiplying the delivery rate, the delivery period and the hours per day the contract energy volume is obtained (Example: 1 MW * 30 days * 24 h/day (Baseload) = 720 MWh).

Unlike in financial markets, power options are options either on electricity delivery or on a future contract as the underlying asset. A call option is the right to buy a given future contract and a put option is the right to sell a given future contract. In both contracts a specific quantity and a certain price are predetermined. In an American style option the buyer has the right but not the obligation to exercise a transaction on every trading day until maturity. In a European style option the buyer merely can choose to exercise his rights on the last trading day. Beside the spot markets and derivative markets, many Power Exchanges also offer over-the-counter (OTC) clearing. (European Energy Exchange EEX, 2012, 2013)

In Europe, there are several Power Exchanges that cover different market areas and offer different products. The umbrella organization for energy exchanges in Europe is EUROPEX.

EUROPEX The association of European Energy Exchanges EUROPEX is a non-profit association of European energy exchanges, registered in Brussels, Belgium. The association has currently 14 members from European countries. EUROPEX's objective is to represent the interests of the exchange based wholesale markets for electrical energy, gas and environmental markets with respect to the developments of the regulatory framework in Europe. The organization provides a discussion platform organized within work groups about certain topics like congestion management. Therefore, the organization, together with others like ENTSO-E plays an important role in the development towards an IEM. The electricity exchanges among the members of this organization are presented in Appendix B and represent the greater part of European power exchanges. (Association of European Energy Exchanges EUROPEX, 2013b, 2013c)

EPEX Spot The European Power Exchange EPEX Spot takes a special role in terms of market coupling. EPEX Spot is a Paris based power exchange for the spot markets of France, Germany, Austria and Switzerland and was created in 2008 through a merger of the power spot activities of Powernext SA (France) and EEX AG (Germany). As such, it is today a joint-venture owned by Powernext (50%) and EEX (50%). EPEX Spot offers an auction market for the delivery zones France, Germany/Austria and Switzerland and an intraday market for France, Germany and Austria, but not for Switzerland. Within the auction trade, orders can be made for individual hours or for block orders that link several hours on an all-or-none basis (that means the bid has to be matched on all hours or the entire bid is rejected). (European Power Exchange EPEX SPOT, 2013d)

The exchange, in cooperation with other exchanges and TSOs played a crucial role in the day-ahead market coupling by integrating the French, Belgian and Dutch day-ahead markets into the Tri-Lateral Market Coupling (TLC) between November 2006 and 2010. Since 2010, a market coupling in Central West Europe which covers Benelux, France and Germany known as CWE has been launched. Since November 2010 the CWE is also volume coupled with the Nordic region through the European Market Coupling Company EMCC (Chapter 3.5) via Interim Tight Volume Coupling ITVC. All these market coupling projects will be described in later chapters. Since October 2010 EPEX SPOT, together with EEX calculates the European Electricity Index ELIX for each delivery day at EPEX SPOT. The calculation of the index is based on the aggregated bid and offer curves for all market areas covered by EPEX SPOT. These markets are France, Germany/Austria and Switzerland and stand together for 36 percent of the European electricity consumption. As such, ELIX is seen as a market price that would result in a single European market without physical congestion, as visualized in Figure 2. The theoretical price curve that would occur within a single European market is represented by the ELIX index. The price history for the years 2010 to 2012 is shown in Figure 3. (European Power Exchange EPEX SPOT, 2013a, 2013b, 2013c)

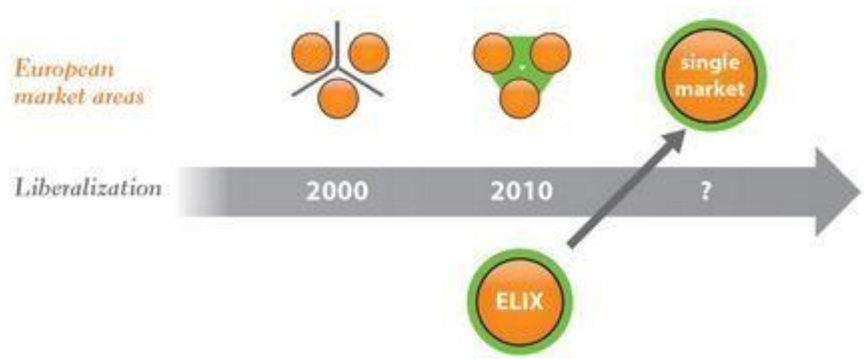


Figure 2: ELIX as theoretical future price of an integrated European power market Source: (European Power Exchange EPEX SPOT, 2013b)

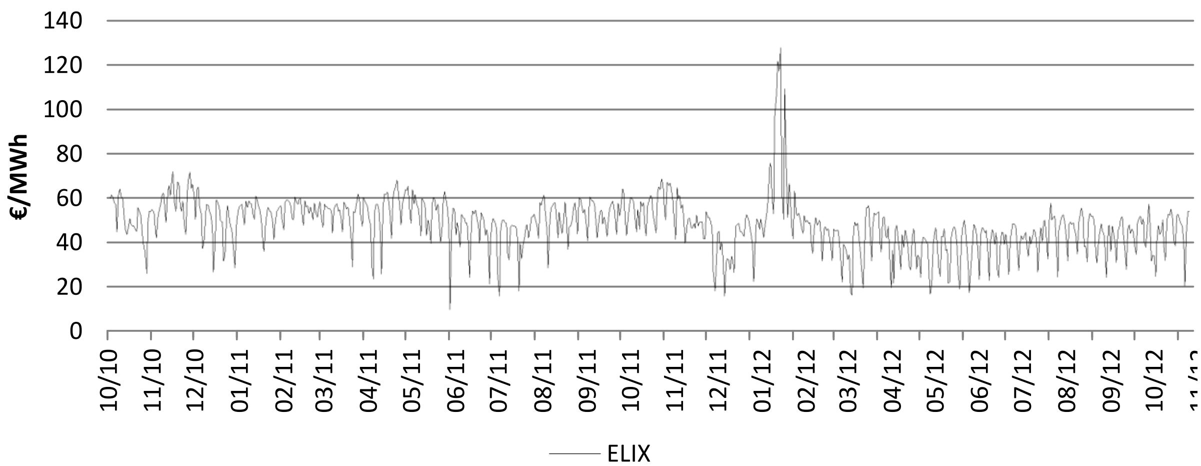


Figure 3: ELIX Price history 10.2010-11.2012[2]

3.4 Transmission System Operators

The transmission system operators (TSOs) are operating the transmission system for electricity in the respective markets. As such, their role is essential for the management of cross-border congestion.

ENTSO-E The *European Network for Transmission System Operators for Electricity* (ENTSO-E) is an association based on Belgian law. It represents 41 transmission system operators (TSOs) from 34 European countries. The organization was founded on December 19, 2008 and is operational since 1st of July 2009. ENTSO-E emerged from the

[2] Data provided by BLOOMBERG

six predecessor associations **Atsoi, Baltso, ETSO, Nordel, UCTE** and **UKTSA** and is legally based on Regulation (EC) 714/2009[3] in which the conditions for the access to the network for cross-border exchanges in electricity are regulated. Regulation (EC) 714/2009 lays the foundation for the establishment of a European network of transmission system operators for electricity to ensure an optimal management of the electricity transmission network. Furthermore, the network has the legal allowance of trading and supplying electricity across borders in the community. The regulation states that the working method of ENTSO-E has to ensure efficiency and transparency. The regulation mentions also the creation of regional initiatives run by TSOs in the corresponding countries: "[. . .] more effective progress may be achieved through an approach at regional level [so that] transmission system operators should set up regional structures within the overall cooperation structure [. . .]" (European Union, 2009). Regulation (EC) 714/2009 mandates ENTSO-E further to draft network codes for twelve areas. These codes include topics like network security, transparency, capacity-allocation, congestion management and energy efficiency and have to be in line with the corresponding guidelines defined by ACER. The network is also responsible for the development of non-binding community-wide ten-year network development plans (TYNDPs). These plans include a generation outlook, scenario developments and the modeling of the integrated network. Further activities are the adoption of annual working programs, common network operation tools and research and development activities. The network's importance is huge; it represents 305'000 km of transmission lines covering an area with 532 million of end-customers. The overall objective of ENTSO-E is the promotion of a reliable operation, an optimal management and an efficient technical development of the European electricity transmission system with the aim to ensure security of supply and to serve the needs of the European Internal Energy Market (IEM). (European Network of Transmission System Operators for Electricity ENTSO-E, 2011, 2012, 2013a, 2013b; European Union, 2009)

Beside ENTSO-E there exist national TSOs which are mostly also member companies of ENTSO-E. The TSOs are in their representative countries responsible for the transmission of electric power through high voltage electric networks. According to non-discriminatory and transparency rules, the TSOs provide grid access in a non-discriminatory manner to electricity market players[4]. The national TSOs also have to ensure security of supply. Therefore they have to guarantee a safe operation of the system as well as its maintenance. The non-discriminatory third party access requires that TSOs are operating independently from other electricity market players. (European Network of Transmission System Operators for Electricity ENTSO-E, 2013c)

[3] As such the organization has its "raison d'être" also in the Third Energy Package on Internal Energy Market
[4] Such as generating companies, traders, suppliers, distributors and directly linked customers

Table 1 provides an overview of European transmission system operators in the representative countries. They are all member companies of ENTSO-E. (European Network of Transmission System Operators for Electricity ENTSO-E, 2013c)

Country	TSO(s)
Austria	• Austrian Power Grid AG • Vorarlberger Übertragungsnetz GmbH
Bosnia/Herzegovina	• Nezavisni operator sustava u Bosni i Hercegovini
Belgium	• Elia System Operator SA
Bulgaria	• Electroenergien Sistemen Operator EAD
Switzerland	• Swissgrid AG
Cyprus	• Cyprus Transmission System Operator
Czech Republic	• CEPS a.s.
Germany	• TransnetBW GmbH • TenneT TSO GmbH • Amprion GmbH • 50Hertz Transmission GmbH
Denmark	• Energinet.dk Independent Public Enterprice
Estonia	• Elering AS
Spain	• Red Eléctrica de España: S.A.
Finland	• Fingrid OyJ
France	• Réseau de Transport d'Electricité
United Kingdom	• National Grid Electricity Transmission plc • Systems Operator for Northern Ireland Ltd • Scottish Hydro Electric Transmission Ltd • Scottish Power Transmission plc
Greece	• Independent Power Transmission Operator SA
Croatia	• HEP-Operator prijenosnog sustava d.o.o.
Hungary	• MAVIR Magyar Villamosenergia-ipari Átiviteli Rendszerirányító Zártkörüen • Müködö Részvénytársaság
Ireland	• EirGrid plc
Iceland	• Landsnet hf
Italy	• Terna-Rete Elettrica Nazionale SpA
Lithuania	• LITGRID AB
Luxembourg	• Creos Luxembourg S.A.
Latvia	• AS Augstprieguma Tïkls
Montenegro	• Crnogorski eletroprenosni system AD
Macedonia	• Macedonian Transmission System Operator AD
Netherlands	• TenneT TSO B.V.
Norway	• Statnett SF
Poland	• PSE S.A.
Portugal	• Rede Eléctria Nacional, S.A.
Romania	• C.N. Transelectrica S.A.
Serbia	• JP Elektromreza Srbije

Sweden	• Affärsverket Svenska Kraftnät
Slovenia	• Elektro Slovenija d.o.o
Slovak Republic	• Slovenska elektrizacna prenosova sustava, a.s.

Table 1: European Transmission System Operators/ Member Companies of ENTSO-E[5]

3.5 Auction Offices for Cross Border Capacity

The calculation of available cross-border transmission and its allocation is in many regions done by specialized auction offices. The most important are:

EMCC The European Market Coupling Company (EMCC) is an organization that improves the market efficiency of cross-border capacity trading in the Central Western European, the Nordic and the Estonian region. The company was founded 2008 in Hamburg, Germany and is a joint venture between Nord Pool Spot, European Energy Exchange (EEX), 50Hertz Transmission GmbH, TenneT TSO and Energinet.dk. The company is responsible for the day-ahead congestion management allocating the available cross-border capacity through implicit auctions (Chapter 5.2.2). The company's vision is to support the integration of regional markets towards a Europe-wide wholesale electricity market by improving the efficiency of cross-border capacity trading. Currently, EMCC carries out market coupling (Interim Tight Volume Coupling ITVC, see Chapter 5.2.4) on the two interconnectors between Germany and Denmark (DK West and DK East) and on the Baltic cable connecting Sweden and Germany. The NorNed cable between Norway and Netherlands was integrated to ITVC on January 12, 2011. (European Market Coupling Company EMCC, 2013a)

CASC.EU CASC.EU is the auction office for cross-border transmission capacity for Central Western Europe and for the borders of Italy, Northern Switzerland and parts of Scandinavia. The company provides a single auction platform for purchasing and selling transmission capacity. Thereby the company applies an explicit auction mechanism for cross-border capacity. The shareholders of the company are the transmission system operators from France, Germany, Benelux, Italy and Greece[6]. The organization emerged from a closer cooperation between the CSE TSOs and CASC-CWE S.A., the forerunner organization of CASC.EU. (CASC.EU, 2013a, 2013b)

CAO The Central Allocation Office (CAO) is the auction office for cross-border transmission capacity for TSOs of the Central East Europe region and since the beginning of 2013 for the borders of Croatia. The company provides an IT solution for capacity calculation and the allocation process called ePortal. The capacity calculation is done by applying an enhanced method of coordinated NTC (net transfer capacity) calculations.

[5] (European Network of Transmission System Operators for Electricity ENTSO-E, 2013c)
[6] These are Creos, Elia, TransnetBW GmbH, TenneT TSO GmbH, Tennet TSO B.V, RTE, Amprion, Austrian Power Grid AG, Electro-Slovnija, Independent Power Transmission Operator S.A., Swissgrid and Terna

The Shareholders of the company are eight TSOs from Germany, Austria, Poland, the Czech Republic, Slovakia, Hungary and Slovenia[7]. (Central Allocation Office GmbH (CAO), 2013a, 2013b).

[7] These are TenneT Germany, 50 Hertz, Polskie Sieci Elektroenergetyczne, CEPS, APG Austria Power Grid, Slovenska electrizacna, MAVIR and Eles

4 Market Integration and Cross-Border Trade in Europe

The stakeholders described in the previous chapter work together to create a single electricity market in Europe, based on the legal framework described in Chapter 2. This chapter analyzes the process of how this pan-European electricity market is intended to be created. First, the creation of different regional electricity markets as interim step towards an IEM is described (Chapter 4.1). Second, the electricity flows between single countries within Europe are described (Chapter 4.2). The analysis is based on data from the year 2012 and provides an overview of most important cross-border electricity flows.

4.1 Regional Electricity Markets

It is a stated objective of the European Commission and its regulators to create a "[. . .] single, efficient and effectively competitive electricity market." (European Regulators' Group for electricity and gas (ERGEG), 2005, p. 3). This vision of an internal electricity market is intended to be realized by creating a number of regional markets as interim steps from national markets towards a pan-European market, visualized in Figure 4.

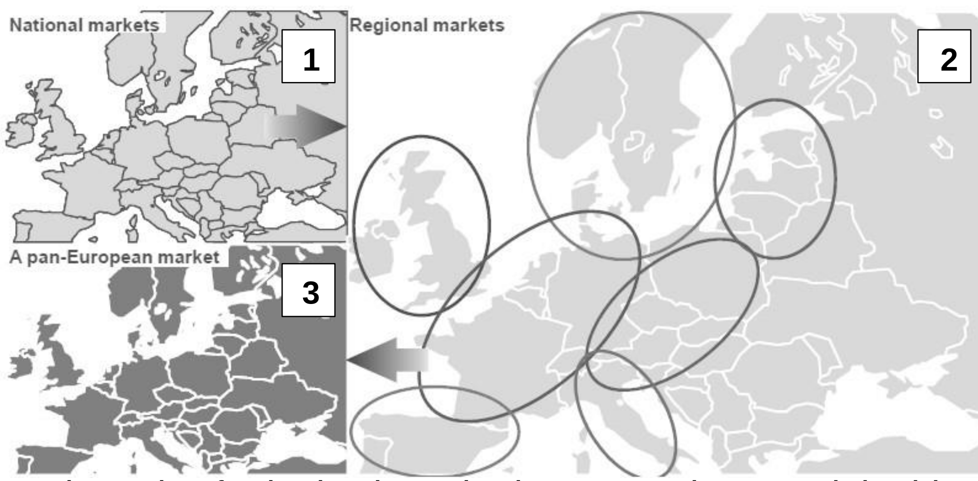


Figure 4: The creation of regional markets as interim steps towards an Internal Electricity Market
Source: (European Market Coupling Company EMCC, 2013b)

ERGEG states that the market arrangements within these regions are expected to be relatively strongly harmonized in a physical, institutional and political way. Beside these harmonizations, it is also mentioned that differences in areas such as taxation, environmental and social measures remain national issues. Although an exact definition of "regional market" is not provided by ERGEG four general conditions have to be fulfilled to qualify as regional market:

1. Between the different local markets within a region sufficient transmission capacity must exist and must be available to market participants through either implicit or explicit auctions.

2. There must not be any distortions in local markets that affect the functioning of the regional market.
3. A legal and regulatory framework that allows action across regional markets has to be existent.
4. National institutions within regional markets must coordinate and cooperate closely with each other. That applies in particular to TSOs, which have to ensure that the interconnector capacity is optimized and allocated efficiently. But it also strongly applies to regulators, who have to guarantee a proper information exchange and monitoring.

(Agency for the Cooperation of Energy Regulators (ACER), 2012; European Regulators' Group for electricity and gas (ERGEG), 2005, pp. 5-6)

The implementation of these regional markets is achieved by several *electricity regional initiative[s]* (ERI), launched in spring 2006 by ERGEG, the predecessor of ACER (see p. 5). The aim of these regional initiatives is to bring together national regulatory authorities (NRAs), TSOs and other stakeholders in a voluntary process to achieve the final goal of an IEM through an improvement of market integration. This approach is especially relevant in terms of congestion management as these regional initiatives represent a bottom-up approach to test solutions for cross-border issues within the regional markets and to get knowledge about good practice. The ERI created seven regional electricity markets (REMs) in Europe:

- **Baltic States (BS):** Estonia, Latvia, Lithuania
- **Central-East (CEE):** Austria, Czech Republic, Germany, Hungary, Poland, Slovakia, Slovenia
- **Central-South (CS):** Austria, France, Germany, Greece, Italy, Slovenia
- **Central-West (CWE):** Belgium, France, Germany, Luxembourg, Netherlands
- **Northern:** Denmark, Finland, Germany, Norway, Poland, Sweden
- **South-West (SWE):** France, Portugal, Spain
- **France, UK and Ireland (FUI):** The Irish electricity market is seen as single electricity market (SEM) as it includes the Republic of Ireland and Northern Ireland.

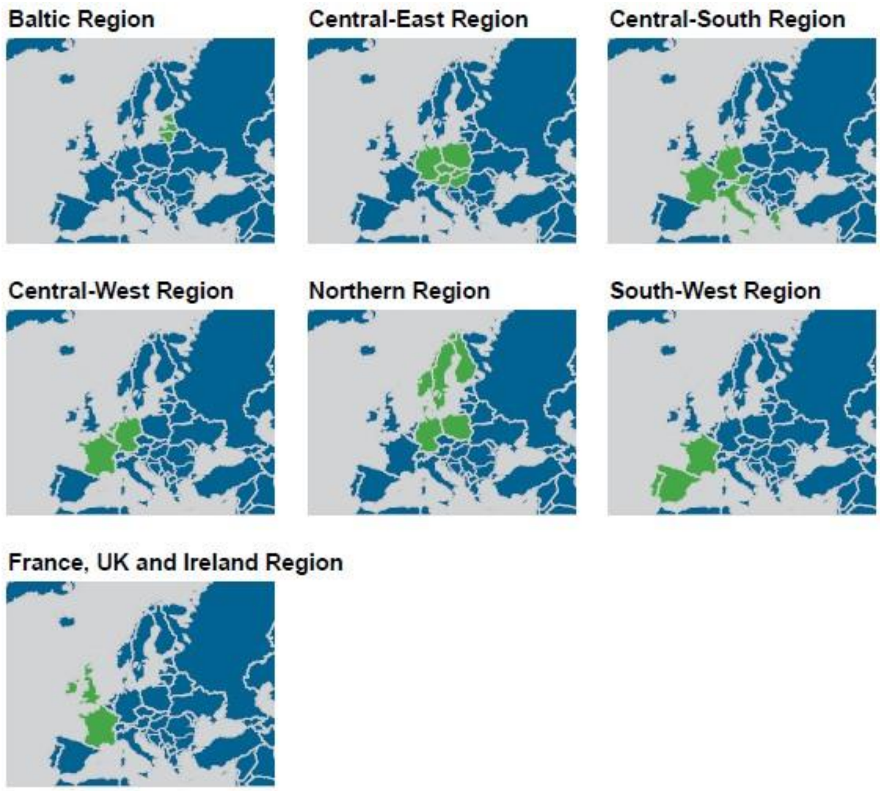


Figure 5: Seven Regional Electricity Markets
Source: ACER (2012)

(Agency for the Cooperation of Energy Regulators (ACER), 2012, 2013; Council of European Energy Regulators CEER, 2013; Weber et al., 2010)

These seven regional electricity markets bring together relevant stakeholders such as regulators, companies, member states and the European Commission beside other interested parties to develop and implement solutions for an improvement in how regional markets progress. The main purpose of these regional markets is to integrate formally fragmented national markets into a broader regional market context. Although they have the same objective, the priorities and difficulties are different and reflect their regional concerns. The progress towards a single EU market is monitored and overviewed at EU level to avoid a hampering in the development and to ensure that a convergence and coherence across regions takes place. The progress and difficulties of each regional market is monitored and presented by ERGEG on an annual basis at the European Regulatory (Florence) Forum. (Council of European Energy Regulators CEER, 2013) The completion of the IEM is planned for 2014. Until then, electricity markets throughout Europe must share several common features and must be linked by an efficient management of the interconnection capacities. To achieve this, Capacity Allocation and Congestion Management (CACM) are set by ACER as priority area. (Agency for the Cooperation of Energy Regulators (ACER), 2013).

4.2 Analysis of Cross-Border Trade

The cross-border trade of electricity in Europe differs between the different REMs. Figure 6 provides an overview of the electricity amount in TWh that is exported and imported for each country across Europe. The chart is based on monthly data from the year 2012 which was summed up for the twelve months. The focus in the chart is laid on physical flows of energy which represent according to the ENTSO-E glossary "the real movements of energy between neighboring countries metered in cross-border Tie Lines [. . .]" (European Network of Transmission System Operators for Electricity ENTSO-E, 2013d)[8]. From the observed countries, France and Germany are the two biggest electricity net exporters in Europe, with a net export amount of 43,516 GWh (France) and 23,096 GWh (Germany). Germany has the highest export and the second highest import. In Eastern Europe, a major net exporter is the Czech Republic. From the net exporting countries which are on the left side of the black line Switzerland represents a special role as it has the third largest export but also a relatively high import. It is supposed that these figures show the role of Switzerland as an important "transit nation" in the heart of Europe. Another reason could lay in Switzerland's pump storage PPs which consume (foreign) electricity to pump up water which is sold (and exported) during the day time for higher prices. This proposition can be supported when looking at Austria, another important transit country with a lot of pump storage PP which has also relatively high import and export amounts of electricity. Another reason could lay in seasonal patterns (exports in the summer, imports in the winter) (tradingeconomics, 2010).

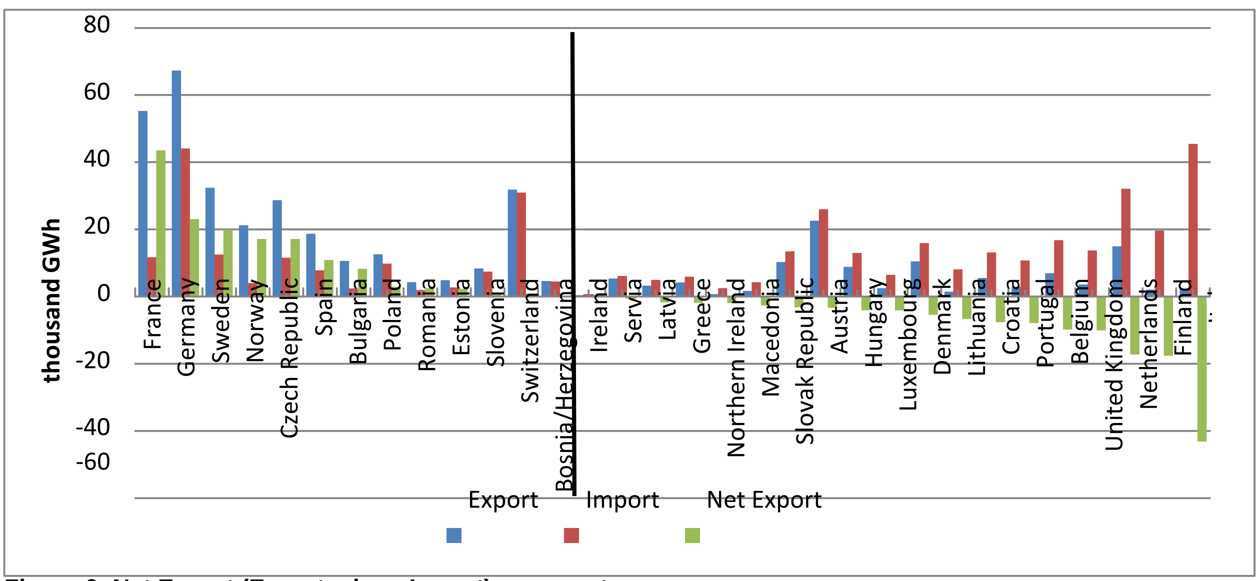


Figure 6: Net Export (Export minus Import) per country

[8] (Pellini, 2012) differentiates between **physical flows** which include the flows resulting from all the electricity markets such as day-ahead market, the intraday market and the market for ancillary services, and correspond to the electricity metered less the unbalances. **Commercial flows**, on the other side, represent according to Pellini (2012) only the flows from the day-ahead market.

Source: (European Network of Transmission System Operators for Electricity ENTSO-E, 2013e)[9]

The biggest net importing countries (right side of the black line in Figure 6) are Italy, which imported 43’192 GWh in 2012, Finland, which imported 17’596 GWh, the Netherlands, which imported 17’230 GWh and United Kingdom with a net import of 10’085 GWh in 2012. (European Network of Transmission System Operators for Electricity ENTSO-E, 2013e)

In the following, the directions of the physical flows between the single countries are investigated in detail to visualize on which borders market coupling is of special relevance. Due to the complexity of how the electricity is flowing between all the countries the research was done by splitting the European market into the previously described seven REMs. For each country in each REM the charts provide information about a country’s production and consumption (without pumps), the electricity flows between two countries whereby the direction of the net flows are visualized by black framed arrows (compared to dashed arrows for net imports). The shades of gray of the arrows represent the amount of the physical flows. The underlying data for each illustration is provided by ENTSO-E.

The most important electricity exchange in the **Baltic region** (Figure 7) was between Estonia and Latvia with 3’351 GWh and Latvia to Lithuania with 2’938 GWh in 2012. Estonia is linked with Finland over Estlink and through this interconnector 1’511 GWh was exported from the Nordic market to the Baltic region. The biggest producer in the Baltics is Estonia with a production of more than 10 TWh in 2012. Latvia ranks second and Lithuania ranks third. In terms of consumption Lithuania ranks first followed by Estonia and Latvia. Over all, the Baltic countries are relatively small markets compared to other REMs.

[9] The data is taken from the ENTSO-E Statistical Database which can be found under: *https://www.entsoe.eu/data/data-portal/.*

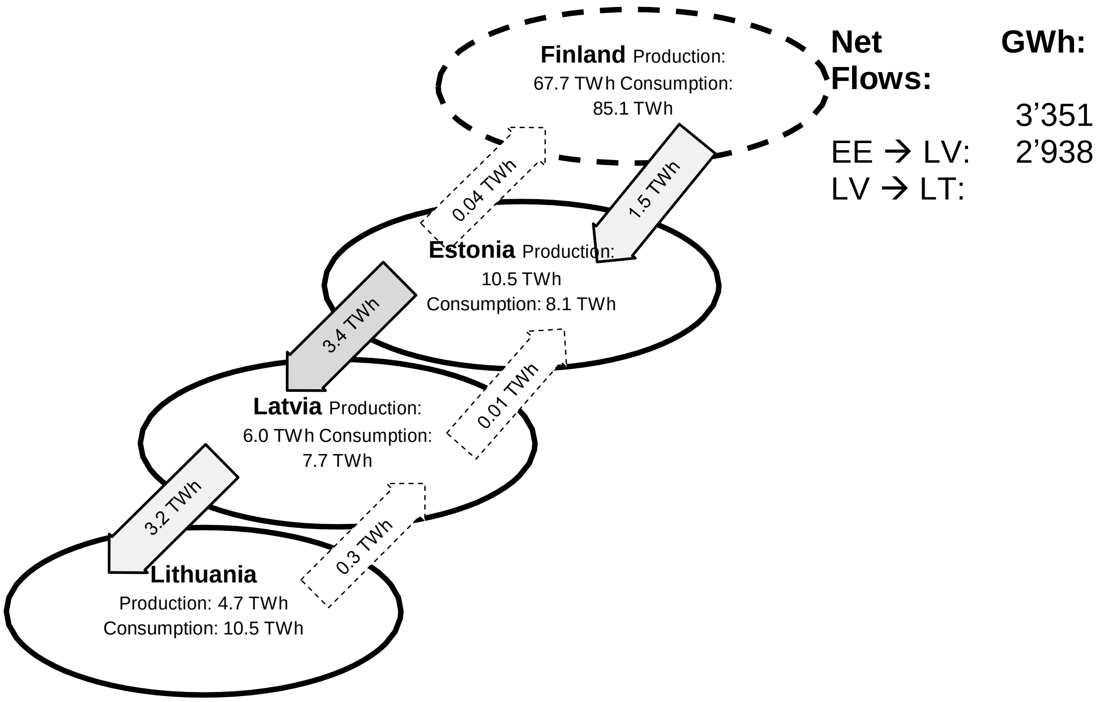
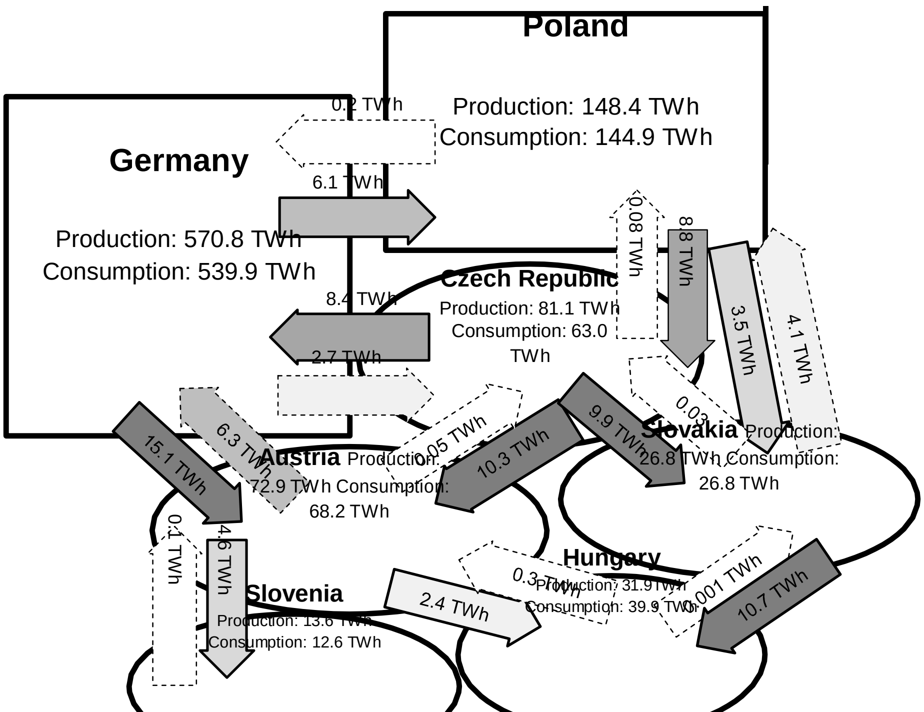


Figure 7: Illustration of physical energy flows, production and consumption across the Baltic Region (and Finland) in 2012

Figure 8 shows the electricity exchange across the **CEE** electricity region. Germany is the CEE’s largest market with a production of over 570 TWh and a consumption of 540 TWh in 2012. Poland ranks second in the CEE followed by the Czech Republic and Austria. Slovenia, Hungary and Slovakia are comparatively small markets. In the Central Eastern Europe market Germany, the Czech Republic, Poland and Slovenia are net exporters while Austria, Hungary and Slovakia are net importers of electricity. The most important cross-border electricity exchange is from Germany to Austria (15.1 TWh), from the Czech Republic to Austria (10.3 TWh) and to Slovakia (9.9 TWh) and further from Slovakia to Hungary (10.7 TWh). In the CEE the Czech Republic was 2012 the main exporting country for other CEE countries with net deliveries to Austria, Germany and Slovakia.



Net Flows:	GWh:
	2’094
AT → HU:	4’485
AT → SL:	10’258
CZ → AT:	5’742
CZ → DE:	9’885
CZ → SK:	8’748
DE → AT:	5’877
DE → PL:	8’754
PL → CZ:	3’498
PL → SK:	10’232
SK → HU:	

Figure 8: Illustration of physical energy flows, production and consumption across CEE in 2012

Also in the **CSE** region (Figure 9) Germany is the biggest market followed by France with a Production of 541.4 TWh in 2012. Germany, France and Slovenia are net exporters. The biggest net importing country, not only in the CSE region but of all European countries, is Italy. The main electricity exchange occurred from France to Germany (13.2 TWh) and from France to Italy (12.6 TWh). Although Switzerland does not belong to the CSE region, it is an important transfer country. In 2012, Switzerland was a net importer of electricity from Germany (9.6 TWh), Austria (7.9 TWh) and France (6.3 TWh). This electricity imports were mainly exported to Italy. In fact, the physical electricity flow from Switzerland to Italy was the biggest cross-border flow in whole Europe in 2012 with a volume of 24.7 TWh. Greece and Slovenia are minor markets within the CSE region.

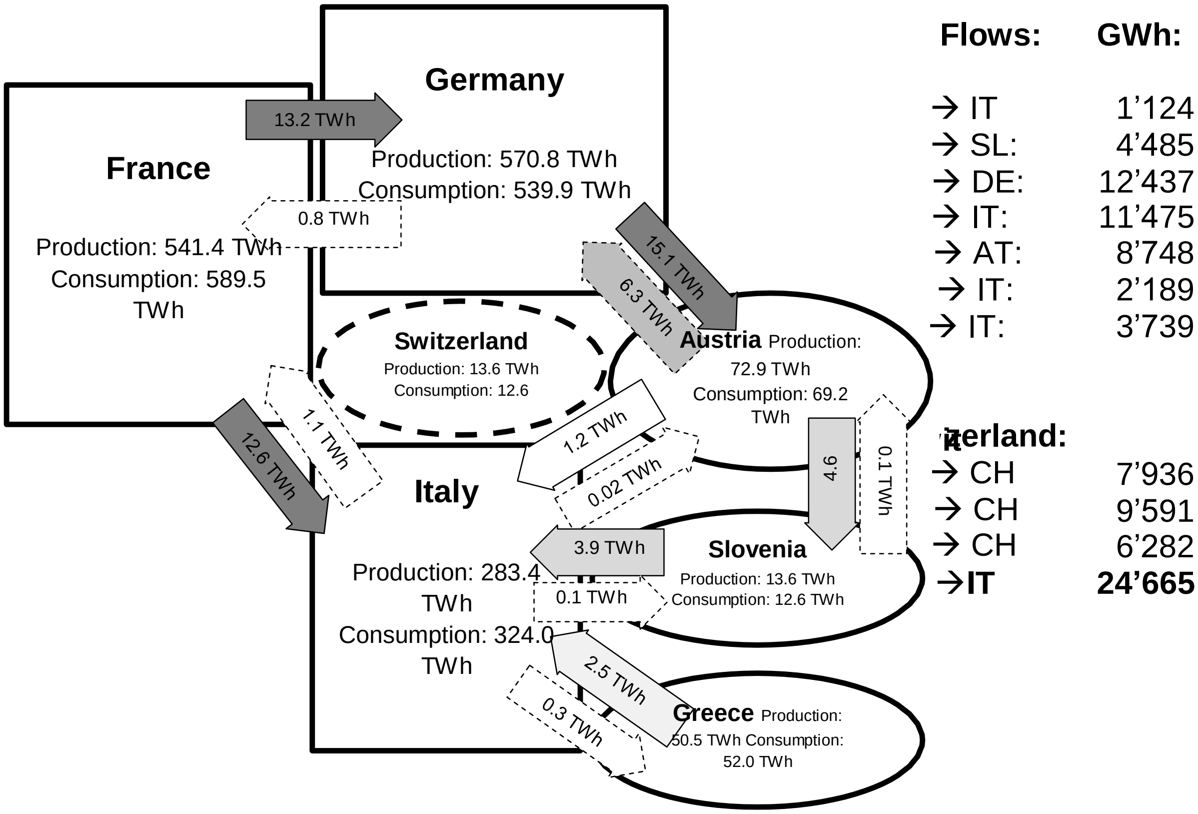
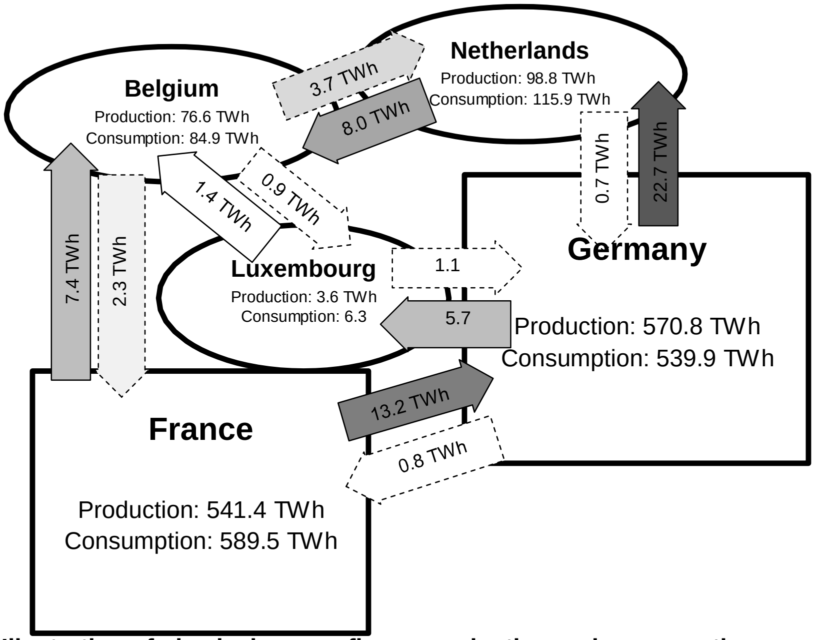


Figure 9: Illustration of physical energy flows, production and consumption across CSE in 2012

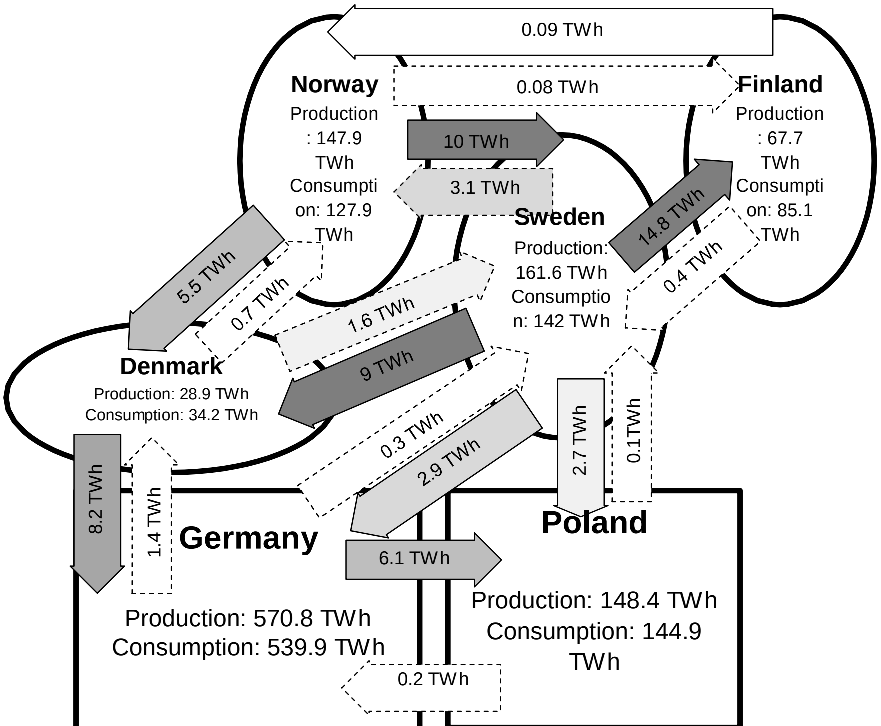
Figure 10 provides an overview of the **CWE** electricity market. Beside the two big players France and Germany the region consist of the Benelux countries. From those, the Netherlands is the largest market (Production of 98.8 TWh) followed by Belgium (76.6 TWh) and Luxembourg (3.6 TWh). All three countries are net importers of electricity. The most important physical flow of electricity in the CWE region occurred from Germany to the Netherlands (22.7 TWh), which is the second biggest cross-border flow in Europe (Behind CH→IT). The electricity flow from France to Germany (13.2 TWh) ranks second in the CWE region, followed by the flows from the Netherlands to Belgium and from France to Belgium.



Net Flows:	**GWh:**
	5’010
FR → BE	12’437
FR → DE	4’592
DE → LU	21’817
DE → NL	508
LU → BE	4’320
NL → BE	

Figure 10: Illustration of physical energy flows, production and consumption across CWE in 2012

In the Northern region Germany is the largest market followed by Sweden (Production 161.6 TWh), Poland (148.4 TWh) and Norway (147.9 TWh). Moreover, Germany, Norway, Sweden and Poland are net exporters whereas Finland is the largest net importer in Europe after Italy. The most important electricity exchange occurred from Sweden to Finland (14.8 TWh), from Norway to Sweden (10 TWh) and from Sweden to Denmark (9 TWh) (see Figure 11).

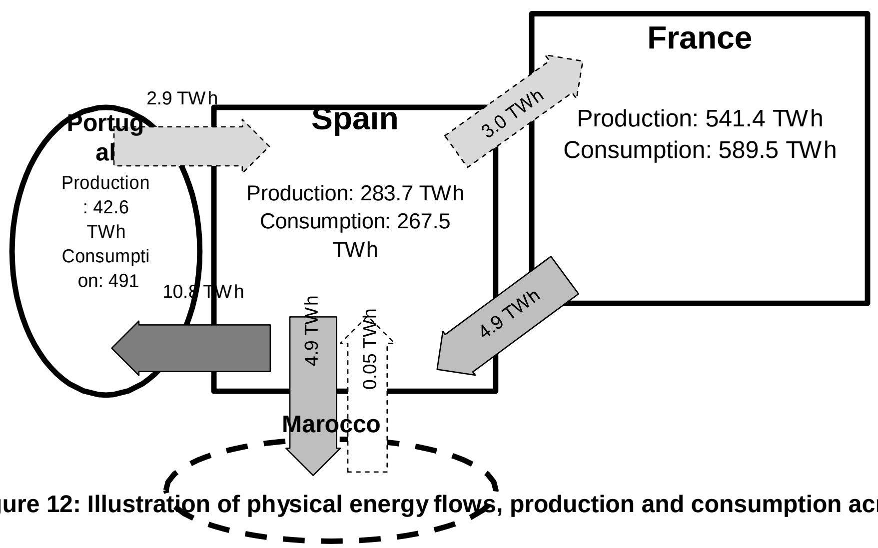


Net Flows: **GWh:**

DK → DE: 6'738
FI → NO: 10
DE → PL: 5'877
NO → DK: 4'782
NO → SE: 6'972
SE → DK: 7'372
SE → FI: 14'359
SE → DE: 2'612
SE → PL: 2'545

Figure 11: Illustration of physical energy flows, production and consumption across the Northern Region in 2012

Figure 12 shows an illustration of electricity exchange within the SWE region. France is SWE's largest market with a production of 541.4 TWh in 2012. Spain ranks second (283.7 TWh) and Portugal third (42.6 TWh). Both, France and Spain are net exporters and Portugal is a net importing country. The highest electricity volume was exchanged from Spain to Portugal (10.8 TWh) and from France to Spain (4.9 TWh). Spain is connected with Morocco. Over this link 4.9 TWh was exported to North Africa.

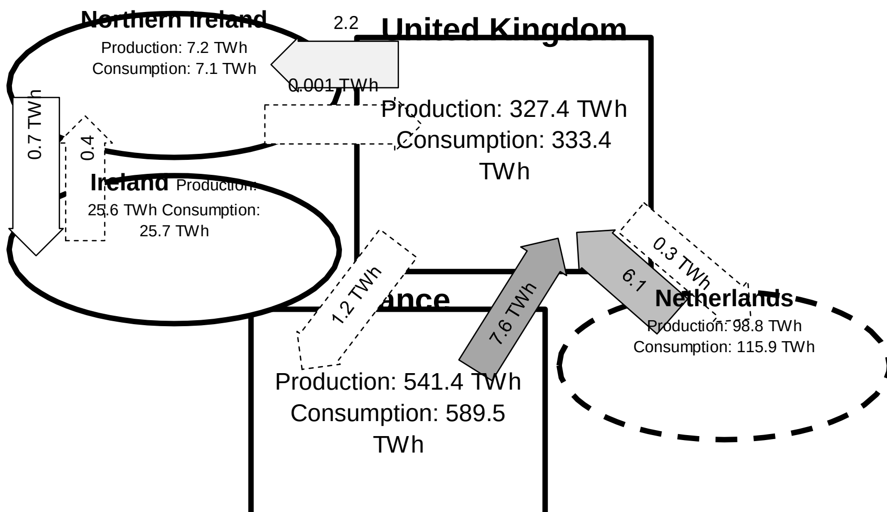


Net Flows: **GWh:**

ES → PT: 7'896
FR → ES: 1'883

Figure 12: Illustration of physical energy flows, production and consumption across SWE and Marocco in 2012

In the FUI region the biggest market is France followed by the UK (327.4 TWh). Northern Ireland and Ireland are relatively small markets. In the FUI region only France is a net exporting country while the United Kingdom is even the fourth largest net importer of electricity in Europe. The most important electricity exchange took place from France to the UK and from the CWE region through the Netherland to the UK. The electricity flows from the UK to Northern Ireland and from Northern Ireland are relatively small, accounting for 2.2 TWh and 0.7 TWh, respectively.



Net Flows:	**GWh:**
FR → UK:	6'429
UK → NI:	2'163
NI → IE:	296

Figure 13: Illustration of physical energy flows, production and consumption across FUI and Netherlands in 2012

5 Congestion Management

This chapter treats the problem of congestion management on cross-border interconnectors. Cross-border congestion became an issue in the process of liberalizing the European electricity market, as described in *Chapter 2*. The European electricity day-ahead markets are based on zonal pricing. That means that the markets are organized in rather broad zones where in each zone a homogenous price for every specific electricity product exists. At each border there is a physical connection between different zones (Janssen, Rebours, & Dessante, 2012). As such, these so called “Interconnectors” are the physical links between different national grids. According to Knops et al. (2001), the interconnectors originally were built for the purpose of better over-all system stability, which should be achieved through the possibility of power exchange between two countries in case of emergency. In a later step some structural exchanges occurred between countries based on long-term contracts. The exchange took place between vertically integrated utilities, which assured that cross-border transports did not exceed the available interconnector capacity. Under the described development towards a liberalized electricity market, the national transmission networks were required to be operated by independent TSOs. A central concept of the liberalization was that customers must be able to buy electricity from a supplier of choice. The supplier must be granted so called “third party access” to the grid so he can deliver electricity to the end customer. If electricity is significantly cheaper in one state than in a neighbor state, large demand of cross-border transmission capacity can occur. If this demand exceeds the available capacity of the cross-border interconnectors, congestion may result. As such, congestion could hinder the full integration of different electricity markets into a single market. (Janssen et al., 2012; Knops, de Vries, & Hakvoort, 2001)

Therefore, an adequate congestion management has to take into account some special and given conditions appearing in cross-border exchange like *physical features* of electricity, the organization of the *electricity system* and the *type of congestion:*

Electricity System An electricity system consists of different activities such as power production, transportation, distribution and trading, which are preceded by different corresponding parties. The electricity system can be divided along different dimensions. Knops et al. (2001) divides the system into two subsystems: a “*technical subsystem* consisting of the equipment to generate and transport electricity and [. . .] an *economic subsystem*, in which power and transport services are traded” (Knops et al., 2001, p. 314). In a liberalized market a transmission system operator is responsible for operational management of the electricity network. This includes ensuring balance between fed in and consumed power, management of all transport flows and management of additional services like voltage and frequency control. The technical system has a corresponding economic system, the electricity market. In a liberalized system with power exchanges the market creates contracts for electricity supply for which the TSO has to arrange transmission. In a single market this is often not a problem as the network is normally constructed for sufficient internal transport capacity. Additionally, in Europe many TSOs have generating units in their system to avoid congestion. (Knops et al., 2001)

In the case of two coupled countries at least two TSO are involved with the management of an interconnector. The interconnector has a certain, fixed transport capacity over which power can be exchanged. It can be differentiated between two types of congestion:

Physical congestion In the situation of physical congestion it is technically impossible to meet power demand. The available generation or transmission resources are insufficient, which in the short run leads to black-outs. The problem of black-outs can only be solved in the long run by investing in generation and or transmission capacity.

Economic congestion In the case of economic congestion it is technically possible to meet the electricity demand everywhere but the scheduled transactions lead to an expected network loading which exceeds at one point the available line capacity. To meet demand the generator dispatch has to be changed from the market's preferred outcome. This then leads to price differentials. Congestion management is constituted by the operational measures to change the generation dispatch. (Knops et al., 2001)

Physical features Electric power has some physical features that make the management of congestion very difficult and complex. A specific feature of electric power is that the electricity flow resulting from a trade on a power exchange is ruled by physical laws like Kirchhoff's law and Ohm's law. That means that electric power takes several parallel "ways" from its source to its destination of the underlying power exchange and not the direct contract path. Transactions lead to physical flows totally different from what could have been intuitively expected. In the highly meshed European network a transaction between Germany and France for example will not necessarily flow directly between the countries involved in the transaction but also through Netherlands-Belgium-France, Switzerland-France and Switzerland-Italy-France. Or, like shown in Figure 14, a commercial transaction between the two areas A and B of 100 MW might lead to the

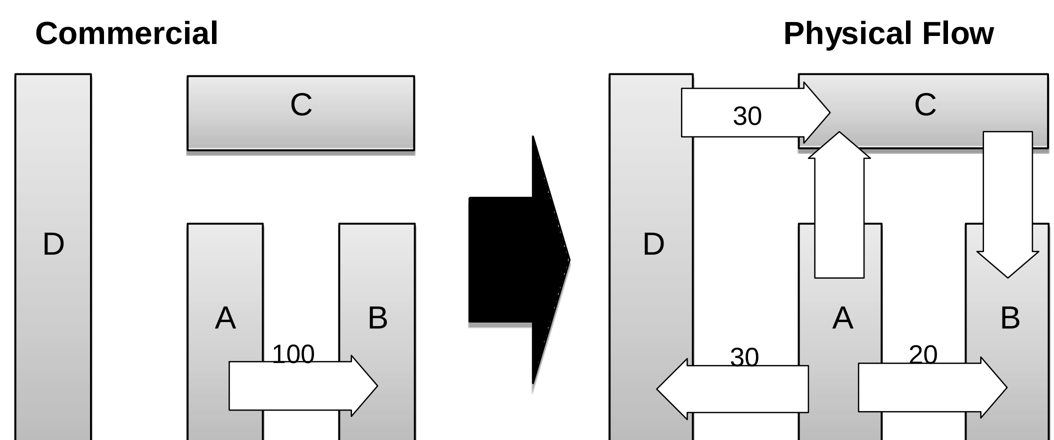


Figure 14: Commercial Flows versus Physical Flows
Source: (Weber, Graeber, & Semmig, 2010)

physical flow as conceptually shown on the right side of Figure 14. This issue needs to be addressed by an adequate congestion management method. Although these flows through parallel paths, also called “loop flow”, are ignored by bilateral capacity allocations they might lead to network security problems in the control area of both TSOs. (Kurzidem, 2010; Weber et al., 2010)

All these aspects have to be taken into account in the management of congestion. The congestion management can be divided in three stages: first, pre-coupling aspects such as how much transmission capacity is made available to the market (Chapter 5.1), second the coupling solution (Chapter 5.2) and third post-coupling aspects such as the financial settlement between PXs and TSOs. (Agency for the Cooperation of Energy Regulators (ACER), 2012).

5.1 Capacity Calculation Methods

The described physical features of cross-border exchanges related to the highly meshed grid structure in Europe require a careful assessment of the cross-border capacity. There are two different approaches for the assessment of capacity: the ATC approach and flow-based approach.

5.1.1 ATC Approach

Within the *Available Transfer Capacity* (ATC) approach, the assessment of capacity, which can be offered safely, is commonly done by so called “load-flow calculations”. First, a “base case” scenario of plant dispatch and consumption is assumed. Then, the production is shifted from region to region and it is examined if the operational security still can be granted. From the maximum possible value not affecting static security a margin for loop flows and contingencies is subtracted. The resulting figure is the maximum capacity that can be offered to the market and is called *Net Transfer Capacity* (NTC). From the NTC the *Already Allocated Capacity* (AAC) is subtracted which results in the *Available Transfer Capacity* (ATC). (Weber et al., 2010)

ETSO defines the available transfer capacity as “the transfer capacity remaining available between two interconnected areas for further commercial activity over and above already committed utilization of the transmission networks.” (ETSO, 2000, p. 9) In the day-ahead market, the ATC is calculated according to Figure 15. (ETSO, 2000)

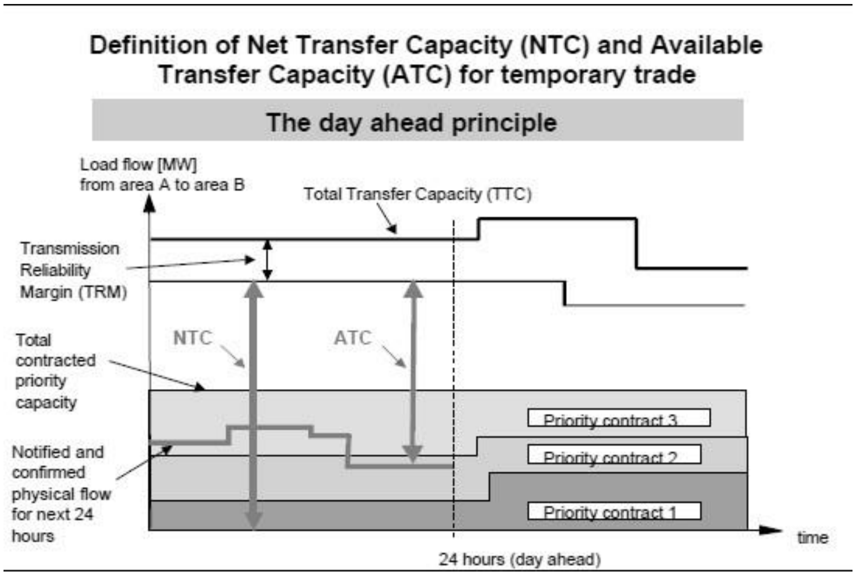


Figure 15: Derivation of ATC
Source: ETSO (2000, p. 10)

This method of calculating the available capacity is widely distributed. Figure 16 shows on which borders the ATC method is in use:

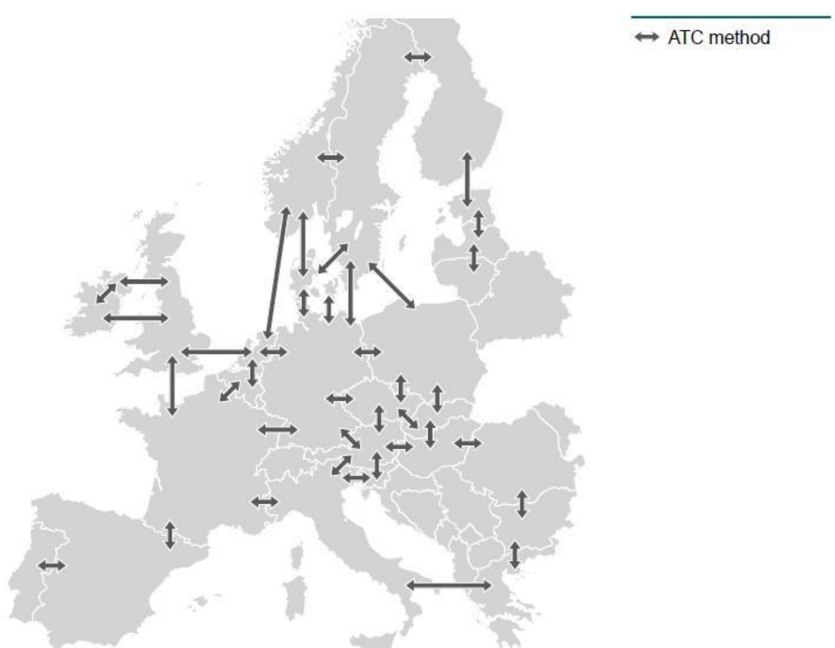


Figure 16: ATC method
Source: (Agency for the Cooperation of Energy Regulators (ACER), 2012, p. 41)

5.1.2 Flow-Based Approach

A different method for calculating the available capacity to the market is the flow-based method. This method is based on so called *Power Transmission Distribution Factors* (PTDFs). PTDF reflect thereby changes in physical flows induced by a shift of production between regions. In other words PTDFs are used to convert commercial exchanges into their physical influences on the cross-border flow (Jullien, Pignon, Robin, & Staropoli, 2012). These flow-based scenarios are very complex and their adequacy to improve welfare depends heavily on the quality of grid models used. (Weber et al., 2010)

The EU Target model for Market Integration and the Framework Guidelines on Capacity Allocation and Congestion Management for Electricity (CACM)[10] propose to apply the ATC method or the Flow-Based method. The flow-based method is especially proposed for short-term capacity calculations in highly meshed grids. The ATC approach is operational in the Central-West region, on the borders of northern Italy, in the South-West region, France, UK, Ireland and the Baltic regions. It is aimed to implement a Flow-based method in the CWE and the CEE region. (Agency for the Cooperation of Energy Regulators (ACER), 2012)

5.2 Capacity Allocation Methods

There are different congestion management methods to allocate available capacity to the market (Figure 17). In the following chapters the six different congestion management methods *explicit auctioning*, *implicit auctioning*, *market splitting, market coupling, redispatching* and *counter trading* shall be explained. These methods are all *market based* congestion management methods. In market-based congestion management methods, "the Net Transfer Capacity (NTC) is allocated in cross-border power auctions in a non-discriminatory and market-based approach." (Kurzidem, 2010, p. 16). An exception is redispatching, which cannot really be considered to be market based. Non-market based methods are allocation methods where the available capacity is allocated by an authority following criteria which are not based on market mechanisms. Examples for non-market based methods are "first-come-first-serve", in which capacity is allocated in the order of requests, "long-before-short", where contracts with a long duration are preferred to short-term contracts and "pro rata" where the interconnector capacity is distributed proportional to the share of the market parties total requests. (Knops et al., 2001; Kurzidem, 2010)

The regulation of the European Union states that the allocation rules of the interconnection capacity must be market based. In market based auctions, the traders can trade yearly, monthly and hourly capacity rights. ("Market Coupling - Netzengpässe für den Wettbewerb optimal nutzen," 2007)

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[10] both explained below; Chapter 6.2

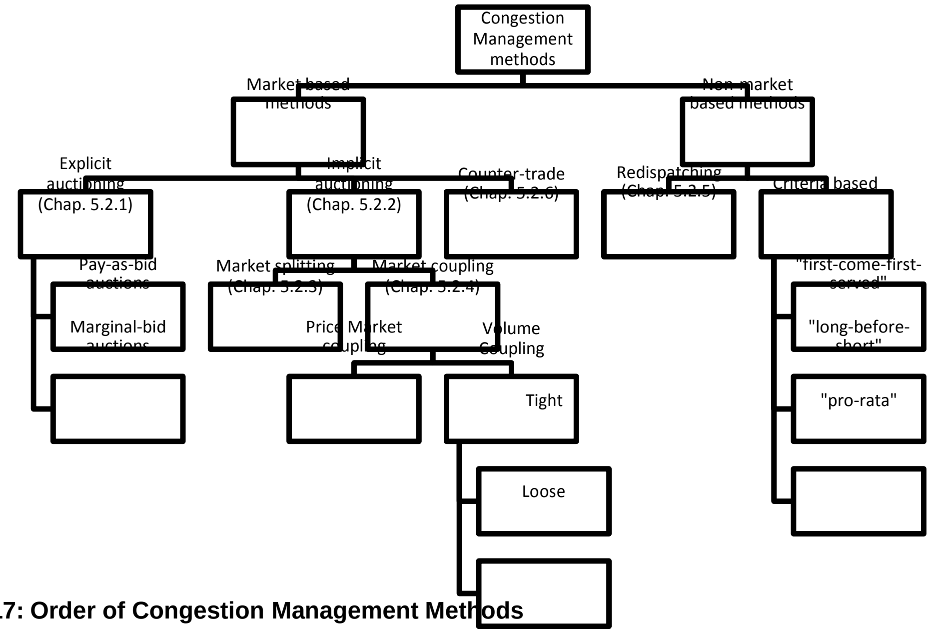


Figure 17: Order of Congestion Management Methods

5.2.1 Explicit Auctions

In explicit auctions interconnector capacity is sold to the highest bidder. The good auctioned is therefore the cross-border capacity as such. This method divides the cross-border transaction into two parts. Firstly, a cross-border electricity contract is needed and secondly, the capacity on the interconnector. There are two different institutions required. An institution that determines the exact amount of available transmission capacity and an institution that is responsible for the auction itself. Explicit auction mechanisms are a good solution if the power markets on either side of the interconnector are differently organized because the capacity is traded separately from the power market and a specific organization of the power market as such is not required. (Knops et al., 2001)

The bidding mechanism for electricity transmission capacity differs from conventional auction mechanisms. In conventional auctions, a certain good is normally sold to the highest bidder. For electricity transmission capacity this does not work because bidders do not bid for the full available capacity. The available capacity is split into multiple bids. Consequently, the highest bid cannot set the price for the over-all capacity as other bidders would have to pay more than they are willing to pay. To solve this problem there are two possible allocation mechanisms for capacity auctions in explicit auctioning schemes.

Pay-as-bid In a pay-as-bid auction the capacity is allocated to each bidder according to its bid price, starting with the highest bid. As such, each participant who wins capacity pays the amount he has bid. Theoretically, this auction form generates the highest revenue stream. In practice, however, bidders would try to estimate the marginal bid and bid close to this price. This bidding behavior to bid less than one's willingness to pay can reduce auction revenues and also the auctions' allocation effectiveness. To overcome these disadvantages, a second auctioning form can lead to better results.

Marginal bid auctions In a marginal bid auction the price to pay for the interconnector capacity is the same for all bidders and equals the level of the marginal bid. The different bids are ranked from high to low and the price paid by all auction participants is the lowest bid to which transmission capacity is allocated. As such, the lowest bid that wins capacity is the price that has to be paid by all capacity-winning participants. This bidding system may reduce the total expected revenue but it gives an incentive to bidders to bid a price reflecting their full willingness to pay. This form of bidding mechanism also leads to more liquid markets as most bidders pay less than their bid, which gives an incentive to participate in the auction in the first place.

(Laurens James. de Vries, 2004; Knops et al., 2001)

5.2.2 Implicit Auctions

Implicit auctioning schemes combine the bidding process for power and transmission capacity. Unlike the case of explicit auctioning, there is no separate capacity market. Therefore, trading electricity becomes less complex for the bidding parties, inefficiencies can be avoided and scarce interconnector capacity is used more economically (Weber et al., 2010, p. 305). Market participants, which want to sell electricity from a lower price country to a higher price country, have to place a bid on an organized electricity spot market in the high-price area. To avoid congestion, a so-called market operator surcharges a certain fee on the bids that use the interconnector. This results in a pricing-out of the market. The surcharge is set at a level, which assures that just as many bids from the lower price area are accepted as the interconnector capacity allows. The market operator can determine this surcharge as he knows both the supply and demand functions in both markets A and B. Mathematically, implicit auction methods treat cross-border transmission capacities as constraints in an optimization problem. (Laurens James. de Vries, 2004; Janssen et al., 2012; Knops et al., 2001; Weber et al., 2010)

Graphically, the functionality of an implicit auction mechanism and the determination of the surcharge can be demonstrated with the basic model shown in Figure 18: Implicit auctioning. On the abscissa the figure shows the generator output and on the ordinate the price and cost. There are two markets; market A and B and an interconnector capacity K. The demand and supply functions in markets A and B as well as the interconnector capacity K are known by the market operator.

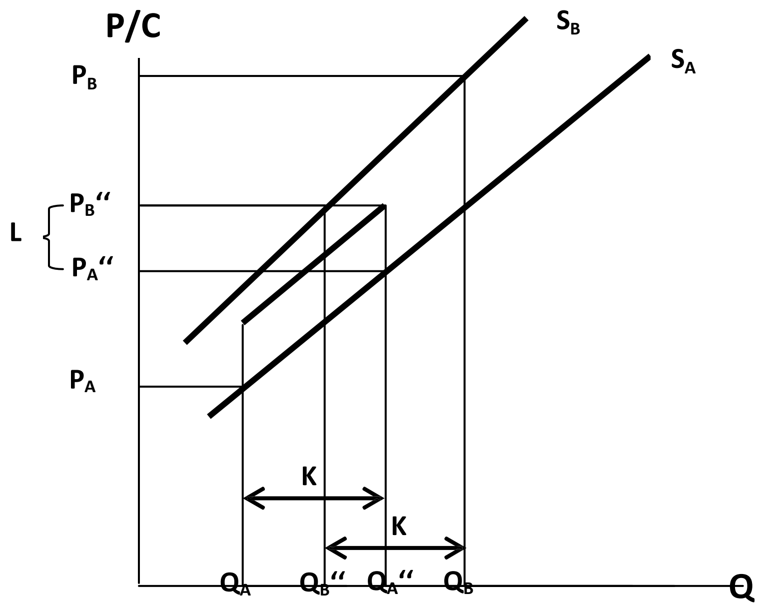


Figure 18: Implicit auctioning[11]

Q_A and Q_B are the generator outputs in the corresponding markets. As the price P_B is higher than P_A generators in market B are willing to produce more electricity and hence the electricity output in B is higher, too. If there is an interconnector capacity producer A can sell electricity in market B up to the interconnector capacity K. This leads to new output levels Q_A'' and Q_B''. With the given supply functions, the market operator can determine the price levels P_A'' and P_B''. As the generators in market A bid on market B, the market operator must increase the bid price by a certain amount so that market B will only demand the most import amount, which just matches the capacity K of the interconnector (Q_A'' - Q_A). The marginal generator that is allowed to export is Q_A'' which bids the price P_A''. The price in market B is P_B'' so the market operator will set the levy L as the difference between the two prices: $L = P_B'' - P_A''$. All generators from market *A* that bid on market B have to pay the fee L. Consequently, the revenues from this implicit auction are for the market operator $R = K * (P_B'' - P_A'')$. This price difference multiplied with the transfer capacity is also called "congestion rent" (Weber et al., 2010). These revenues are equal to the revenues achieved by marginal-bid explicit auctions and are the interconnector capacity times the price difference. The main advantage of implicit auctioning is that energy flows are not separated from transmission capacity, which makes the process much simpler for involved market participants. They simply bid on a power exchange where the best bids are honored until the capacity of the interconnector is fully used. The main difference is that revenues from implicit auctions are accumulated by the market operator and not by transmission system operators as in explicit auctions. (Laurens James. de Vries, 2004)

[11] This model is based on the description in (Laurens James. de Vries, 2004, pp. 240-245)

Implicit auctioning can be implemented over the two methods “market splitting” and “market coupling”. Although the definitions for these two approaches vary in literature in the following two chapters generalized definitions are proposed.

5.2.3 Market Splitting

Market splitting can be seen as a form of implicit auctioning. In its original form as it has been performed in the Nordic market it is executed by a market operator who experiences congestion within his region. As a consequence the market operator splits the market across the congested interconnector. By using market information the market operator manages the congestion. Based on this initial situation with two “split” markets participants bid in the organized electricity market on their side of the congestion. In a first step the two markets are treated as completely independent. Normally this results in a price difference between both markets. Subsequently, the market operator buys electricity in the lower-price market up to the amount of the interconnection capacity and sells it in the higher-price market. This transaction leads to a price increase in the exporting market and to a price decrease in the importing market. However, the price difference does not fully disappear. To perform market splitting an organized electricity market on both sides of the interconnector is required as well as good coordination and cooperation between the market operators or two closely cooperating power exchanges. The transaction profit is kept by the market operator. Although in the case explained above a joint market was split into two markets, this allocation mechanism also can be applied to markets already separated. In the later case market parties only have access to their own national or regional network. An example of a region which practices markets splitting is the Scandinavian market. The revenue of the market operator is the same as in the case of implicit auctioning; the market operator buys electricity in the cheaper market for the price P_A'' (marginal generator cost in market A) and sells it on market B for the price P_B''. The transaction can be executed only for the quantity K, given by the interconnector capacity. This leads to the same revenue $R = K * (P_B'' - P_A'')$ as described in section 5.2.2. (Laurens James. de Vries, 2004; Knops et al., 2001)

A slightly different definition is provided by (Weber et al., 2010) where market splitting is defined as an approach used in a market operated by a single power exchange. Similarly (APX, 2007) describes market splitting as a method where only “[. . .] one power exchange operates across several price zones whereas market coupling links together separate markets in a region.”(APX, 2007).

These differences in definitions mainly stem from different use of terms. In Scandinavia market splitting is used as an expression for a method where a single market is “split” in case of congestion. In continental Europe, however, market splitting often means the coordinated use of power exchanges where different neighboring markets are operated separately before congestion. (ETSO, 2001)

5.2.4 Market Coupling

Market coupling is defined as the use of implicit auctioning involving two or more power exchanges (PXs). The main difference between market coupling and market splitting is the following. Market coupling is the implementation of implicit auctions in a market operated by co-operation of multiple power exchanges whereas market splitting describes a method used in a market operated by a single power exchange (Chapter Market Splitting). ((EMCC), 2013; Weber et al., 2010)

As European power markets cannot be designed from scratch the integration of the European power market has to build on existing structures. To address the diversity of national markets, which have to be integrated, different market coupling models exist. Markets linked with an interconnection can be coupled "[. . .] either through the coordination of the volumes of use of the interconnection capacity [called volume coupling] or through a wider mechanism combining price and volume coordination [price coupling]." (Glachant, 2010, p. 2). Market coupling is typically used at the *day-ahead* stage. For every hour of operation either prices across energy markets converge or all available transmission capacity is utilized, with power flowing towards the high price area. In Implicit auctions, the capacity between bidding areas is made available to the spot price mechanism operated by the power exchanges (APX, 2007). The two coupling mechanisms differ mainly in the way they produce prices:

Volume Coupling Volume coupling is defined as a "[. . .] coordinated day-ahead auction involving two or more power markets [where] cross-border volumes computed by an Auction Office are transferred to the power exchanges, which consider them as price inelastic bids into their local system. The calculated flows are based on anonymous order books and the available transmission capacities, while the pricing authority remains with the involved power exchanges." (European Network of Transmission System Operators for Electricity ENTSO-E, 2010, p. 2). Another definition is provided by Janssen et al., (2012) who describes Volume coupling as a "[. . .] form of implicit allocation which has a more humble objective than price coupling. [. . .] it only fixes the cross-border flows on a set of interconnectors between various areas that can cover one or more zones. It thus only serve the allocation objective for a set of interconnectors." (Janssen et al., 2012). The process of volume coupling works therefore as follows: Firstly, the capacity of the interconnector is calculated by TSOs and communicated to the coupled markets. Secondly, the capacity of the interconnection is allocated according to the balance of supply and demand in each trade zone and the constraints of the interconnector. Lastly, the trade zones determine the prices in their zones separately by taking into account the cross-border import and export volume attributed to them by the quantity allocation mechanism. Therefore, "volume coupling" allows the coupled markets to stay more independent while being coupled (Glachant, 2010). The main difference between volume coupling and price coupling is where the price calculation takes place. If the price calculation is done centrally the coupling is called price coupling and if the price calculation is done on a decentralized basis it is called volume coupling. In the case of volume coupling the price calculation can thus be kept at the power exchanges. (ENTSO-E, 2010; Weber et al., 2010)

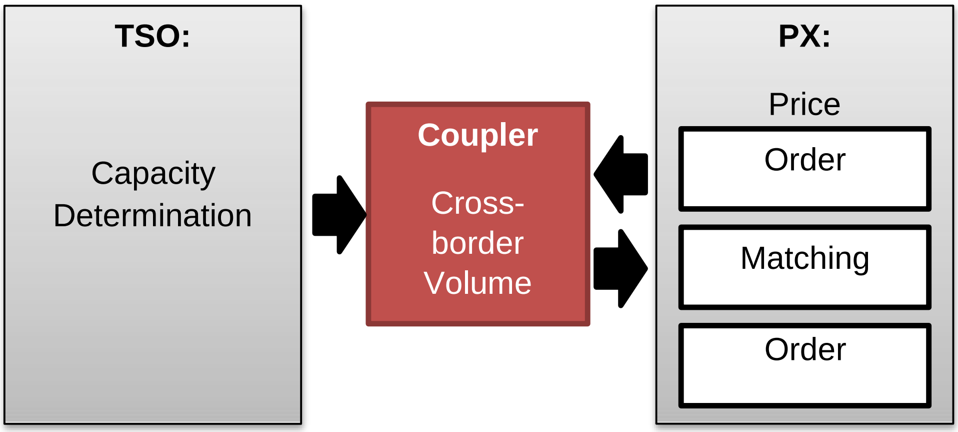


Figure 19: Volume coupling based on Glachant (2010)

Tight Volume Coupling Tight Volume Coupling is a system that determines the tradable volumes between countries and regions before the individual energy exchanges calculate their own prices. The term "tight" means in this context that the traded volume is calculated based on all *relevant information* such as the amount of cross border capacity, order books of all energy exchanges and TSOs in the coupled area. (Tennet, 2013)

Loose Volume Coupling In the variant of a loose coupling the volume traded between two countries or regions is calculated in a first step and then prices are calculated separately in a second step. The difference compared to Tight Volume Coupling is that in Loose Volume Coupling the calculation is performed using just some of the relevant information, and not all. Therefore, this method offers the lowest quality level within the different market coupling methods. (Tennet, 2013)

Price Market Coupling The approach used the most is *price market coupling* or simply *price coupling*. In this approach, a single coupling algorithm is computing centrally both, prices and cross-border volumes at the same time based on all *relevant information*. According to Weber et al., (2010), this means that "[. . .] the power exchanges of the regions involved do not set prices but just forward bids to the coupler and receive prices (and volumes) in return." (Weber et al., 2010, p. 306). Price coupling between different countries allows the creation of a single exchange zone and consequently a single price zone if interconnection capacities do not limit cross-border power exchange. Price coupling was first introduced in 2006 between France, Belgium and the Netherlands

(Trilateral Market Coupling TLC). One advantage of price coupling is that this process avoids price or flow discrepancies like exports from a high price zone to a low price zone or price differences in case of no congestion (ENTSO-E, 2010; Glachant, 2010; Tennet, 2013; Weber et al., 2010). Therefore, price coupling is serving both, the allocation and the matching objectives at the same time (Janssen et al., 2012).

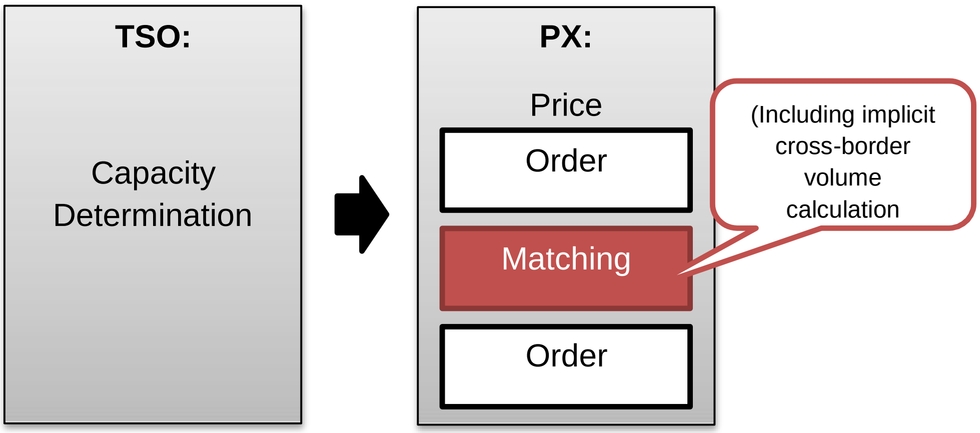


Figure 20: Price coupling based on Glachant (2010)

5.2.5 Redispatching

Redispatching is a corrective congestion management method, which works as follows: market participants trade as if there was no congestion. As a consequence, a single electricity market price is determined for the two markets. When congestion occurs, the cooperating TSOs intervene directly in terms of electricity generation on both sides of the interconnector. The electricity output in the exporting area is reduced and the generation in the importing area is increased upon the point where the net flow through the interconnector matches the available capacity. This process with direct intervention of the TSOs to electricity production is called redispatching. To ensure that this method works, the TSO has to pay to the new producing facilities their marginal costs and to the generators whose production is cancelled a reimbursement for their lost marginal costs. This method takes place only in the *technical subsystem*. Redispatching does not intervene into the market directly and is therefore not considered as a *market-based* congestion management method. This method does not require specific institutional forms and can be implemented in a short time frame. (Knops et al., 2001)

5.2.6 Countertrade

Countertrading is a congestion management method similar to redispatching. The congestion management activity does not influence market prices for the connected systems. The TSO intervenes into the market by buying and selling power counter to the flow on the constrained interconnector. The TSO has therefore to pay a price which lies below market prices. On the other side, the TSO will receive also prices which are below market prices. The main difference between redispatching and countertrade is that in the first case, the financial transaction between the TSO and the electricity generators is based on marginal production cost and marginal avoided costs whereas in the second case the costs are based on the bidding process. This congestion management method requires that the TSO can enter the electricity market and buy and sell power. (Knops et al., 2001)

6 Market Coupling in Practice

The goal of this chapter is to provide an explanation how the previously described congestion management methods are implemented in practice. In Europe, there are various *market coupling mechanisms* in use, as described in section 6.1. In the long run, it is the stated goal of the European Union to implement a single, market-based mechanism. Therefore, the EU provides a so called EU Target Model (section 6.2). As explained in previous chapters, electricity trade takes place in different timeframes. Consequently, this fact has to be taken into account in the implementation of transfer capacity allocation mechanism. Section 6.3 provides an overview of market coupling under different time frames.

6.1 Market Coupling Initiatives

The emergence of different market architectures in Europe has led to the adoption of different transmission capacity management solutions, whereby the degrees of harmonization between the participating countries differ. Table 2 provides an overview of the most recent market coupling initiatives:

Markets	Participating countries	Degree of harmonization	Capacity Allocation Method	Capacity Calculation Method	Starting Date	Ending Date
NPS	Norway, Sweden, Finland, Denmark and (Estonia since 10th May 2010)	High (Single PX)	Market splitting	ATC	1996	
MIBEL	Spain and Portugal	High (Single PX, two divisions)	Market splitting	ATC	1st Jul. 2007	
Italy	Several internal zones	High	Market splitting			
TLC	Belgium, France and the Netherlands	Medium (Separate PXs)	Price and Volume coupling	ATC	21st. Nov. 2006	9th Nov. 2010
EMCC	Germany and Denmark (and Sweden)	Medium (Separate PXs)	(Tight) Volume coupling	ATC	9th Nov. 2009	9th Nov. 2010
CWE-MC	Belgium, Luxembourg, the Netherlands, Germany and France	Medium (Separate PXs)	Price and Volume coupling	ATC and Flow base	9th Nov. 2010	

Table 2: Market Coupling Initiatives ordered by the degree of harmonization[12]

The largest degree of harmonization between national markets can be found in the Nordic power market **Nord Pool Spot NPS** and in the Iberian market (**MIBEL**). In both markets the single countries are linked through market splitting where one power exchange

[12] Table is based on (Creti, Fumagalli, & Fumagalli, 2010)

manages both, the capacity and energy auctions. The oldest market coupling initiative runs in the Scandinavian where an implicit auctioning based on market splitting is in operation since 1996, when the Norwegian day-ahead trading system was extended to Sweden and later on to Finland (1998), Denmark (2000) and Estonia (2010). (Creti et al., 2010)

TLC Trilateral Market coupling (TLC) is an Implicit Market Coupling Initiative for daily cross-border capacity between Belgium, the Netherlands and France. The Trilateral Market Coupling was operated by the power exchanges of the three countries and was operational since November 2006. As such, the first implicit trading system on the European continent emerged. The TLC has been replaced by CWE market coupling (**CWE MC**) on the 9th of November 2010. (Belpex, undated)

Beside these market-coupling initiatives, in each of the seven described electricity regional initiatives additional coupling projects were implemented or are planned to be:

- **Baltic:** Estonia is coupled with Nordic markets
- **Central east:** Markets of Hungary, Slovakia and the Czech Republic are coupled
- **Central south:** Italy and Slovenia are coupled
- **Central west:** Countries are coupled over CWE initiative (see table above) and are coupled with the Nordic region over the ITVC initiative
- **Northern:** Countries are coupled with each other under Nordic (see table above), over ITVC with the CWE region, over the NorNed cable with the Netherlands and over the SwePol-cable between Sweden and Poland
- **South west:** MIBEL (see table above)
- **FUI:** The IFA interconnector couples the UK with France, the East West interconnector connects UK with Ireland and on a cross-regional level through the BritNed cable linking the UK over Netherland with the CWE region.

(Gillian Carr, 2012, p. 23)

Cross-Regional Market Coupling: NWE In a second step, different electricity regions are coupled through cross-regional coupling projects to inter-regional markets. The main cross-regional project is the **NWE** (North-Western Europe) price coupling project. NWE price coupling aims at coupling the day-ahead markets across CWE, Nordic countries and Great Britain and later the Baltic countries and the SwePol link between Sweden and Poland. The project's lead is held by CRCC, a *Cross Regional Coordination Committee* of NRAs from CWE, the Netherlands and Great Britain along with a partnership between 13 TSOs and 4 PXs. NWE will cover 75% of the European electricity market, accounting for approximately 2'400 TWh consumption. As starting point, a coupling solution for the NWE project is developed under the so called PCR initiative (Price Coupling of Regions, see below). It is planned, that the different REMs are joining the NWE market one by one. In 2013, the SWE REM, CEE REM and the Baltic countries are integrated. In 2014, the coupling implementation for the CSE REM and the remaining FUI countries shall follow until a Single European Price Coupling (EPC) is achieved by the end of 2014 at latest. The SEE REM is planned to be integrated at latest by 2015. For the Integration of the different REM it is necessary that different regional market coupling solutions like e.g. ITVC are changed to fit the European solution of Price coupling. Over all, the NWE aims at optimizing the congestion management of more than twenty borders across thirteen countries and to maximize social welfare in the involved countries. The project was targeted to "go live" in November 2013. According to the latest monthly progress report, the NWE project is on schedule with this date. (Agency for the Cooperation of Energy Regulators (ACER), 2011a; NordPool Spot, 2013; North Western Europe Day Ahead Price Coupling Project, 2013; NWE Project Partners, 2013)

Price Coupling of Regions (PCR) The solution applied in the NWE price coupling is called Price Coupling of Regions (PCR). PCR is an initiative of seven European Power Exchanges[13] to develop a single price coupling solutions, which is used to calculate the electricity prices across Europe and to allocate cross border capacity on a day-ahead basis. The development of one single coupling mechanism is crucial to achieve the overall goal of a harmonized European electricity market. PCR is based on a price algorithm called Euphemia that calculates day-ahead electricity prices and allocates cross-border capacity by optimizing social welfare and increasing transparency of prices and flows. (Price Coupling of Regions PCR, undated)

6.2 The EU Target Model

As mentioned in previous chapters, electricity is traded in different ways. Unlike in financial markets, the spot market for electricity can be divided into an auction based market and an intraday market. The auction based market, often based on so called day-ahead auctions, trades spot market contracts for electricity deliveries for the next day. In the intraday market contracts, which lead to electricity deliveries within the same day, are continuously traded. In the Forward or Future market, Futures/Forwards with different maturities are traded. In coupled markets with an interconnector the available transfer capacity has to be traded according to the representative electricity contract. To reach clarity in this issue, the European Commission in cooperation with relevant stakeholders has developed a target model for market integration. The EU Target Model for Market Integration is a model that proposes a market design for forward, day-ahead and intraday markets for a single electricity market in Europe. The target model was developed by involving the European Commission, Regulatory associations like ACER, National regulators (NRAs), Transmission system operators and other relevant stakeholders (Chapter 3). In December 2009 the establishment of the European Target Model for

[13] APX-ENDEX, Belpex, EPEX SPOT, GME, Nord Pool Spot, OMIE and OTE

congestion management in electricity markets was approved by the European Commission and relevant stakeholders at the Electricity Regulatory (Florence) Forum. Since then, a basic *Framework on Capacity Calculation and Congestion Management* was developed, which contains propositions on the handling of cross-border issues within a single European electricity market. (Agency for the Cooperation of Energy Regulators (ACER), 2011b; European Network of Transmission System Operators for Electricity ENTSO-E, unknown).

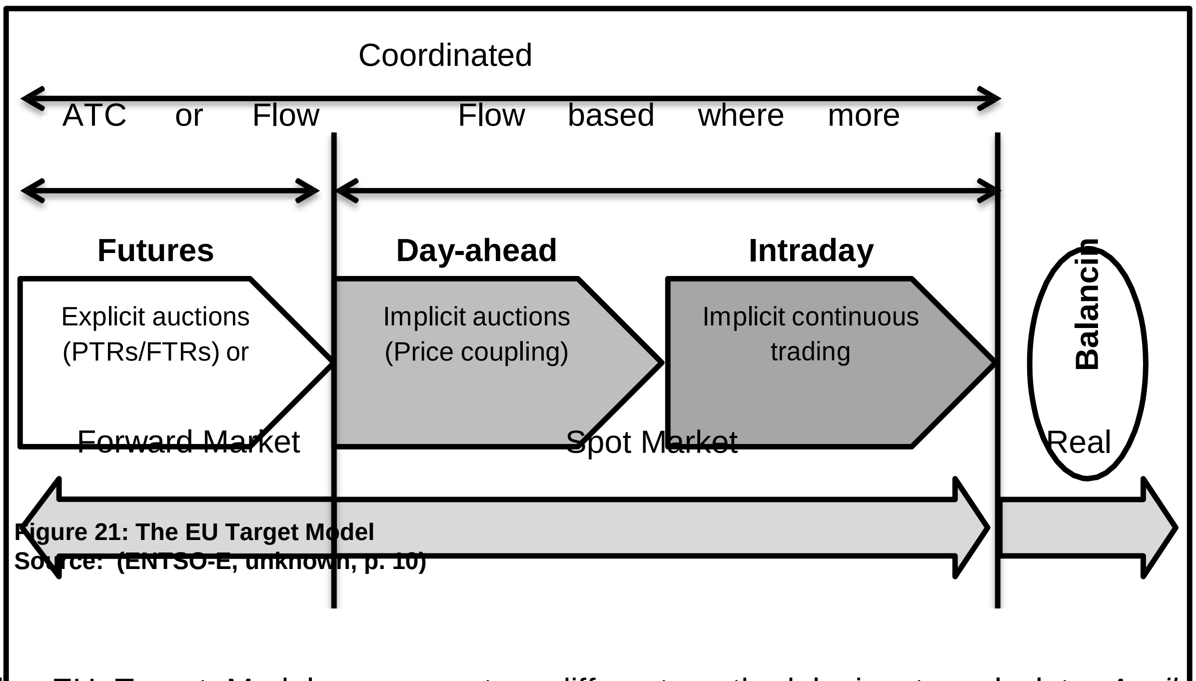


Figure 21: The EU Target Model
Source: (ENTSO-E, unknown, p. 10)

The EU Target Model proposes two different methodologies to calculate *Available Transfer Capacity* (ATC). For the Day-Ahead and the Intraday market the Flow-Based methodology is prefered. For the Forward market the target model forsees both methods, the ATC and Flow-based approach. The tranfer capacity allocation for future markets is propoesed to be done in explicit auctions via *Physical Transmission Rights* (PTRs) with "use-it-or-sell-it" principle or via *Financial Transmission Rights* (FTRs). In some cases, Contracts for Differences CfDs may be sufficient. The Target model for the Day Ahead markets is based on implicit auctions, respectively Market Coupling. It was agreed, that the model should be based on one single price coupling algorithm within the EU, the previousley explained Price Coupling. For the intraday market the target is also an implicit allocation of capacity. Unlike in the day-ahead market the implicit allocation of transfer capcity is based on continous trading instead of auctions. (European Network of Transmission System Operators for Electricity ENTSO-E, unknown)

Based on this EU Target Model, the Agency for the Cooperation of Energy Regulators worked out Framework Guidelines on Capacity Allocation and Congestion Management (referred as CACM). This Framework sets the deadline for the implementation of the target model for CACM for 2014.

6.3 Market Coupling within Different Timeframes

CACM provides a more detailed framework with objectives and principles for the capacity calculation and the capacity allocation within different timeframes.

Capacity allocation methods for the intraday market The main objective of the intraday market is to trade energy as close to real-time as possible to enable market participants a (re)balancing of their positions. This is particularly important to adjust generation in unexpected events like power outages. The *intraday target model* for cross-border trade is a *continuous implicit trading* system. This method requests a harmonized gate closure time, the time when electricity can be traded for a specific delivery time, for intraday cross-zonal trade. Additionally, regional auctions may complement the implicit continuous allocation mechanism if there is sufficient liquidity. In this case, the implicit auctions should have bidding deadlines (Latest times when bids in the intraday auctions can be submitted) so that the necessary flexibility and coordination with linked markets is provided. Implicit continuous trading requires a shared order book function with an algorithm, which performs an automatic matching of all bids, including appropriate block bids, as well.

Capacity allocation methods for the day-ahead market The CACM Framework proposes for the day-ahead market an implicit auction mechanism via a single price coupling algorithm, which simultaneously determines both, volumes and prices in the relevant zones. The implementation shall be based on a harmonization of the day-ahead bidding deadlines in the involved zones. This is the latest time at which bids can be submitted in the day-ahead markets.

Capacity allocation methods for the forward market The main objective for long-term transmission rights is to provide market participants with the possibility to hedge in the long term against congestion costs and in the short term against day-ahead congestion pricing. The options (rights) to hedge against risk in cross-border trading are either Financial Transmission Rights (FTR) or Physical Transmission Rights (PTR) with a so-called Use-it-or-Sell-it (UIOSI) clause.

(Agency for the Cooperation of Energy Regulators (ACER), 2011b)

The current situation presents itself as follows: For the **day-ahead** markets there are various market coupling solutions in use, as shown in Figure 22.

The method of **price market coupling** (Chapter 5.2.4) is in use:

- On the Iberian Peninsula (light yellow)
- In the CWE region (green)
- Between the Czech Republic, Slovakia and Hungary (red, belong to the CEE region)
- Between Italy and Slovenia (yellow, belong to the CSE region)
- Between Ireland north and south (light blue).

On the level of a **cross-regional coupling** solution **price market coupling** exists:

- Between CWE and Great Britain through the interconnector BritNed cable (green arrow)
- Between the Nordic region and Estonia through Estlink (blue arrow)
- Between the Nordic Region and Poland through the interconnector SwePol Link (also blue arrow).

A **volume coupling** solution, called Interim Tight Volume Coupling (ITVC) was implemented on a regional-level between the Nordic area and the CWE region (grey arrows).

(Agency for the Cooperation of Energy Regulators (ACER), 2012)

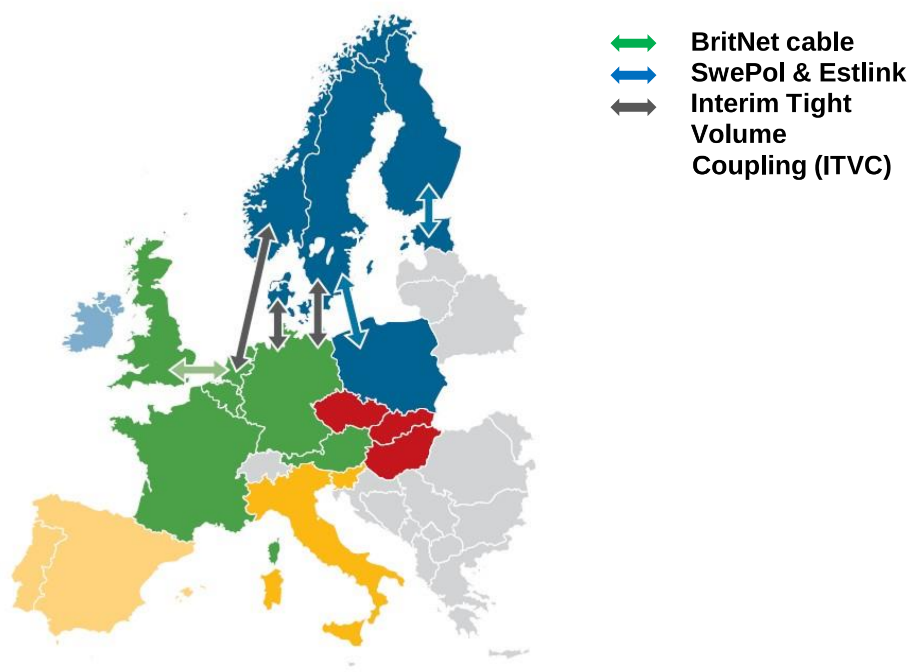


Figure 22: Implemented market coupling in the day-ahead market
Source: (Agency for the Cooperation of Energy Regulators (ACER), 2012, p. 27)

For **intraday markets** different types of allocation methods are in operation (Figure 23). An **implicit continuous** method (green arrows) is in use:

- Within the Nordic market (through the ELBAS platform)
- Between the Netherlands and Belgium
- Between the Netherlands and Norway
- Between Germany and Denmark through the interconnector Kontek cable.

On a cross-regional level, there is an implicit continuous coupling in use:

- Between the Nordic market and Estonia
- Between Germany and France (through the FITS platform). Furthermore, a continuous explicit capacity auction is in operation between the two countries through the DBS platform (dashed arrow).

Implicit auctions (blue arrow) are in operation on the interconnector:

- Between Spain and Portugal
- Between the Italian market zones
- Between UK-Ireland.

Explicit auctions (light yellow arrows) are in operation:

- Between France and England
- France and Spain
- Romania and Hungary
- Romania and Bulgaria
- England and the Netherlands (BritNed)
- Northern Italian borders (It-Fr, It-Au, It-Slov).

Explicit continuous allocations of cross-border capacity (red arrows) are in operation:

- On interregional level in the CEE region through the CEPS Damas Energy platform.
- On an international level, the method is applied between Germany and the Netherlands and Germany and Denmark through the DBS platform.

An improved **pro-rata explicit allocation** (dark yellow arrow) is in operation between France and Belgium. Borders without any allocation solutions are visualized by grey arrows. A special role take Germany and Austria as these two countries are one market (price) area, no congestion exists on the German-Austrian border. (Agency for the Cooperation of Energy Regulators (ACER), 2012)

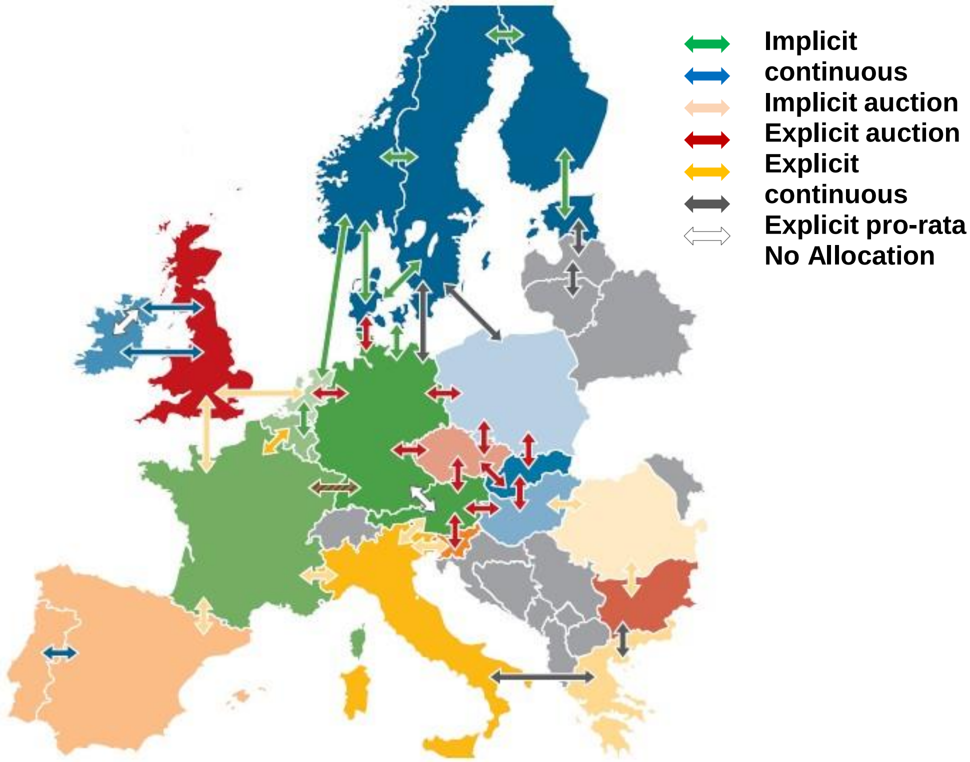


Figure 23: Implemented market coupling in the intraday market
Source: (Agency for the Cooperation of Energy Regulators (ACER), 2012, p. 33)

For **Long-Term Transmission Rights** different Cross-Regional allocation types are in operation to provide market participants the possibility to hedge against congestion costs and day-ahead congestion pricing. There are currently different rules implemented and the trade of long-term transmission rights takes place on different auction platforms. CASC is operating on the borders of CWE, CSE and Switzerland (green) and CAO is operating on the borders of the CEE region (blue). Physical Transmission Rights (PTRs) are applied within the CWE and CEE regions. Financial Transmission Rights (FTR) are applied within the Italian market zones. A coordinated approach is in operation between UK, Ireland and France. Financial hedging instruments such as Contracts for Differences (CfDs) are in operation in the entire Nordic area. No long-Term (LT) hedging products are available on the borders marked with a white arrow and bilateral agreements are in use on borders with a red arrow. (Agency for the Cooperation of Energy Regulators (ACER), 2012)

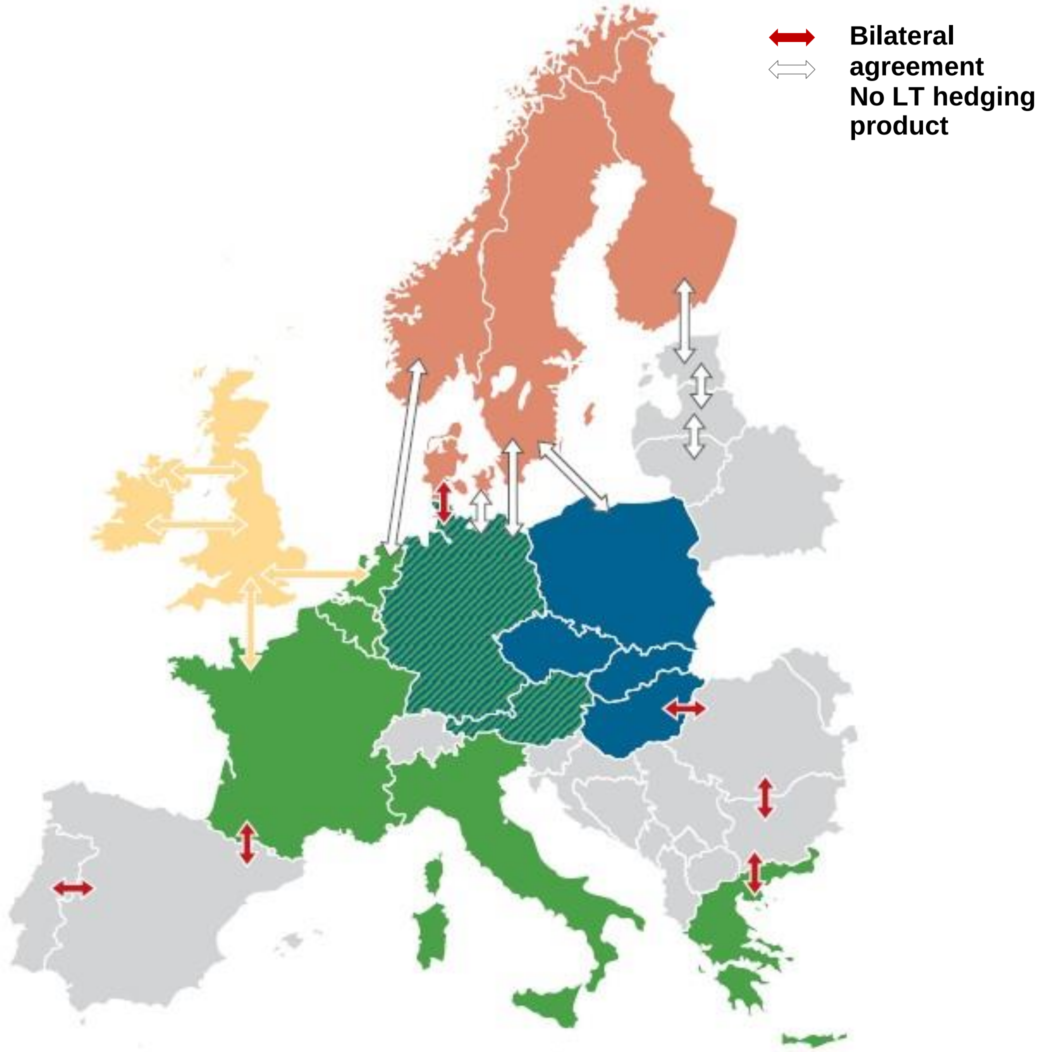


Figure 24: Long-term Transmission Rights
Source: (Agency for the Cooperation of Energy Regulators (ACER), 2012, p. 37)

7 Qualitative Evaluation of Market Coupling

The following chapter aims at assessing the previously explained capacity allocation methods from a qualitative viewpoint. Based on research literature that was published in different scientific journals, I provide an overview of different dimensions of evaluation. Due to the relatively new phenomena of market coupling, only a little amount of research is published so far, although the economic literature is growing. For my desk research I considered journals such as the *Journal of Energy Markets*, *Energy Business Journal*, *Energy Economics*, *The Energy Journal* and *Operations Research*. I accessed these journals over the databases *ProQuest* and *EBSCO*.

The published research can be organized along different dimensions. I propose to divide between three main streams of research literature. The first group of papers compares the different congestion management methods (section 7.1). A second group of papers focuses on the impact of market integration (through market coupling) on market power (section 7.2). As a third group I propose to name papers which focus mainly on social welfare and economic effects of newly integrated markets (section 7.3). I considered scientific journals for the years 2001-2014 as presented in the following three tables:

Research focus on the comparison of different congestion management methods (section 7.1)

2001	2002	2003	2004	2005	2006	2007
-	de Vries and Hakvoort (2002)	-	de Vries (2004)	-	-	-
2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
-	-	Glachant (2010)	Blijswijk & de Vries (2011) Hobbs & van der Weijde (2011)	Julien, Pignon, Robin & Staropoli (2012) Oggioni & Smeers (2012)	Oggioni & Smeers (2013)	-

Table 3: Authors focusing on the comparison of congestion management methods

Research focus on the impact of market coupling on market power (section 7.2)

2001	2002	2003	2004	2005	2006	2007
Borenstein, Bushnell & Stoft (2000)	-	-	-	-	-	-
2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
-	Fridolfsson & Tangeras (2009)	-	Balaguer (2011)	Mirza & Bergland (2012)	-	-

	Ehrenmann & Neuhoff (2009)					

Table 4: Authors focusing on the impact of market coupling on market power

Research focus on welfare and economic effects (section 7.3)

2001	2002	2003	2004	2005	2006	2007
-	-	-	-	Hobbs, Rijkers & Boots (2005)	-	Kristiansen (2007)
2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
-	-	-	Fleten, Heggedal & Siddigui (2011)	Pellini (2012) Nepal & Jamasb (2012)	-	-

Table 5: Authors focusing on social welfare and economic effects

7.1 Comparison of Different Capacity Allocation Methods

Oggioni & Smeers (2013) provide in their research paper an analysis of different congestion management methods. In their paper the authors differentiate between nodal pricing and zonal pricing. Nodal pricing is a market architecture where energy and transmission markets are controlled by a single entity. Thus, it represents the highest degree of market integration where electricity prices directly include congestion costs. In a zonal pricing model energy and transmission markets are separated. The energy market is subdivided into price zones which are operated by different PXs. In a zonal pricing market architecture, market coupling is seen as most efficient solution for handling congestion as it includes both the energy market operated by PXs and the transmission system controlled by TSOs. Although nodal systems have generally been more successful than zonal architecture, the EU foresees the implementation of a zonal system based on market coupling. An example of the difficulties market coupling can bring along is the coupling between the Danish and North German markets in October 2008. The coupling had to be stopped after one week of operation and was reactivated only in 2009 due to data issues. Based on an illustrative analysis with a six node example the authors proof nodal pricing systems as the first best solution. But a combination of market coupling with counter-trading can be efficient compared to nodal pricing as well, depending on how countertrading is organized. The organization is therefore characterized by the degree of coordination between the TSOs at zonal level. Concluded, the research paper provides evidence that countertrading and market coupling are more complementary than substitutional and that in a zonal market architecture market coupling is seen as the best solution (G Oggioni & Smeers, 2013). The same authors published a research paper in 2012 that investigates different congestion management methods by looking at the degree of coordination between PXs and TSOs. They develop a set of models that represent different degrees of coordination between the energy market and the transmission market as well as among national TSOs. The main focus is laid on the market coupling where energy and transmission are operated separately by PXs and TSOs. The main findings are that firstly economic losses in energy markets are due to a separation of the energy and transmission market and secondly because of costs for counter-trading resulting from a lack of coordination between TSOs. The paper shows that an organization of market coupling relying on an integrated TSO is reasonably efficient due to the reduction of counter-trading costs. Inefficiency is in this case limited to the separation of the energy and transmission markets but allow an efficient cooperation of TSOs (Giorgia Oggioni & Smeers, 2012).

Jullien et al. (2012) provide a comparison between “implicit auctions” and “coordinated explicit auctions”. An advantage of the explicit auctions is according to the authors that it is still possible for each country to keep its own power exchange. Especially in Europe with its institutional context, this is seen as a factor for market reform success as it addresses the fragmented market framework with different market designs more adequately. The negative side of explicit mechanisms is that they are less efficient. For their evaluation, the researchers use an experimental methodology. They model the different effects of the auctions mechanism with a three-node network. In their laboratory setting, the coordinated explicit auction shows its inefficiency with mispricing and misallocations. This is mainly due to so called “must use” rules. When the transmission capacity is bought it has to be used otherwise there will be a penalty. This leads in turn to higher price volatility in energy markets. The paper provides evidence that the implicit auction is more efficient for both allocation of transmission capacity and energy. In explicit auctions, individuals have to form expectations about the energy market prices and the transmission prices what leads to a higher degree of complexity in the trading process (Jullien et al., 2012). To the same conclusion comes de Vries (2004). The author states that “explicit auctions are likely to create higher transaction costs than other methods, as they require two separate transactions for cross-border trade of electricity, whereas the other methods require market parties only to make a single transaction.” (Laurens James. de Vries, 2004, p. 256). Thus, the author confirms results from earlier work as in de Vries & Hakvoort (2002). The authors provide evidence that market based congestion pricing methods (explicit and implicit auctioning, market splitting) are in most cases preferable to corrective methods (redispatching and counter trading) (Laurens J. de Vries & Hakvoort, 2002).

An analysis on redispatching as a non-market based congestion management method is provided by van Blijswijk & de Vries (2011). The researchers investigate a basic redispatching method which was implemented by the Dutch government for the internal market. The authors compared redispatching with market based congestion management methods whereby the following advantages and disadvantages are found:

Method	Short description	Advantages	Disadvantages
Market splitting	A market is divided into different nodes, although it is cleared as one single market. If desired transactions cannot be implemented, the market is split into several nodes with price differences corresponding to the shortage of transmission capacity	• Economically efficient • Increased liquidity • Locational incentives are provided	• No incentive for TSO to expand capacity
Market coupling	A number of nodes in an electricity system with no internal congestion are assumed. The coupling mechanism then determines a spot market outcome for each node separately and calculates the optimal transmission flows between the areas.	• Economically efficient • Regional incentives are provided	• No incentive for TSO to expand capacity
PX-based method (*explicit auction*)	Geographical cost differentiation is applied with a uniform pricing. Producers offer their production into a central spot market and place a bid for transmission capacity. Depending on the feasibility of market transaction patterns, some originally accepted offers are rejected.	• Uniform pricing is maintained • Incentives for capacity expansion are maintained	• Provides no locational incentives for demand
Basic system *Redispatch*	Generators in a constrained area are constrained off and compensatory power is acquired elsewhere by the TSO. Constrained off producers are credited for their intended production. They sell same volume as originally contracted but as their plants don't run they save their variables costs. Consequently, they pay the TSO an amount up to these variable costs. Congestion costs arise because constrained on power is more expensive than constrained off payment benefits. These costs can partially be socialized to customers	• Cost allocation flexibility • Low transaction costs	• No incentive to locate outside congestion area • Vulnerable to market power and gaming

Table 6: Advantages and disadvantages and summary of different congestion management methods
Source: (van Blijswijk & de Vries, 2011, pp. 12-13)

(van Blijswijk & de Vries, 2011)

Hobbs & van der Weijde (2011) focus their analysis more on the calculation of available transfer capacity. In their research, they provide evidence that market coupling based on so called locational marginal pricing (LMP, also known as nodal pricing or *flow-based allocation*) is more efficient then market coupling based on the *Net transfer capacity* (NTC) method. By using stochastic models for the behavior of electric generators subject to transmission lines, they proof that LMP benefits from a consistent consideration of all network constraints both, in the day-ahead timeframe and in real time. The researcher's results propose savings in the fuel costs of non-baseload plants of 0-2% due to a better dealing with uncertain load and wind forecasts. (van der Weijde & Hobbs, 2011)

Glachant (2010) compares three different coupling solutions. In the Nordic region (Norway, Sweden, Finland and Denmark) the coupling of national markets was achieved through a single PX as a subsidiary of the Nordic TSOs. The PX runs a single day ahead price zone if there are no constraints and splits the region in different areas when structural constraints occur. This is the already explained market splitting model and is seen as success. The second solution is the less centralized single pricing mechanism between the three national PXs of the Netherlands, Belgium and France. The PXs are coupled by a common pricing algorithm coordinating the price formation between the three markets. Glachant (2010) assess this trilateral market coupling as success story and it has been validated as an EU model for other regional markets. The third model- a counter model, has been experimented between Germany and Denmark. The two market coupled the volumes (volume coupling) linking the quantities offered to the market while keeping the price formation in the two markets separated. This coupling failed and started working only when elements of price coupling were introduced. These three examples show that in practice mainly the price coupling solution in the trilateral case was successful whereas the volume coupling between Germany and Denmark failed. (Glachant, 2010)

7.2 Impact of Market Coupling on Market Power

The second group of research paper lays their focus on how an improved electricity transfer between single countries is changing the behavior of electricity producers and thus changing market power in the representative country. The presence of sufficient transmission capacity is important for ensuring a competitive market. If transmission lines are constrained, that works as if there is limited entry in the market. Mirza & Bergland (2012), for example, analyze the impact of transmission bottlenecks on producer behavior in the Norwegian electricity market supposing that local producers can raise electricity prices when transmission lines between two areas are constrained. This thesis is tested by using hourly data for the Norwegian power market and by looking if producers exercise market power when electricity imports are constrained. They provide evidence that the transmission capacities between Norway and Denmark are sufficiently large to keep prices close to the marginal cost of production. Their results also show that the transmission capacity itself plays a significant role if the market equilibrium is close to competitive levels or not. The authors consequently recommend that enough transmission capacity between markets could guarantee the competition between local generators (Mirza & Bergland, 2012). As such, this paper confirms earlier work like the results of Borenstein et al. (2000). In the context of the deregulated electricity market in California, the authors show that the capacity of transmission lines will determine the degree to which generators in different locations compete with one another. The authors conclude that “relatively small investments in transmission may yield surprisingly large payoffs in terms of increased competition.” (Borenstein, Bushnell, & Stoft, 2000, p. 294). A broader literature review of empirical research assessing market power in the Nordic wholesale market can be found in Fridolfsson et al. (2009). The authors highlight that market power can manifest itself within different dimensions. They are investment incentives, vertical integration, buyer power and withholding of base-load capacity

(Fridolfsson & Tangeras, 2009). The impact of different auction methods on market power is investigated by Ehrenmann & Neuhoff (2009). The authors analyze the difference between explicit and implicit auction mechanism and proof that implicit auctioning reduces market power (Ehrenmann & Neuhoff, 2009).

Reverse to that, Balaguer (2011) applies a different approach to examine the influence of market integration on market power. The author looks at the pricing behavior of electricity exporters in Norway and Switzerland. The pricing behavior of Norwegian exporters indicates a high degree of market integration with its neighboring countries Denmark and Sweden. This contrasts with the case of Swiss exporters. Differences in the pricing behavior between Italy, France and Germany indicate according to the author that exporters in Switzerland take advantage of international market segmentation and divergences in the market structures. As such, price differences between countries cannot be fully explained by transmission costs as stated by other research papers but also by the behavior of market participants. The author concludes that market integration can have a positive effect not only for market power but also for social welfare (Balaguer, 2011).

7.3 Welfare and Economic Effects

The third group of research literature builds up on market power and investigates the welfare and economic gains that can be achieved by opening markets through an efficient allocation of transfer capacity. Pellini (2012), for example, evaluates the replacement of explicit auction mechanism with market coupling in the Italian electricity market by applying a research methodology which is based on a deterministic simulation of the Italian day-ahead market under two alternative market scenarios. The simulations are done by using a model called ELFO++ which is a production cost-based model for simulating the outcomes of a liberalized day-ahead market with the option that the generation companies either sell their power output to a power exchange or over OTC contracts. By the use of market coupling the use of interconnection capacity can be maximized as it allows flows-netting and an elimination of inefficient arbitrage. The results of the paper support the theoretical view that market coupling provides a net welfare gain for market participants. The paper states for its *reference scenario* (weak electricity demand in the Italian economy and an overcapacity on the supply side) a net welfare gain of € 33m/year to € 396m/year for 2012. For a modeled *high scenario* (higher demand and higher cost of production) the estimated output ranges even between € 132m/year and € 741m/year for 2012. Thus, it is summarized that a high price area such as Italy could greatly benefit from the introduction of market coupling mechanism (Pellini, 2012). Another research paper that investigates the potential of market integration in terms of welfare and economic effects was written by Nepal & Jamasb (2012). In the case of the Irish electricity market the authors provide evidence that Ireland could profit if existing interconnectors to Great Britain would be increased. They expect that increased cross-border trade would have a downward pressure on domestic prices for electricity.

Furthermore, the researchers suggest an increase in the security of supply and that the volatility of electricity prices in Ireland is expected to decrease (Nepal & Jamasb, 2012).

Hobbs et al. (2005) investigate in their research paper the impact of market coupling for the electricity markets in Belgium and the Netherlands (the analysis was done before the introduction of the Trilateral Coupling between France, Belgium and the Netherlands). The researchers calculate social welfare surplus by applying a model called COMPETES that is based on a Cournot-Nash equilibrium approach. The simulations are done for different market environments whereby market participants act either as dominant players or price-takers. The paper provides evidence that the economic efficiency can be increased by introducing market coupling. If the main producers play strategically, the change in the social surplus totally would be significant (about € 200 m/year) although the distribution would be negative for Dutch consumers by raising the prices in the Netherlands. If the main players act as price-takers in Belgium the social surplus gain would be smaller (about € 50 m/year) but more equally distributed between Belgium and the Netherlands.(Hobbs, Rijkers, & Boots, 2005)

A further assessment of market coupling in the case of East Denmark and Germany over the Kontek (KT) cable[14] is presented by Kristiansen (2007). It was expected that the KT price correlates more with the European Energy Exchange (EXX) price because arbitrage normally balances the prices. However, both prices remained high and volatile (Kristiansen, 2007). In this case, the market coupling didn't lead to social welfare gains as in both markets prices remained high.

A different perspective is laid in a paper published by Fleten et al. (2011). Main research focus is put on the investment opportunity of constructing a high-voltage, direct current (HVDC) cable between Norway and Germany. The profitability depends mainly on electricity price differentials between the regions. The construction of an interlink will in turn affect the price difference which has to be considered. The investment costs are calculated by using a real options valuation framework. As the option price depends on the volatility of future payoffs, the investment will only be undertaken if policy measures and other market characteristics do not increase the volatility of annual revenues (Fleten, Heggedal, & Siddiqui, 2011). Thus, a stable market environment works as incentive for investments in interconnection cables and will in turn increase social welfare.

[14] Kontek is a 170 km long cable connecting the German power grid and the Danish grid of the island

Sealand.

8 Descriptive Statistics of Market Coupling Initiatives

The previous chapter relied on desk research to assess the different market coupling methods and initiatives. This chapter focuses on how market coupling initiatives are changing the wholesale prices of coupled markets. In theory, the prices of two coupled markets should converge when no congestion occurs and expand when congestion occurs. The goal therefore is to analyze by descriptive statistics if this assumption can be observed or not and if the previously presented results from the qualitative analysis can be confirmed. As such, different time series for different national markets are analyzed before and after the date they were coupled with other markets.

8.1 Data set

The time series used in this thesis are daily electricity spot prices for the German, French, Dutch and the Danish markets. The data series are dating from November 28, 2005 to 7 years ahead (November 27, 2012). This date was chosen because it was the earliest common available. As such, the observation periods provide between 2535 and 2777 data points (trading days), depending on holidays in the representative countries. The spot prices are in € per Megawatt hour (€/MWh) for day-ahead markets. The data set was chosen because each of them represents a certain market coupling project. Germany and France were coupled through the CWE MC, France and the Netherlands through the earlier TLC and Germany and Denmark through EMCC. Table 7 shows the type and the source for each country:

Country	PX	Contract type	Source
Germany	European Power Exchange EEX (but contract traded at EPEX Spot)	Phelix Base load (hours 1-24)	BLOOMBERG
France	EPEX Spot	Base load (hours 1-24), day ahead auction	BLOOMBERG
Netherlands	APX ENDEX	Average Index for base load hours (24 h), Day-ahead auction	BLOOMBERG
Denmark	Nord Pool Spot NPS	DK2	BLOOMBERG

Table 7: Type and source of data

For Denmark, there are two prices available, DK 1 and DK 2 which represent two different price zones. Both are traded at Nord Pool Spot and both are included in the EMCC market coupling. In this analysis, DK2 was chosen because the time series has less missing observations than DK1. The data series for EEX, EPEX, APX and NPS are provided by BLOOMBERG. All contracts refer to the electricity price for one day but the way they are calculated differs. EEX Phelix base-load and EPEX spot are both base-load block contracts. This means that the contract leads to an electricity delivery for 24 hours on the next day (Day-ahead auction). Consequently, the bidder pays for one single contract and the prices are directly calculated at the PX. The APX price and the NPs Copenhagen are both Indices for base load hours and represent the average for the single prices for each hour. Nevertheless, for the purpose of this thesis both “types” should be comparable.

Descriptive statistic Table 8 reports the summary of the descriptive statistics for the prices for the four markets which are analyzed in this study. Figure 25 APX (Netherlands) to Figure 28 indicate a very high volatility, price spikes, price jumps and seasonal patterns. These observations are characteristically for the price behavior of electricity market data.

Daily spot prices	EEX (Germany)	EPEX (France)	APX (Netherlands)	NPS DK2 (Denmark)
Mean	47.77	49.83	51.02	46.13
Median	45.83	46.87	48.85	44.14
Std. Dv.	18.35	23.92	18.71	19.54
Kurtosis	19.88	139.50	13.24	139.58
Skewness	2.35	7.38	2.16	7.36
Min	-35.57	9.51	14.83	7.85
Max	301.54	612.77	277.41	505.68
N	2557	2557	2557	2534

Table 8: Descriptive Statistics for daily spot prices €/MWh

The highest mean and median price over the whole observed period was in the Netherlands with a mean of 51 €/MWh and a Median of 49 €/MWh. The lowest average price, as well as the lowest median was in Denmark. The highest coefficient of variation is observed in the French market EPEX (23.92/49.83=48%). The highest occurred price was in France with a value of 613 €/MWh and the lowest, even negative value in the German market (-36 €/MWh). In fact, negative prices occur in the German market more than one time as plotted in Figure 25[15].

Both, kurtosis and skewness give indication that the price series are not normally distributed with a high occurrence of extreme values. The log transformation of the price series reduces the skewness and the kurtosis. The largest volatility of the log returns occurs in Germany. Table 9 presents the values for the transformed log returns:

[15] The appearance of negative prices in the German market can be explained by the high share of off-shore wind power plants that produce a high amount of electricity in a time where the market does not demand it.

An example could be a storm in the night that leads to a high electricity output of off-shore wind farms which is not demanded as the electricity consumption is lower during night times than day times.

Daily log returns	EEX (Germany)	EPEX (France)	APX (Netherlands)	NPS DK2 (Denmark)
Mean	0.00	0.00	0.00	0.00
Median	-0.02	-0.02	-0.02	-0.01
Std. Dv.	0.28	0.27	0.23	0.21
Kurtosis	3.01	8.24	4.50	7.70
Skewness	0.64	0.83	0.56	0.28
Min	-1.56	-2.21	-1.54	-1.79
Max	1.74	2.66	1.69	1.67
N	2556	2556	2556	2556

Table 9: Descriptive Statistics for daily log returns

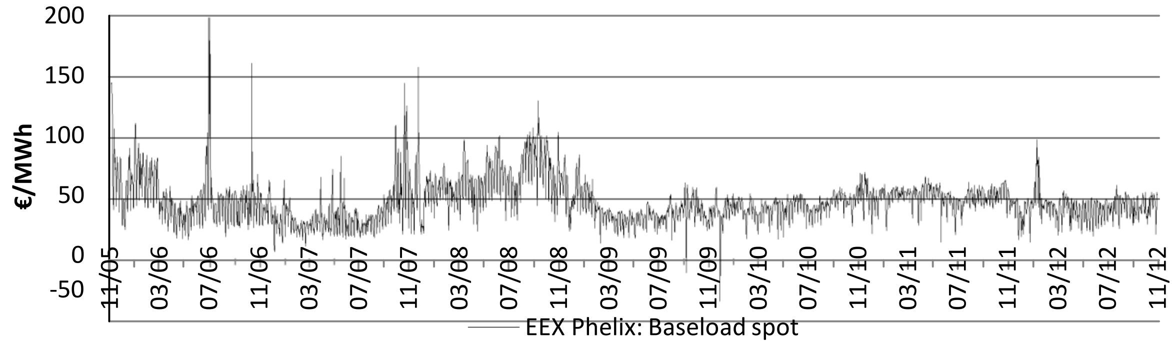


Figure 25: EEX (Germany)

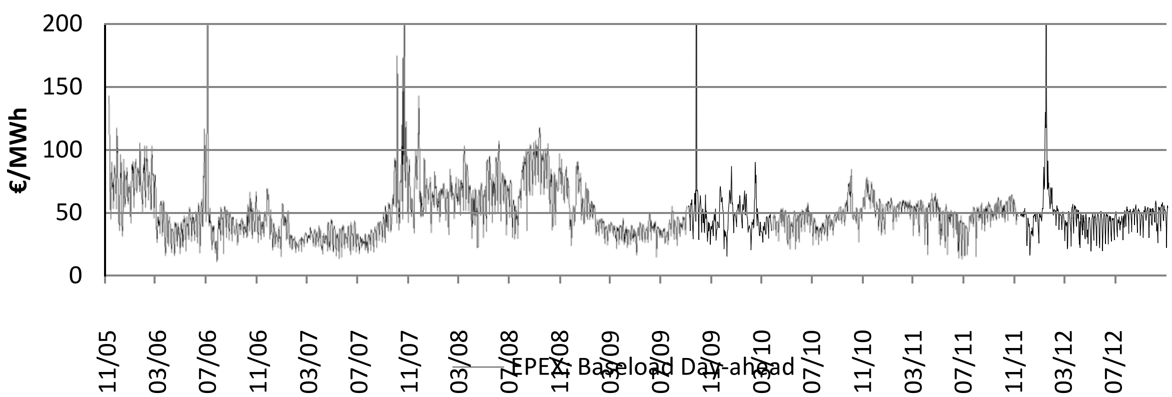


Figure 26: EPEX (France)

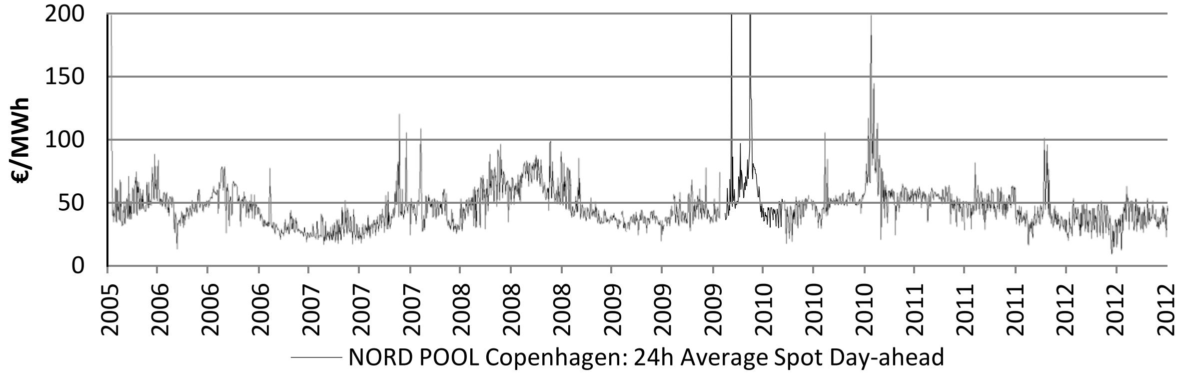


Figure 27: Nord Pool Spot Copenhagen NPS (Denmark DK2)

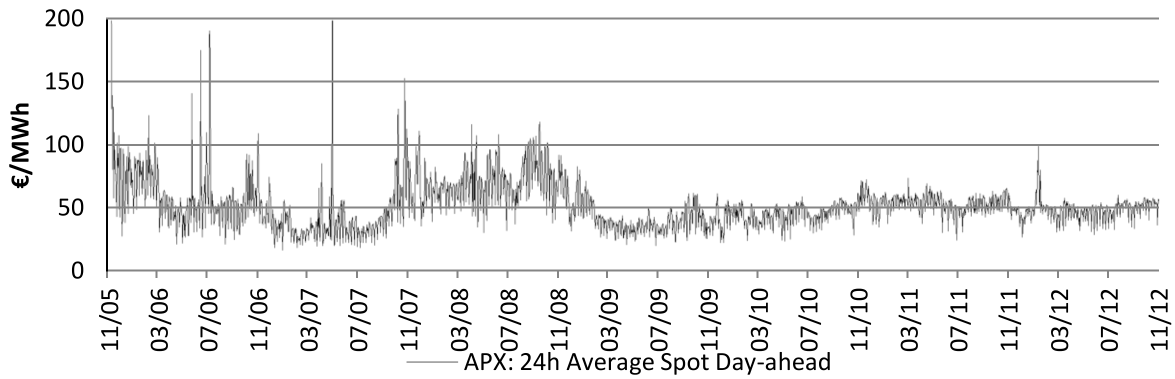


Figure 28: APX (Netherlands)

8.2 Price Convergence and Market Coupling

In the following, three market coupling projects are investigated. The goal is to test if prices converge after the coupling date. A simple way to obtain suggestive evidence about that is to compare the same-day price differences of the involved markets for the pre-coupling and the post-coupling period. The method is to split the time series in two sub series, pre-coupling and post-coupling, and then to compare the absolute price differences between the two time series. With a t-test it is tested if the average of the price differentials is statistical relevant. A Wilcoxon test examines if the median of the price differentials is statistically relevant. Additionally, I analyzed how the distribution of the absolute price differences changed after the coupling. A similar method was applied by Kristiansen (2007).

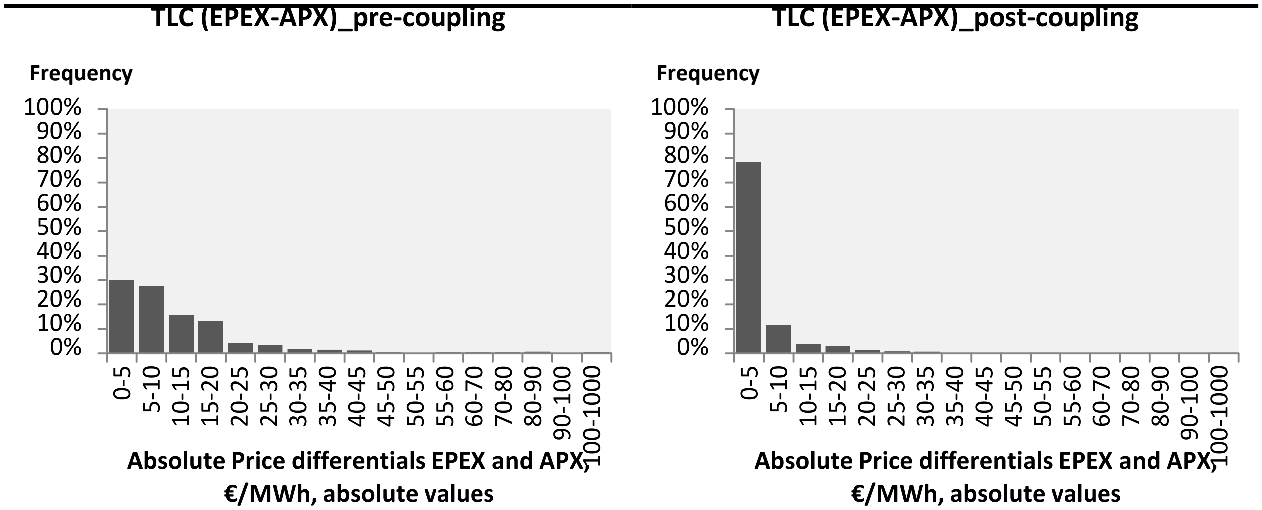
TLC The trilateral market coupling started on the 21st November 2006. It is a price volume coupling between the three countries France, Belgium and the Netherlands. For the analysis of the TLC initiative, the price history of France and the Netherlands has been chosen as the Belgian data set was not available. Although France and the Netherlands do not share a common border but are linked over Belgium, the prices in the two countries nevertheless are supposed to converge. For the pre-coupling period, 358 daily price pairs are available. The post-coupling period consists of 1449 daily prices for the French market and 1450 daily prices for the Dutch market. This difference is due to a missing price in the French market. The end date is the 9th November 2010. On this date, the coupling initiative was expanded on Germany and the Central Western Europe market coupling (CWE MC) was launched (see third paragraph).

Table 10 reports the summary of the descriptive statistics for the TLC coupling. For both markets, the average price decreased. In France, the price decrease was from 52.54 €/MWh to 49.68 €/MWh and in the Netherlands from 61.44€/MWh to 48.85 €/MWh. As such, the mean in France and the Netherlands were similar after the coupling. Also the Median slightly decreased in the French case and considerably in the case of the Netherlands.

	Pre-coupling	
	EPEX	**APX**
Mean	52.54	61.44
Median	45.34	55.66
Std. Dv.	25.86	24.61
Kurtosis	8.55	5.67
Skewness	2.02	1.80
Min	9.51	19.65
Max	234.45	191.81
	Post-coupling	
	EPEX	**APX**
Mean	49.68	48.85
Median	44.02	43.96
Std. Dv.	26.38	20.11
Kurtosis	149.76	12.15
Skewness	7.95	1.97
Min	12.17	14.83
Max	612.77	277.41

Table 10: Descriptive Statistics TLC, in €/MWh

Figure 29 reports the distribution of price differentials in the two markets. The figure provides evidence that the prices converged after the market coupling. The average price difference between France and the Netherlands decreased from 11.79 €/MWh to 4.48 €/MWh and the Median of the price difference from 8.64 €/MWh to 1.35 €/MWh. Both, the t-test statistic for the mean and the Wilcoxon-test statistic for the median indicate that the decrease of the absolute price difference is statistically significant. Furthermore, a price difference between 0 and 5 €/MWh, for example, occurred in 78% of the days compared to 30% before the coupling. These results confirm earlier research such as Glachant (2010) who assess the TLC coupling initiative as success story in terms of price convergence.



Mean of price differentials	(pre coupling): 11.79	(post coupling): 4.48	
_T-test		t=8.8***	p-Value < 2.2E-16
Median of price differentials	(pre coupling): 8.64	(post coupling): 1.35	
_Wilcoxon-test		W=63370	p-Value < 0.00

Figure 29: Frequency Distribution of Price Differentials for the TLC Coupling

EMCC The European market coupling company (EMCC) couples the Nordic power market with the central Europe power market over several interlinks. These interlinks are installed between Norway and the Netherlands, between Sweden and Germany and over two different links (DK1 and DK2) between Denmark and Germany (European Market Coupling Company EMCC, 2013a). The EMCC market coupling has its origin in August 2008 with the goal to couple the German and Nordic countries. After initial problems the coupling was interrupted after only ten days. On 9th November 2009, finally, Germany and Denmark coupled their markets through a tight volume coupling. This EMCC market coupling was finally integrated in the CWE region through an inter-regional tight volume coupling (ITVC) on 9th November 2010 (Gilian Carr, 2012; Creti et al., 2010).

As such, the time series of Germany and Denmark can be split in three sub- periods. The first “pre-coupling” before the coupling date (9th November 2009), the second “post-coupling” until the Nordic market was integrated in the CWE region on 9th November 2010 and the third after the integration. The pre-coupling period consists of 2557 daily spot prices for Germany and 2535 for Denmark (DK2). The post-coupling period consists of 365 price series for Germany and 353 for Denmark before the broader integration of the Nordic and Central European market. This divergence in the data set is due to missing prices in the Danish time series. For the analysis of the price differentials, these gaps in the data set were taken into account by not considering the German data if the representative Danish price was missing.

Table 11 reports the summary statistics for the EMCC market coupling. In Germany, the average prices decreased from 48 €/MWh to 42 €/MWh whereas the average priced in Denmark increased from 46 €/MWh to 52 €/MWh. Consequently it seems that the Danish consumers did not profit from this market coupling.

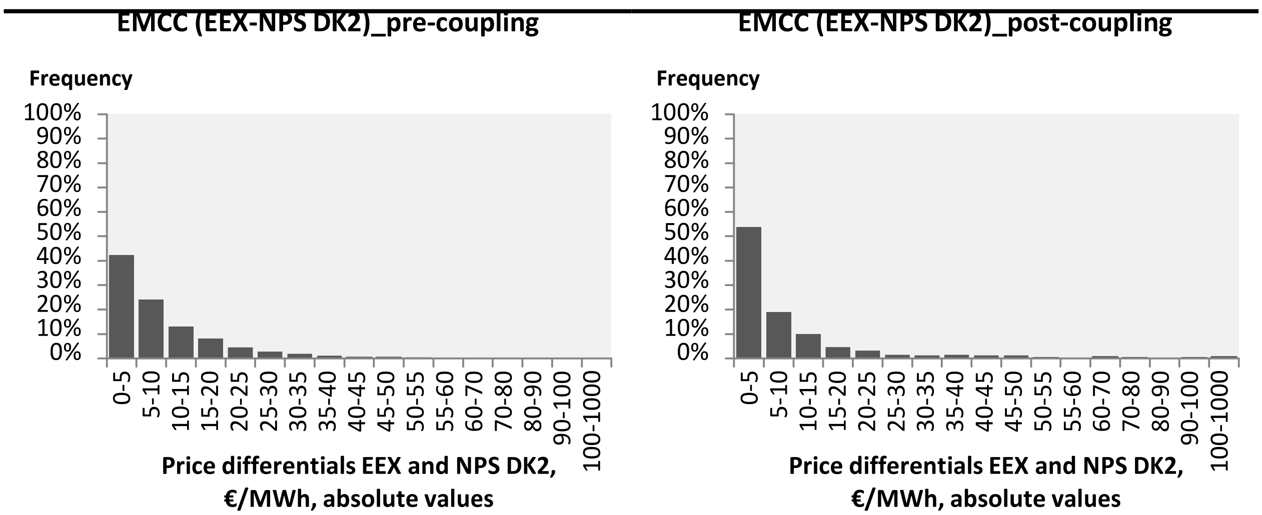
	Pre coupling	
	EEX	**DK2**
Mean	49.27	44.67
Median	44.20	42.12
Std. Dv.	22.63	16.39
Kurtosis	13.73	13.02
Skewness	2.10	1.81
Min	-11.59	11.85
Max	301.54	235.71
	post coupling	
	EEX	**DK2**
Mean	41.95	52.01
Median	43.16	47.75
Std. Dv.	9.04	31.57
Kurtosis	14.49	130.77
Skewness	-2.18	10.03
Min	-35.57	16.18
Max	59.71	505.68

Table 11: Descriptive Statistics EMCC, in €/MWh

Figure 30 reports the distribution of price differentials between the EEX price serie and the NPS DK2 one. The amount of price differences in the range of 0 to 5 €/MWh increased from 42% to 54% after the coupling date. The average of the price difference between the two market increased from 10.25 €/MWh to 11.45 €/MWh which seems counterintuitive as it is expected that prices converge. A reason might be the distribution of the price differentials and the occurrence of more extreme values in the price difference after the coupling[16]. Furthermore, the difference in the mean is statistically not relevant, as

[16] Extreme values can for example occur in the case of a power plant shut down

indicated by the t-test statistic in Figure 30. The median decreased from 6.42 €/MWh to 4.20 €/MWh after the coupling date, which is according to the Wilcoxon-test statistically significant. Nevertheless, the prices did not converge as much as in the previous TLC coupling initiative and the EMCC market coupling initiatives can't be seen as successful under the assumption that market coupling is supposed to lead to a price convergence. Thus, the results also are in line with previous analysis as for example in Glachant (2010). The author states that the EMCC market coupling initative became only successful when elements of a price coupling (see chapter 5.2.4) were introduced and thus the coupling mechansims became more efficient (Glachant, 2010).



Mean of price differentials _T-test	(pre coupling): 10.25	(post coupling): 11.45 t=-0.55	p-Value=0.58
Median of price differentials _Wilcoxon-test	(pre coupling): 6.42	(post coupling): 4.20 W=808288	p-Value =0.00

Figure 30: Frequency Distribution of Price Differentials for the EMCC Coupling

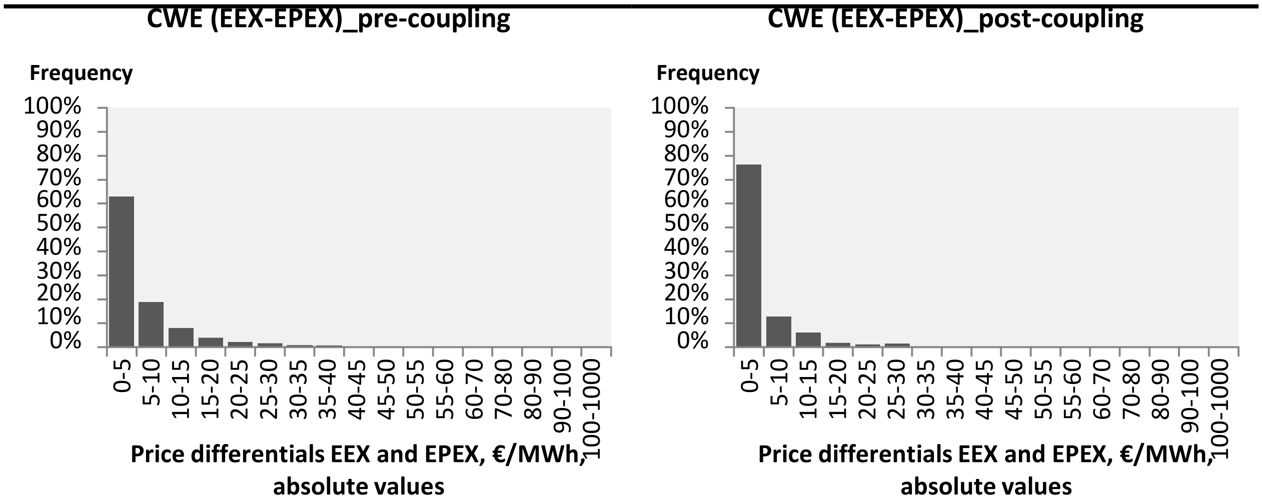
CWE MC The CWE market coupling can be seen as extension or successor of the TLC because it consists of France, the Netherlands, Belgium (TLC) and new Luxembourg and Germany. The CWE MC went live on the 9th November 2010. In this analysis the focus is put on France and on Germany. It is interesting to see how this market coupling initiative is changing prices as both countries are the biggest power markets in the CWE region. It has to be considered that there might be many other countries influencing the prices in Germany and France so the analysis will deliver limited results. Nevertheless, it will provide intuitive evidence of the degree of success of this coupling initiative. For the analysis, the two time series were split into two sub series. This leads to a pre-coupling series with 1807 data pairs for Germany and France. The post coupling series contain 750 daily data points.

Table 12 reports the summary of the descriptive statistic for the CWE market coupling. The average prices in both markets decreased after the coupling date and the mean and the median were similar in both countries. A counter intuitive result is the increase in median prices after the coupling date.

	Pre coupling	
	EEX	**EPEX**
Mean	47.79	50.24
Median	43.70	44.34
Std. Dv.	20.82	26.30
Kurtosis	16.42	122.54
Skewness	2.28	6.81
Min	-35.57	9.51
Max	301.54	612.77
	post coupling	
	EEX	**EPEX**
Mean	47.72	48.85
Median	48.67	49.35
Std. Dv.	10.16	16.81
Kurtosis	1.58	174.22
Skewness	-0.23	9.47
Min	13.63	11.26
Max	98.98	367.60

Table 12: Descriptive Statistics CWE MC, in €/MWh

Figure 31 provides evidence that the prices in the two markets converged after the coupling date. Nevertheless, the degree is not as distinctive as in the case of the TLC coupling. The average price differential decreased from 6.76 €/MWh to 4.33 €/MWh and the median price difference from 3.27 €/MWh to 1.78 €/MWh. Both changes are statistically significant, as indicated by the t-test statistic and the Wilcoxon-test statistic in Figure 31. Already before the coupling the price difference was in 63% of the days only small and lied between 0 and 5 €. After the coupling, the degree increased to 76%. It can be summarized that in this case market coupling did not deliver as impressive results as in the TLC coupling. Nevertheless, earlier results that cite that prices converged on average 66% of the time in 2011 in the CWE region can be confirmed (Gilian Carr, 2012).



Mean of price differentials _T-test	(pre coupling): 6.76	(post coupling): 4.33 t=4.09***	p-Value < 4.4E-5
Median of price differentials _Wilcoxon-test	(pre coupling): 3.27	(post coupling): 1.78 W=1360633	p-Value=0.00

Figure 31: Frequency Distribution of Price Differentials for the CWE Coupling

Market Coupling Initiative	Participating countries	Degree of harmonization	Capacity Allocation Method	Capacity Calculation Method	Starting Date	Ending Date
TLC	Belgium, France and the Netherlands	Medium (Separate PXs)	Price and Volume coupling	ATC	21st. Nov. 2006	9th Nov. 2010
EMCC	Germany and Denmark (and Sweden)	Medium (Separate PXs)	(Tight) Volume coupling	ATC	9th Nov. 2009	9th Nov. 2010
CWE-MC	Belgium, Luxembourg, the Netherlands, Germany and France	Medium (Separate PXs)	Price and Volume coupling	ATC and Flow base	9th Nov. 2010	-

Table 13: Summary of the three investigated coupling projects

Summary The analysis of the three market coupling initiatives aims at testing if the results in the previously described research literature can be confirmed. The method I used was to take the absolute difference between prices in two coupled markets and to test if the average and the median of these price differentials changed significantly after the introduction of market coupling. My thesis and assumption is that the prices should converge and thus the price differentials should decrease. It can be stated that my results are in line with previous conclusions in other research papers. The most successful market coupling in terms of price convergence is the TLC market coupling between France, Belgium and the Netherlands. My results show that market coupling led to an increase of the amount where prices were similar (in the range of 0-5 €/MWh) from 30% to 78%. Thus, the TLC coupling can be assessed as success. For the EMCC coupling between Germany and Denmark, the results are less impressive. The mean of the price difference even increased which is counterintuitive. Thus, my assumption that prices converge has to be denied. Nevertheless, the results also are in line with previous analyses and the statement that the volume coupling of EMCC was not a success can be confirmed. Finally, the CWE coupling which was assessed by analyzing the German and the French market led to a price convergence of the German and French prices. But the results show that prices were already before the coupling in 63% of the observed price pairs nearly identical (range 0-5 €/MWh). Thus, the CWE coupling confirms my thesis although with less impressive figures. The method I used provides only limited evidence as further, external factors that affect the price levels in different markets were not taken into account. Also the interrelationship between more than the two investigated countries was not considered. Nevertheless, the method provides an intuitive assessment of these three market coupling projects.

9 Cointegration Test

The following chapter investigates the interrelationship between different electricity markets with focus on the extent of change due to market coupling. To investigate this, a cointegration analysis is proposed as a more sophisticated tool than just a simple correlation analysis. One example of a research paper that investigates the relationships between different electricity markets and also to other energy commodities was written by Veka et al. (2012). The authors investigate the extent to which the price of Nordic electricity derivatives correlates with EEX electricity contracts as well as with crude oil, coal and carbon emission contracts. They find significant time-varying relationships between the investigated energy commodities except oil. The authors apply a multivariate generalized autoregressive conditional heteroskedasticity (MGARCH) model. As such, their focus of interest is on the variances and covariances in different markets but they propose cointegration analysis for analyzing how events in one market will influence price level or returns in other markets if there are linkages between prices (Veka, Lien, Westgaard, & Higgs, 2012). Cointegration tests are common in the investigation of interrelationships between different commodity prices. Dahl et al. (2012), for example, test whether oil and gas prices in the United Kingdom are cointegrated or not. The authors find a structural shift in the stochastic trend in 2006 and 2007 for Brent oil and gas (Dahl, Oglend, Osmundsen, & Sikveland, 2012). De Jong and Schneider (2009) provide a cointegration analysis between gas and power spot prices in Benelux countries. The authors find cointegration of gas and power prices only for long-term forward prices (de Jong & Schneider, 2009). This chapter aims at testing if the price behavior changed after market coupling. Therefore, the chapter is structured as follow:

Section 9.1 introduces the methodology of cointegration according to Engle and Granger's (1987) two step approach. Section 9.2 presents the results of the Unit root test and Section 9.3 presents the cointegration test results.

9.1 Methodology

This thesis applies the two step approach used by Engle and Granger (1987) to test for cointegration. The idea is to test if two time series move in a similar, connected relationship and have the same stochastic trend. Consequently, cointegration can be described as follows: if "an individual economic variable, viewed as a time series, can wander extensively and yet some pairs of series may be expected to move so that they do not drift far apart."(Engle & Granger, 1987, p. 251). Alternatively, cointegration is defined by Ogunc & Hill as follow: "two non-stationary series are cointegrated if their differences are stationary" (Ogunc & Hill, 2008). Mathematically, cointegration can be expressed as a linear combination of two non-stationary time series:

$$r_{1t} = \alpha + \beta r_{2t} + e_t$$

Where r_{1t} and r_{2t} are two time series and e_t denotes an error term.

Unit root tests like an augmented Dickey-Fuller (ADF) test examine if an autoregression (AR) process is stationary or not (see below). In the Engle-Granger test framework, this approach is applied on the residuals of a regression between two time series. The null hypothesis is that the residuals of the regression between two time series are non-stationary (have unit root). Rejecting the null-hypothesis leads to the conclusion that the residuals are stationary and therefore the series must be co-integrated. (Engle & Granger, 1987; Ogunc & Hill, 2008, p. 185). Time series data are stationary when their means, variances and covariance are constant and don't depend on the period, in which they are measured, respectively if the distribution function is constant over time. (Ogunc & Hill, 2008). The augmented Dickey-Fuller (ADF) test has thereby the following mathematical form:

$$x_t = c_t + \beta x_{t-1} + \sum_{i=1}^{p-1} \Phi_1 \Delta x_{t-i} + e_t$$

If $\beta > 1$, the Autoregression (AR) process is instable. If $\beta = 1$, the process has a unit root and is non-stationary. If $-1 < \beta < 1$, the process is stationary (Wilmott, 2007). By applying the mathematical mutation:

$$\Delta x_t = x_t - x_{t-1}$$

(Subtracting x_{t-1}) the AR process can be represented in the form:

$$\Delta x_t = c_t + \beta_c x_{t-1} + \sum_{i=1}^{p-1} \Phi_1 \Delta x_{t-i} + e_t$$

Where $\beta_c = \beta - 1$ and Δx_t =difference, x_{t-1}=lag and $\Phi_1 \Delta x_{t-i}$= difflag. The null hypothesis H_0 is now that $\beta_c = 0$ ($\beta = 1$; process is not stationary) versus H1: $\beta_c < 0$. If the ADF critical values are less than the t-values of the Regression analysis of the residuals, the null hypothesis can be rejected and the residuals are stationary with the consequence that the time series are co-integrated. The ADF test values are calculated by applying the following ADF-test:

$$\mathrm{ADF-test} = \frac{\hat{\beta} - 1}{\mathrm{std}(\hat{\beta})}$$

Where $\hat{\beta}$ denotes the least squared estimate of β (Engle & Granger, 1987; Ogunc & Hill, 2008).

9.2 Empirical Results Unit Root Test

It is required to test in a first step the time series for non-stationarity. Therefore, the ADF test tests for unit root for the log price series of EPEX, APX, EEX and NPS DK before and after the coupling date. To get a well-fitted model, it is necessary to consider the log prices. The test is done using a constant in the testing equation (see previous section) taking into account the intercept of the time series. In the test equation, a time trend is not included since a drift is not observed in the time series. Researchers such as Ng and Perron (2001) point out, that an adequate lag length choice for an ADF test is important. The authors state that "the bias in the sum of the autoregressive coefficients is highly dependent on k [amount of lags][. . .]" (Ng & Perron, 2001, p. 1).

In this thesis the ADF test is performed using the Akaike Information Criterion (AIC) to choose the lag length. Therefore, the analysis was performed with different lag lengths. Then, the final results are derived with a lag length in which the AIC is minimal. A low (high negative) value for the significance level for the log prices in Table 14 indicates that there is evidence that the null hypothesis of a unit root can be rejected and thus the time series are assumed stationary. A cointegration analysis of time series that are stationary does not make much sense.

In the pre-coupling period, the test cannot reject the presence of a unit root at a 5% significance level for EPEX and APX (TLC coupling), for EEX and NPS DK2 (EMCC coupling) and in the CWE coupling for EEX. However, the null hypothesis can be rejected for EPEX in the CWE coupling period. Nevertheless, the results show that the EPEX time series is very sensitive to the lag lengths. That shows that all time series are non-stationary except the EPEX one for the pre-coupling period.

In the post-coupling period, the test cannot reject the presence of a unit root at a 5% significance level only for EPEX and APX (in the TLC case). For the EMCC and for the CWE coupling, the presence of a unit root can be rejected and the time series consequently seem to be stationary.

	Lag selection criteria AIC					
	TLC		EMCC		CWE	
Pre-Coupling	**EPEX**	**APX**	**EEX**	**NPS DK**	**EEX**	**EPEX**
Significance level						
Log prices	-2.435	-2.497	-2.751*	-2.482	-2.567	-3.170**
Lag length	14	14	21	23	28	29
Post Coupling	**EPEX**	**APX**	**EEX**	**NPS DK**	**EEX**	**EPEX**
Significance level						
Log prices	-2.308	-2.039	-3.687***	-3.280**	-3.027*	-3.668***
Lag length	21	21	14	7	21	21

Table 14: Significance levels and lag length of ADF unit root tests before and after coupling

Note: Values smaller than -2.57 indicate that the null hypothesis of a unit root must be rejected at a 10% significance level (*), smaller than -2.86 at a 5% significance level (**) and smaller than -3.42 at a 1% significance level (***)

Table 14 provides mixed findings. The majority of time series is assumed to be non-stationary at a 5% significance level. But for the EMCC coupling the null hypothesis can be rejected at a 5% level for the whole post-coupling period. Thus, it seems that the time series are not anymore non-stationary since the coupling date. This result is surprising as it indicates that the mean and volatility after the coupling date becomes stable in the EMCC case. As stated, a cointegration analysis should be performed on non-stationary data. Thus, a cointegration analysis in the EMCC (post coupling) case and for the EPEX price series in the CWE case does not make much sense.

9.3 Empirical Results Engle-Granger Cointegration Test

Based on the findings from the previous section it is assumed that in the TLC coupling the EPEX and APX log price series are non-stationary as well as the EEX and the NPS DK ones in the pre-coupling period and the EEX for CWE. The analyses therefore tests in a next step whether the six series are cointegrated or not. As explained in section 9.1 the Engle-Granger (1987) two step approach is applied for each market pair in the corresponding market coupling project. The test framework was thereby the following: The time series were divided in a pre-coupling and in a post-coupling period. The hypothesis of this paper is that the coupling leads to a cointegrated behavior of time series pairs as market coupling leads to a more efficient linking of the different electricity markets and thus also to the prices.

The test methodology is the same as above: First, a regression between the data pairs is estimated and in a second step the error terms are tested for stationarity. Again, an ADF test is therefore applied. If the null hypothesis of a unit root for the residuals cannot be rejected, the residuals are assumed to be non-stationary and the two time series are not cointegrated. If the test rejects the null hypothesis, the residuals are assumed to be stationary and the time series are cointegrated.

Table 15 reports the t-statistics for the ADF test for the three market coupling projects TLC (EPEX vs. APX and APX vs. EPEX), EMCC (EEX vs. NPS DK2 and NPS DK2 vs. EEX) and CWE (EPEX vs. EEX, EEX vs. EPEX) in the pre-coupling periods with the representative lag length according to AIC. A high t-statistic for a market indicates that the cointegration hypothesis cannot be rejected. It has to be noted that the normal critical values for the ADF test are not valid. Instead, valid critical values can be found in Dickey-Fuller Test tables which consider adjusted critical values (Kirchgässner & Wolters, 2007, p. 167).

	Lag length selection criteria AIC							
	EPEX	**Lags**	**APX**	**Lags**	**EEX**	**Lags**	**NPS DK**	**Lags**
_EPEX			-5.162***	6	-9.108***	6		
_APX	-4.604***	4						
_EEX	-8.709***	6					-3.809***	13
_NPS DK2					-4.488***	20		

Table 15: ADF T-statistics for cointegration tests in the pre-coupling periods
Note: Values smaller than -2.57 indicate that the null hypothesis of a unit root must be rejected at a 10% significance level (*), smaller than -2.86 at a 5% significance level (**) and smaller than -3.42 at a 1% significance level (***)

The results in Table 15 indicate that the price pairs in the TLC market coupling were cointegrated already before the coupling date. In the case of EPEX to APX as well as APX to EPEX the null hypothesis must be rejected at a 1% significance level. Also in the case of EMCC (EEX to NPS and NPS to EEX) the null hypothesis has to be rejected with clear significance. The highest critical values are given by the CWE market coupling project. In both directions EPEX to EEX and EEX to EPEX the critical values are high and above the 1% significance level. These results are somewhat contradicting to my assumed thesis that the price series would not be cointegrated before the coupling. This thesis can be criticized by the argument that there is no economic reason to assume that the prices in the pre-coupling period would not be cointegrated. Although the markets were not coupled, it might be that the same economic forces drive prices in the long run throughout different markets. The results for the CWE coupling might also be distorted because the EEX time series are stationary.

Table 16 reports the results of the cointegration analysis for the post-coupling periods. In the case of the TLC coupling the critical values increase (to a higher negative level) significantly compared to the pre-coupling period. This provides evidence that the market coupling in the TLC case led to a “higher degree” of cointegration. In the case of the EMCC market coupling the results might be misleading as the data series are as stated in the previous chapter stationary and the method of cointegration is supposed to be applied on non-stationary data. Nevertheless, the post-coupling results are not significantly different from the pre-coupling results in table 14. This result seems to support the findings in chapters 7 and 8 which provide evidence that the EMCC coupling was not successful in terms of price convergence. A somehow counterintuitive result is the critical values for the CWE market coupling. The critical values are lower than in the pre-coupling case.

	Lag length selection criteria AIC							
	EPEX	**Lags**	**APX**	**Lags**	**EEX**	**Lags**	**NPS DK**	**Lags**
_EPEX			-7.556***	6	-4.718***	6		
_APX	-10.663***	2						
_EEX	-4.367***	6					-4.174***	2
_NPS DK2					-3.386***	14		

Table 16: ADF T-statistics for cointegration tests in the post-coupling periods
Note: Values smaller than -2.57 indicate that the null hypothesis of a unit root must be rejected at a 10% significance level (*), smaller than -2.86 at a 5% significance level (**) and smaller than -3.42 at a 1% significance level (***)

Summary The results of the cointegration analysis show that the three market pairs were already cointegrated before the coupling. This can have different reasons. First of all, my cointegration analysis considers only two markets. But a single market in turn can be linked with other neighboring countries with the result that many interdependencies occur. Germany, for example, trades electricity with all neighboring countries as presented in the chapter ”Analysis of Cross-Border Trade” (p. 18). In consequence, the investigation of only the French and German market might be a too simplified approach. It has also to be noted that the investigated markets were not only interlinked since the market coupling date. Market coupling is only a method to create the cross-border electricity trade more efficient and to link countries more closely. But electricity trade between the countries was also possible before the market couplings. Nevertheless, especially the case of the TLC coupling indicates that not only the prices converge but also the behavior of the prices equalize.

10 Conclusion and Outlook

The goal of this thesis is to investigate if market coupling as allocation method of spare interconnector transfer capacity leads to the desired outcome of price convergence in linked markets. Thus, the main contribution of this thesis is the following line of argumentation with its findings: In a first step the thesis provides an overview of the European Union's effort to create a single, integrated electricity market. As the European electricity market represents itself as highly complex with many different actors, the thesis provides a layout of relevant stakeholders and how these stakeholders are affected by a changing market framework and the introduction of implicit auction mechanisms. As market coupling enables the linking of national countries towards an integrated electricity market it is relevant to investigate the "electricity flows" through Europe. This is done in the fourth chapter when the cross-border electricity trade throughout Europe is presented in a comprehensive way by focusing on different regional electricity markets (REMs). This chapter clarifies on which borders cross-border trade is of particular relevance. The fifth chapter introduces as a consequence possible methods of how to allocate cross-border transfer capacity. Furthermore, the chapter aims at explaining these methods comprehensively. Possible methods are thereby non-market based methods that follow "criteria-based" rules and market-based methods with delegation of the price finding for transfer capacity to the market. The European Union states market coupling, a sub-type of implicit auctioning methods, as the preferred allocation mechanism. The sixth chapter provides therefore an overview of the different implemented methods for both, different regions and different timeframes. As such, this chapter functions as a "map" of the different implemented allocation methods and provides the reader a clear picture of the "status quo" in the end of 2013. Up to chapter six, the main goal of the thesis is to provide a comprehensive representation of cross-border trade throughout Europe as the key issue of creating a single, integrated electricity market. Thus, the added value of this first part is the reduction of the complexity of the European electricity market framework. It offers a first, compromised explanation and investigation of the main players and the key issues which are relevant when dealing with market coupling. The seventh chapter offers an assessment of different market-based interconnector-capacity allocation methods. This assessment is based on a qualitative literature review and is organized along three relevant dimensions. First, different allocation methods are compared, especially implicit and explicit auction mechanisms. The results show that market coupling offers an efficient way to allocate transfer capacity as market participants have to participate in only one auction that includes both, electricity contracts and the interconnector transfer contract. Thus, market efficiency can be improved. On the other side, the implementation represents itself as being much more complex as for example explicit auctions. The TSOs and PXs of different countries have to coordinate and cooperate closely. Second, the impact of these different allocation methods on the market power of electricity producers is investigated. The main finding is thereby that market coupling can lead to a higher degree of competition in the electricity markets as new competitors have easier access to the domestic market. Thus, the market power of electricity producers can be decreased. This leads to the third dimension of research papers focusing on economic and welfare effects. Based on the thesis' findings, market coupling can have positive welfare effects as the price level tend to decrease. The main contribution of this seventh chapter is the provision of a structured, broadly underpinned investigation of the key topics of recent research. The eighth chapter investigates to what degree the main goal of price convergence could be achieved. Therefore, the thesis investigates the three market coupling initiatives trilateral market coupling (TLC), the market coupling between Denmark and Germany operated by the European market coupling company (EMCC) and the coupling in the Central Western European region (CWE). The main findings of this thesis are therefore that the goal of price convergence could be reached in the TLC case. Consequently, this market coupling initiative works as reference project within the European Union. EMCC, on the other side, did not lead to a price convergence and is seen as example for a market coupling project that failed. Consequently, this chapter is elementary as it provides evidence for the complexity of implementing market coupling initiatives. In the ninth chapter it is the goal to investigate if market coupling leads also to a similar price behavior in linked markets. To investigate that I conduct a cointegration analysis according to the Engle & Granger (1987) two step approach. This test led to mixed results: First of all, a cointegration test has to be executed on non-stationary time series. The results from the Unit Root tests indicate that only in the TLC case the time series were non-stationary. In the case of the EMCC, the time series were stationary, especially after the coupling date. And in the CWE case, the EPEX price series seems also to be stationary. Thus, cointegration tests of stationary time series do not make much sense. Secondly, the results of chapter nine provide evidence that the time series in the investigated markets were already before the coupling date cointegrated. As such, the initial thesis that market coupling leads to the same behavior of prices in formally uncoupled markets cannot be approved. Nevertheless, the case of the TLC coupling indicates that the "degree" of market coupling increased after the coupling date.

As such, this thesis has several limitations. First of all, it investigates the topic on a European level. Thus, specific national issues of particular countries were ignored. Secondly, the thesis was written in the end of the year 2013 and represents as such an appraisal at that time. Thirdly, quantitative analysis has been done for three market coupling initiatives with a pair of markets, respectively. As such, additional external factors and interrelationships which most certainly have a considerable influence on the price data were not considered. Fourthly, the cointegration analysis is predominantly reasonable in the TLC case and partially in the CWE case as the other time series were stationary and thus cointegration analyses do not make much sense. Fifthly, the investigated price series pairs were already cointegrated before the market coupling. The reason therefore might be that the different markets were already before the coupling date linked with each other. Cross-border electricity trade was possible before market coupling, although market coupling allows an easier and more efficient way of cross-border electricity trade. Thus, the initial hypothesis that market coupling leads to cointegrated time series can as such not be confirmed.

Beside these limitations, the thesis has several political and economic implications. First of all, it confirms that market coupling can lead to a price convergence in coupled markets. Especially on the example of the trilateral market coupling it can be seen, that price coupling as congestion management method leads to a convergence of prices in involved markets. This is especially relevant for high-price areas. Thus, it provides evidence that social welfare can be improved and the market power of electricity producers can be reduced. On the other side, the thesis points out the complexity of implementing market coupling as indicated on the example of the market coupling between Denmark and Germany. The implementation process can be circuitous and accompanied by delays. It requires also an adaptation of the institutional framework of two countries. For countries which desire to remain a higher degree of independence, other capacity allocation methods can be favorable.

For further research it is proposed to take the mentioned interrelationships into account and to apply other econometric methods. Furthermore, it might be interesting for future researchers to investigate how market coupling opens new opportunities in terms of combining renewable energy sources in different countries. Market coupling can be a promising way to deal with an increasing diversity in the production mix as well as to minimize the risks that new production mixes might bring with (diversification effect). Additionally, future research could look at some political implications like for example changing investment incentives for Swiss pump storage power plants based on the possible introduction of market coupling. Furthermore, market coupling could be investigated from the perspective of a single country.

References

Agency for the Cooperation of Energy Regulators (ACER). (2012). The Agency. Retrieved May 24, 2013, from http://www.acer.europa.eu/The_agency/Pages/default.aspx

Agency for the Cooperation of Energy Regulators (ACER). (2011a). Cross-regional roadmap for Day-Ahead Market Coupling.

Agency for the Cooperation of Energy Regulators (ACER). (2011b). Framework Guidelines on Capacity Allocation and Congestion Management for Electricity (pp. 15). Ljubliana, Slovenia.

Agency for the Cooperation of Energy Regulators (ACER). (2012). Regional Initiatives Status Review Report 2012- The Regional Initiatives and the Road to 2014 (pp. 76).

Agency for the Cooperation of Energy Regulators (ACER). (2013). Regional Initiatives. Retrieved June 12, 2013, from http://www.acer.europa.eu/Electricity/Regional_initiatives/Pages/default.aspx

APX. (2007). Market Coupling: Key to EU Power Market Integration *APX Energy Viewpoints* (pp. 5).

Association of European Energy Exchanges EUROPEX. (2013a). Highlights. Retrieved June 7, 2013, from http://www.europex.org/index/pages/id_page-51/lang-en/

Association of European Energy Exchanges EUROPEX. (2013b). Members. Retrieved June 7, 2013, from http://www.europex.org/index/pages/id_page-9/lang-en/

Association of European Energy Exchanges EUROPEX. (2013c). Mission. Retrieved June 6, 2013, from http://www.europex.org/index/pages/id_page-11/lang-en/

Balaguer, J. (2011). Cross-border integration in the European electricity market. Evidence from the pricing behavior of Norwegian and Swiss exporters. *Energy Policy, 39*(9), 4703-4712. doi: http://dx.doi.org/10.1016/j.enpol.2011.06.059

Belpex. (undated). Trilateral Market Coupling. Retrieved June 21, 2013, from http://www.belpex.be/index.php?id=94

Borenstein, S., Bushnell, J., & Stoft, S. (2000). The competitive effects of transmission capacity in a deregulated electricity industry. *RAND Journal of Economics, 31*(2), 32.

Carr, G. (2012). European power market: CWE's next challenges. *Energy Risk*. Retrieved April 5, 2014 from risk.net: http://www.risk.net/energy-risk/feature/2196426/european-power-market-series-cwe

Carr, G. (2012). Market Coupling Marches Forward: risk.net.

CASC.EU. (2013a). CASC.EU Presentation. Retrieved June 3, 2013, from http://www.casc.eu/en/About-us/Our-History

CASC.EU. (2013b). Home. Retrieved June 3, 2013, from http://www.casc.eu/en

Central Allocation Office GmbH (CAO). (2013a). Auctions. Retrieved June 20, 2013, from http://www.central-ao.com/auctions-2013

Central Allocation Office GmbH (CAO). (2013b). Shareholder structure. Retrieved June 20, 2013, from http://www.central-ao.com/company/shareholder-structure

CEZ Group. (2013). Annual Report 2012 (pp. 326).

Council of European Energy Regulators CEER. (2013). Electricity Regional Initiative (ERI). Retrieved June 12, 2013, from http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_ACTIVITIES/EER_INITIATIVES/ERI

Council of European Energy Regulators (CEER). Abouth the European Energy Regulators. Retrieved June 3, 2013, from http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_ABOUT

Creti, A., Fumagalli, E., & Fumagalli, E. (2010). Integration of electricity markets in Europe: Relevant issues for Italy. *Energy Policy, 38*(11), 6966-6976. doi: http://dx.doi.org/10.1016/j.enpol.2010.07.013

Dahl, R. E., Oglend, A., Osmundsen, P., & Sikveland, M. (2012). Are oil and natural gas going separate ways in the United Kingdom? Cointegration tests with structural shifts. *The Journal of Energy Markets, 5*(2), 27.

de Jong, C., & Schneider, S. (2009). Cointegration between gas and power spot prices. *The Journal of Energy Markets, 2*(3), 21.

de Vries, L. J. (2004). *Securing the public interest in electricity generation markets. The myths of the invisible hand and the copper plate.* Technical University of Delft.

de Vries, L. J., & Hakvoort, R. A. (2002). An Economic Assessment of Congestion Management Methods for Electricity Transmission Networks. *Journal of Network Industries, 3*, 43.

E.ON SE. (2013a). Daten und Fakten zu E.ON. Retrieved June 4, 2013, from http://www.eon.com/de/ueber-uns/profil/daten-und-fakten.html

E.ON SE. (2013b). Profil-Überblick. Retrieved June 4, 2013, from http://www.eon.com/de/ueber-uns/profil.html

EDF Group. (2013a). Financial Report 2012 (pp. 222).

EDF Group. (2013b). Key Figures 2011. Retrieved 4 June, 2013, from http://about-us.edf.com/profile/key-figures-43669.html

Ehrenmann, A., & Neuhoff, K. (2009). A Comparison of Electricity Market Designs in Networks. *Operations Research, 57*(2), 13.

EnBW Energie Baden-Württemberg AG. (2013a). Important financial ratios. Retrieved June 5, 2013, from http://www.enbw.com/company/the-group/about-us/at-a-glance/key-figures/index.html

EnBW Energie Baden-Württemberg AG. (2013b). Report 2012 (pp. 174).

Endesa. (2013). Annual Report 2012 Activities.

Enel. (2013). Annual Report 2012 (pp. 338).

Engle, R. F., & Granger, C. W. J. (1987). Co-Integration and Error correction: Representation, Estimation and Testing. *Econometrica, 55*(2), 25.

ENTSO-E. (2010). A decisive step towards a single European Electricity Market. 4.

ETSO. (2000). Net Transfer Capacities and Available Transfer Capacities: ETSO.

ETSO. (2001). *Position paper on congestion management.* Paper presented at the Florence Forum, May 7th & 8th, 2001.

European Energy Exchange EEX. (2012). EEX Product Brochure Power (pp. 22). Leipzig.

European Energy Exchange EEX. (2013). At the Centre of European Energy Trading (pp.

88). Leipzig.

European Market Coupling Company EMCC. (2013a). About EMCC. Retrieved June 3, 2013, from http://www.marketcoupling.com/about-emcc/about

European Market Coupling Company EMCC. The concept of Market Coupling. Retrieved May 22, 2013, from http://www.marketcoupling.com/market-coupling/concept-of-market-coupling

European Market Coupling Company EMCC. (2013b). The European market. Retrieved June 12, 2013, from http://www.marketcoupling.com/market-coupling/european-market

European Network of Transmission System Operators for Electricity ENTSO-E. (2010). A decisive step towards a single European Electricity Market. 4.

European Network of Transmission System Operators for Electricity ENTSO-E. (2011). Factsheet 2011.

European Network of Transmission System Operators for Electricity ENTSO-E. (2012). Memo 2012.

European Network of Transmission System Operators for Electricity ENTSO-E. (2013a). ENTSO-E Factsheet. Retrieved June 3, 2013, from https://www.entsoe.eu/publications/memo-entso-e-facts-figures/factsheet/#c645

European Network of Transmission System Operators for Electricity ENTSO-E. (2013b). ENTSO-E Following a Proud History. Retrieved June 4, 2013, from https://www.entsoe.eu/about-entso-e/a-proud-history/

European Network of Transmission System Operators for Electricity ENTSO-E. (2013c). ENTSO-E Member Companies. Retrieved June 3, 2013, from https://www.entsoe.eu/about-entso-e/member-companies/

European Network of Transmission System Operators for Electricity ENTSO-E. (2013d). Glossary of terms (pp. 6).

European Network of Transmission System Operators for Electricity ENTSO-E. (2013e). Statistical Database. from https://www.entsoe.eu/data/data-portal/

European Network of Transmission System Operators for Electricity ENTSO-E. (unknown). Network code on Capacity Allocation & Congestion Management (CACM) (pp. 71). Brussels, Belgium.

European Power Exchange EPEX SPOT. (2013a). About EPEX SPOT. Retrieved June 11, 2013, from http://www.epexspot.com/en/company-info/about_epex_spot

European Power Exchange EPEX SPOT. (2013b). ELIX: Towards a single European market price. Retrieved June 10, 2013, from http://www.epexspot.com/en/market-coupling/elix_towards_a_single_european_market_price

European Power Exchange EPEX SPOT. (2013c). Market Coupling- A major step towards Market Integration. Retrieved June 10, 2013, from http://www.epexspot.com/en/market-coupling

European Power Exchange EPEX SPOT. (2013d). Products Trading. Retrieved June 11, 2013, from http://www.epexspot.com/en/product-info

European Regulators' Group for electricity and gas (ERGEG). (2005). The Creation of Regional Electricity Markets. An ERGEG Discussion Paper (pp. 123).

Fleten, S.-E., Heggedal, A. M., & Siddiqui, A. (2011, Spring). Transmission capacity between Norway and Germany: a real options analysis. *The Journal of Energy Markets,* 121-147.

Fridolfsson, S.-O., & Tangeras, T. P. (2009). Market power in the Nordic electricity wholesale market: A survey of the empirical evidence. *Energy Policy, 37*, 12.

GDF Suez. (2013a). 2012 Annual Results.

GDF Suez. (2013b). 2012 Key Figures. Retrieved June 5, 2013, from http://www.gdfsuez.com/en/investors/key-figures/

GDF Suez. (2013c). Appendices.

Glachant, J.-M. (2010). The Achievement of the EU Electricity Internal Market through Market Coupling *RSCAS Working Papers* (Vol. 2010/87). Italy.

Hobbs, B. F., Rijkers, F. A. M., & Boots, M. G. (2005). The More Cooperation, The More Competition? A Cournot Analysis of the Benefits of Electric Market Coupling. *The Energy Journal, 26*(4), 28.

Iberdrola. (2013a). 2012 Data. Retrieved June 5, 2013, from http://www.iberdrola.es/webibd/corporativa/iberdrola?IDPAG=ENWEBCONENCIDATOPERATD12

Iberdrola. (2013b). 2012 in Figures. Retrieved June 5, 2013, from http://www.iberdrola.es/webibd/corporativa/iberdrola?IDPAG=ENWEBCONENCIC12

International Confederation of Energy Regulators ICER. About ICER. Retrieved June 3, 2013, from http://www.icer-regulators.net/portal/page/portal/IERN_HOME/ICER_HOME

Janssen, T., Rebours, Y., & Dessante, P. (2012). Tight Volume Coupling: Analytical Model, Adverse Flow Causality and Potential Improvements *RSCAS EUI Working Paper* (Vol. 2012/09): European University Institute.

Jullien, C., Pignon, V., Robin, S., & Staropoli, C. (2012). Coordinating cross-border congestion management through auctions: An experimental approach to European solutions. *Energy Economics, 34*(1), 1-13. doi: http://dx.doi.org/10.1016/j.eneco.2011.08.017

Kirchgässner, G., & Wolters, J. (2007). *Introduction to Modern Time Series Analysis*: Springer.

Knops, H. P. A., de Vries, L. J., & Hakvoort, R. A. (2001). Congestion Management in the European Electricity System: An Evaluation of the Alternatives. *Journal of Network Industries, 2*(3-4), 42.

Kristiansen, T. (2007, January 16). A preliminary assessment of the market coupling arrangement on the Kontek cable. *Energy Policy*, 3247-3255.

Kurzidem, M. J. (2010). *Analysis of Flow-based Market Coupling in Oligopolistic Power Markets.* ETH Zurich, Zurich. (Diss ETH No. 19007)

Market Coupling - Netzengpässe für den Wettbewerb optimal nutzen. (2007). Retrieved May 28, 2013, from http://www.vde.com/DE/FG/ETG/ARCHIV/PUBLIKATIONEN/RUNDBRIEFE/2007-OEFFENTLICH/MI-1/TECHNIK-TRENDS/2006-EXKLUSIV/Seiten/Market%20Coupling.aspx

Mirza, F. M., & Bergland, O. (2012). Transmission congestion and market power: the case of the Norwegian electricity market. *The Journal of Energy Markets, 5*(2), 29.

Nepal, R., & Jamasb, T. (2012). Interconnections and market integration in the Irish Single Electricity Market. *Energy Policy, 51*(0), 425-434. doi: http://dx.doi.org/10.1016/j.enpol.2012.08.047

Ng, S., & Perron, P. (2001). Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power. *Econometrica, 69*(6), 36.

NordPool Spot. (2013). North-Western European Price Coupling (NWE). Retrieved June 21, 2013, from http://www.nordpoolspot.com/How-does-it-work/European-Integration/NWE/

North Western Europe Day Ahead Price Coupling Project. (2013). NWE Monthly Progress Report.

NWE Project Partners. (2013). North-Western Europe Price Coupling- Joint Declaration.

Oggioni, G., & Smeers, Y. (2012). Degrees of Coordination in Market Coupling and Counter-Trading. *The Energy Journal, 33*(3), 50.

Oggioni, G., & Smeers, Y. (2013). Market failures of Market Coupling and counter-trading in Europe: An illustrative model based discussion. *Energy Economics, 35*(0), 74-87. doi: http://dx.doi.org/10.1016/j.eneco.2011.11.018

Ogunc, A. K., & Hill, R. C. (2008). *Using Excel for Principles of Econometrics*: John Wiley & Sons, Inc.

Pellini, E. (2012). Measuring the impact of market coupling on the Italian electricity market. *Energy Policy, 48*(0), 322-333. doi: http://dx.doi.org/10.1016/j.enpol.2012.05.029

Price Coupling of Regions PCR. (undated). PCR Project- Main features.

Regulation (EC) No 714/2009 of the European Parliament and the Council of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003 (2009).

RWE. (2013a). 2012 key figures at a glance. Retrieved June 5, 2013, from http://www.rwe.com/web/cms/en/1029926/rwe/about-rwe/profile/rwe-group-key-figures/

RWE. (2013b). Corporate Profile. Retrieved June 5, 2013, from http://www.rwe.com/web/cms/en/1029638/rwe/about-rwe/profile/

Scheepers, M. J. J., Wals, A. F., & Rijkers, F. A. M. (2003). Position of large Power Producers in Electricity Markets of North Western Europe *Report for the Dutch Energy Council on the Electricity Markets in Belgium, France, Germany and The Netherlands*.

Statkraft. (2013). Annual Report 2012.

Tennet. (2013). Market coupling - Variants. Retrieved May 28, 2013, from http://www.tennet.eu/de/en/grid-projects/international-projects/market-coupling/variants.html

The European Parliament and The Council of the European Union. (1996). Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity. *Official Journal of the European Communities*, 10.

The European Parliament and The Council of the European Union. (2003a). Directive 2003/54/EC of the European Parliament and of the Council, of 26 June 2003, concerning common rules for the internal market in electricity and repealing Directive 96/92/EC. *Official Journal of the European Union*, 19.

The European Parliament and The Council of the European Union. (2003b). Regulation (EC)) No 1228/2003 of the European Parliament and of the Council of 26 June 2003 on conditions for access to the network for cross-border exchanges in electricity. *Official Journal of the European Union*, 10.

The European Parliament and The Council of the European Union. (2009a). Directive 2009/72/EC of the European Parliament and of the Council, of 13 July 2009, concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC. *Official Journal of the European Union*, 39.

The European Parliament and The Council of the European Union. (2009b). Directive 2009/73/EC of the European Parliament and of the Council, of 13 July 2009, concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC. *Official Journal of the European Union*, 43.

The European Parliament and The Council of the European Union. (2009c). Regulation (EC) No 713/2009 of the European Parliament and of the Council, of 13 July 2009, establishing an Agency for the Cooperation of Energy Regulators. *Official Journal of the European Union*, 14.

The European Parliament and The Council of the European Union. (2009d). Regulation (EC) No 714/2009 of the European Parliament and of the Council, of 13 July 2009, on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003. *Official Journal of the European Union*, 21.

The European Parliament and The Council of the European Union. (2009e). Regulation (EC) No 715/2009 of the European Parliament and of the Council. *Official Journal of the European Union*, 19.

tradingeconomics. (2010). from http://www.tradingeconomics.com/switzerland/energy-imports-net-percent-of-energy-use-wb-data.html

van Blijswijk, M., & de Vries, L. J. (2011). *Managing congestion in the Dutch transmission grid.* Delft University of Technology, Delft, the Netherlands.

van der Weijde, A. H., & Hobbs, B. F. (2011). Locational-based coupling of electricity markets: benefits from coordinating unit commitment and balancing markets. *Journal of Regulatory Economics, 39*(3), 28.

Vattenfall AB. Operations: Electricity generation 2012. Retrieved June 4, 2013, from http://www.vattenfall.com/en/operations---facts--fig.htm

Vattenfall AB. (2013a). Finance, Group-wide total. Retrieved June 4, 2013, from http://www.vattenfall.com/en/finance---facts--fig.htm

Vattenfall AB. (2013b). Operations: Electricity generation 2012. Retrieved June 4, 2013, from http://www.vattenfall.com/en/operations---facts--fig.htm

Veka, S., Lien, G., Westgaard, S., & Higgs, H. (2012). Time-varying dependency in European energy markets: an analysis of Nord Pool, European Energy Exchange and Intercontinental Exchange energy commodities. *The Journal of Energy Markets, 5*(2), 30.

Weber, A., Graeber, D., & Semmig, A. (2010). Market Coupling and the CWE Project. *Zeitschrift für Energiewirtschaft*, 7.

Wilmott, P. (2007). *Paul Wilmott introduces Quantitative Finance* (Second Edition ed.). Chichester, West Sussex, England: John Wiley & Sons Ltd.

Appendix

A. List of the most important power producers in Europe

E.ON SE E.ON is a diversified Energy company based in Germany. The activities involve Power production, Gas exploration and production, Trading, Gas and Power Transmission and distribution. The sales volume was € 132 bn. and the EBIT € 7.0 bn. in 2012. The Power generation output was **740.4 TWh** (2012). Main markets with important generation capacities in Europe are Germany, Great Britain, Sweden, Spain, France and the Benelux-Area. (E.ON SE, 2013a, 2013b)

EDF Group EDF Group is a French based company that had a sales volume of € 72.7 bn. in 2012 and an Operating profit of € 8.3 bn. The Power production output was **628.2 TWh** (2011, worldwide). Main markets of Production of the company are Central and East Europe. The company's activities reach from power production to power transmission, distribution, trading and engineering. (EDF Group, 2013a, 2013b)

RWE Group RWE is a German electricity and gas company. The revenue in 2012 was € 53 bn. with an Operating result of € 6.4 bn. The electricity production was **227.1 TWh** in 2012. The company is one of the largest in Germany, Netherlands and the United Kingdom and has also a strong position in Central Eastern Europe. (RWE, 2013a, 2013b)

Vattenfall AB Vattenfall is a company based in Stockholm, Sweden, with Electricity generation units in Sweden, Finland, Denmark, Germany, Netherlands and the UK. The company's sales were € 19.5 bn. in 2012 with an EBIT of € 3.0 bn[17]. The group-wide generation capacity was **178.9 TWh** in the year 2012. (Vattenfall AB, 2013a, 2013b)

GDF Suez Europe GDF Suez is a French energy company, which is globally active in the fields of electricity, natural gas and services. The revenues 2012 in Europe were € 77.1 bn. (worldwide € 97 bn.) and the Operating Income was € 9 bn. The main markets of the company are France, Belgium, Netherlands, Germany, Italy and the United Kingdom. The Electricity production in Europe in 2012 was **136.0 TWh**. (GDF Suez, 2013a, 2013b, 2013c)

Iberdrola Iberdrola is a Spanish energy company with group revenues of € 34.2 bn. and a net profit of € 1.99 bn. in 2012. The company's main activities are in the field of Network and Wholesale business with the main markets Spain and UK in Europe and a strong position in Latin America. The electricity net production of the company has attained **134 TWh** in 2012. (Iberdrola, 2013a, 2013b)

[17] Calculated with an Exchange rate SEK/EUR=1/0.12, 4.6.2013

Endesa Endesa is a Spanish Electricity and Gas company with the main markets Spain and Portugal and with a strong position in Latin America. The power output in Europe (Spain and Portugal) was 2012 **77.4 TWh** (Worldwide 141.4 TWh). The revenues in Europe in 2012 were € 23.14 bn. (worldwide € 33.9 bn.) and the EBIT € 1.99 bn (worldwide € 4.4 bn.). (Endesa, 2013)

Enel Group Enel is an Italian power and gas company and active in markets in Europe and Latin America. The revenues were € 85.0 bn. and the Net Income € 3.5 bn. in 2012. The group is the largest electricity company in Italy and also active in Spain, Portugal, Slovakia, France, Romania and Greece. The total power generated in 2012 was **64.0 TWh**. (Enel, 2013)

Statkraft Statkraft is a Norwegian power company with the core business in hydropower, wind power, gas power and district heating and therefore Europe's leader within renewable energy. The total power production in 2012 was **60 TWh**. The group's net operating revenues were € 2.47 bn. and the net operating income € 704 m in 2012[18]. (Statkraft, 2013)

EnBW EnBW (Energie Baden-Württemberg AG) is a German based energy company in the fields of power and gas generation, trading, transport and services. EnBW had revenues of € 19 bn. and an EBIT of € 1.27 bn. in 2012. The company has **59.1 TWh** generation capacities. The main market is Germany but the company is also active in other European countries. (EnBW Energie Baden-Württemberg AG, 2013a, 2013b)

CEZ CEZ Group is an energy company headquartered in the Czech Republic in the fields of electricity generation, distribution and natural gas trading. 2012, **59.6 TWh** electricity was generated. The company is mainly active in Eastern Europe in the markets of Poland, Czech Republic, Slovakia, Hungary, Bulgaria, Romania and Turkey. The operating revenues 2012 were € 4.41 bn. and the Net Income € 1.45 bn[19]. (CEZ Group, 2013)

[18] Exchange rate NOK/EUR=1/0.13 (7.6.2013)

[19] Exchange rate CZK/EUR=1/0.04 (7.6.2013)

23

B. Table of Power Exchanges in Europe

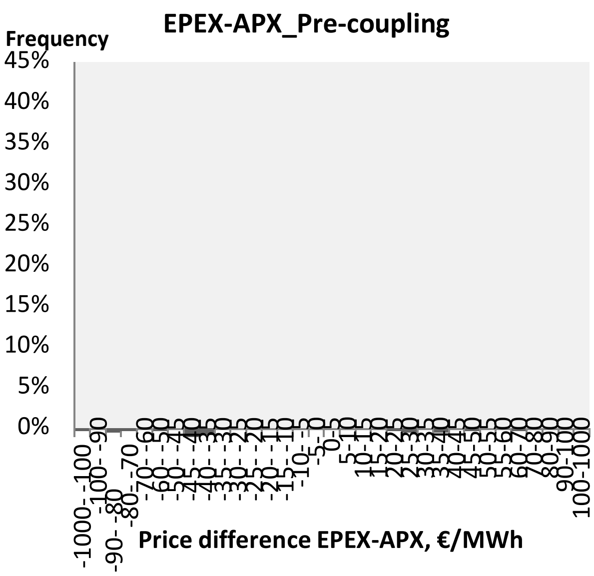
Power Exchange	Market Areas	Spot Market	Derivatives Market	Indexes
APX (NL)	• Netherlands • United Kingdom • Belgium	• Day ahead auction for NL, UK, BE • Intraday for NL	-	• APX • Belix (over Belpex) • APX UK
Borzen (SL)	Provides a Balancing market for Slovenia	-	-	-
CEGH (Central European Gas Hub)	*Gas exchange*	-	-	-
EEX (DE)	• Germany/Austria • France • Switzerland	**EPEX SPOT:** • Day-ahead auction for D/A, F, CH • Intraday for D/A, F	• Phelix Futures (D/A) • French Futures (F) • Phelix Options (D/A)	• ELIX • Phelix • Swissix • KWK-Index • EPEX France (traded over EPEXSPOT)
Gestore Mercati Energetici (GME) (IT)	• Internal Italian zones (Central-northern It., Central-southern It., Sicilia, Sardegna etc.)	• Day ahead auction • Intra-Day Market • Ancillary Services Market	Base-load and Peak-load with monthly, quarterly and yearly delivery	-
Croatian Energy Market Operator HROTE (HR)	Croatia	Only a bilateral market is in operation	-	-
HUPX (HU)	Hungary (Coupled with Czech and Slovak)	• Day-ahead auction (DAM)	• Physical Futures (PhF)	HUPXDAM HUPXPhF
ICE ENDEX (NL)	• UK • Benelux	Only natural Gas traded	• Power Futures for Belgium and the Netherlands • TTF Futures (GAS)	• ICE ENDEX BE and NL (Power) • TTF, OCM, ZTP (Gas)
LAGIE (GR)		-	-	-
NasdaqOMX Commodities	-	-	-	-
NordPOOL Spot (NO)	**OMIP (PT) OPCOM (RO)**	Different bidding areas, whereby the amount can vary: • Norway (currently 5) • East Denmark • West Denmark • Finland • Estonia • Lithuania • Latvia • Sweden (2011 four bidding areas)	• Day-ahead (Elspot) • Intraday (Elbas)	
OKTE (SK)				
OMEL (ES)				

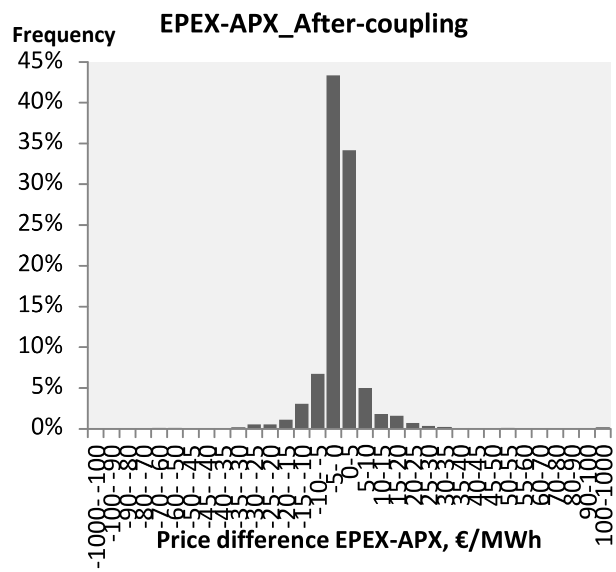
- For each bidding area price indexes exist

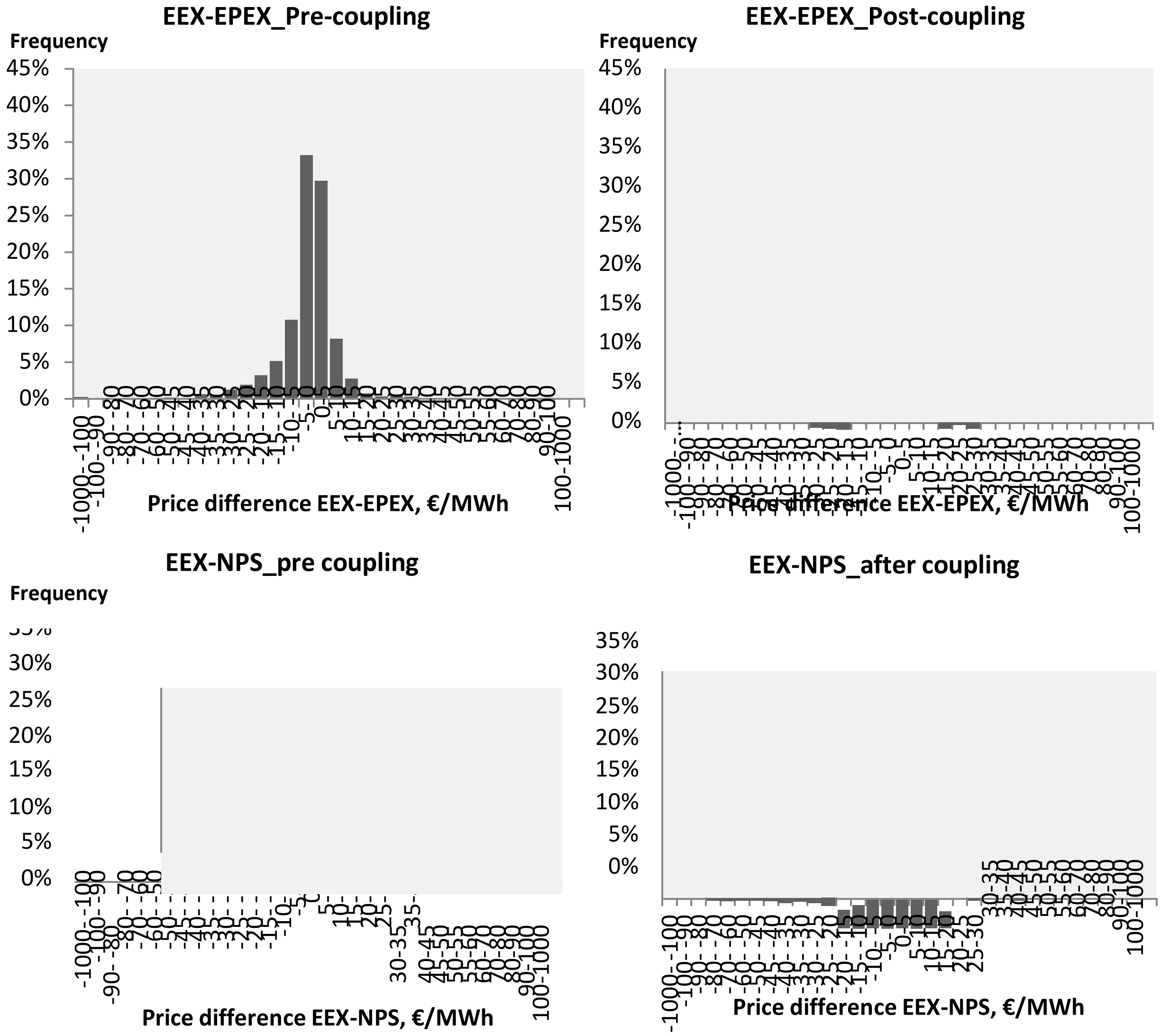
OTE (CZ)	Czech Republic	Day-ahead, Intra-day and Balancing market	OTC	Spot market Index
Powernext SA (FR)	Operates electronic trading platforms for spot and derivatives power markets	EPEX Spot	EEX Power Derivatives	-
SEMO (IR)				
TGE (Polish Power Exchange) (PO)				

Table 17: Energy Exchanges in Europe

C. Price distribution of market coupling initiatives and further price charts






EEX-EPEX_Pre-coupling
Frequency
Price difference EEX-EPEX, €/MWh
EEX-EPEX_Post-coupling
Frequency
Price difference EEX-EPEX, €/MWh
EEX-NPS_pre coupling
Frequency
Price difference EEX-NPS, €/MWh
EEX-NPS_after coupling
Price difference EEX-NPS, €/MWh


Finland
€/MWh
200
150
100
50
0
11/05
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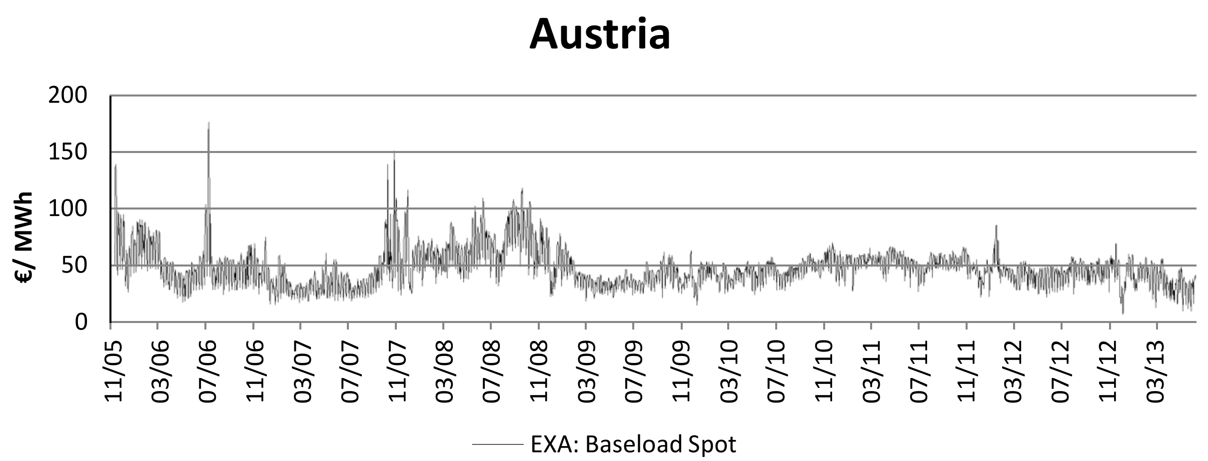
03/12
07/12
11/12
NORD POOL Helsinki: 24h Average spot Day-ahead


Austria
€/ MWh
200
150
100
50
0
11/05
03/06
07/06
11/06
03/07
07/07
11/07
03/08
07/08
11/08
03/09
07/09
11/09
03/10
07/10
11/10
03/11
07/11
11/11
03/12
07/12
11/12
03/13
EXA: Baseload Spot

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Dominique-Cristian Baumann
Chemin du Crêt 18a
2533 Evilard
Switzerland

26

E-Mail: dominique.baumann2@student.unisg.ch
dominique.c.baumann@gmail.com