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# COMPETITION AND MARKET INTEGRATION
# –
# ROLE OF EUROPEAN POWER EXCHANGES

(MASTER DISSERTATION)

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Author: Václav Mrhač

Supervisor: doc. Ing. Ingeborg Němcová, CSc., University of Economics, Prague

# Declaration of Authorship

I hereby declare that I compiled this dissertation independently, using only resources and literature listed.

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At this place, I would like to take the opportunity to express my gratitude and appreciation to my supervisor doc. Ing. Ingeborg Němcová, CSc. for her helpful comments and suggestions.

# Abstract

The main focus of this thesis is to find out degree of market integration in power exchanges in the European Union. Well integrated electricity markets imply existence of single European electricity market and advanced level of liberalization process in this sector.

The thesis provides estimates of degree of market integration for six most evolved European power exchanges. Therefore, British, Dutch, French, German, Spanish and Scandinavian power exchanges have been selected during sample period 2004 - 2012.

After conducting correlation and convergence analysis, the results have not suggested existence of single European electricity market and prove the effect of liberalization at regional level.

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# Introduction

Energy sector in the European Union (EU) experienced in last twenty years significant changes. Liberalization of electricity power industry is one of the main objectives of the European energy policy. Consequently, the aim of the European Union, covering body of the European energy policy, is further liberalization, integration and creation of single European electricity market.

Essential legislative acts of the European Union concerning electricity market are so called Energy Packages. There have been adopted three Energy Packages so far - in 1996, 2003 and 2009. Most importantly, the second and the third Energy Package accelerated the process of liberalization and integration. The packages created basic steps in process including unbundling of vertically integrated sectors, introduction of independent system and transmission operators and competences of national regulators. Implementation of this legislation is supposed to be finished by the end of 2014.

The aim of this thesis is to examine level of market liberalization and integration in the European energy sector with main focus on European power exchanges. To do so I divided my thesis into 3 parts.

The first part of this thesis is devoted to process of liberalization. This section embodies vital part of liberalization – that is necessity to have something that needs to be liberalized. In this case, brief summary of progress from monopoly to liberalized markets follows. Next, development of the Energy Packages is accounted for.

The second part of this thesis deals with structure of electricity market and difference between bilateral markets and power exchange markets. Historical evolutions of local European power exchange markets is also included, pointing out differences between European countries and relating tradition of these markets. More specific attention is paid to power exchange markets integration between most developed European power exchanges.

Empirical analysis is conducted in third part. An overview about existing literature was obtained thanks to framed literature review. As the first step of analyzing I implemented correlation analysis to find out level of integration between bilateral markets and power exchange markets. My sample consists of six countries over the to time series 2004-2008 and 2009-2012. Next step of estimating power exchange market integration is conducted through convergence analysis. Specific steps taken are implementing of Kalman filter approach and

Pellinnis classification of degree of convergence. Sample again consists of six countries, but this time just over period 2004-2012.

In the last part I discuss potential future scenarios of development of the European power exchange market. There are four potential scenarios according to Karas and Sulamaa (2013). Relating advantages and disadvantages of these are summarized.

# 1. European electricity markets

The main focus in this chapter is a basic overview of the liberalization process in electricity markets in European context.

The electricity market is an industry that tends to create a natural monopoly, meaning conditions making it often more effective for electricity to be offered only by a single company. The electric industry is also very capital-intensive. Investments are related predominantly to power grid expansion and maintenance and construction of conventional power plants, such as nuclear and thermal power stations. Construction of parallel power grids or stations would clearly not be profitable. It is convenient instead to take advantage of economies of scale, which arise when average unit costs decrease with increasing scale of production.

The electric power sector, however, works in more complex ways than other network industries. Electric power, transported and distributed through the power grid, has a different character than other bulk commodities. It is not supplied only when it has been ordered. It is determined by the current need and drawn directly from the grid. Customers decide their orders continuously and in real time. There is almost no delay between production and delivery and a need to maintain quality. This means electric energy must be produced at the same moment it is being consumed elsewhere. This has led to vertically integrated undertakings under government supervision (Jamasb, T., Politt, M., 2005b).

The value-creating chain in the electric power industry can be divided into four segments: generation, transmission, distribution, and trade. However, not all of these segments represent a natural monopoly. Only transmission and distribution do. Electricity generation and trading, on the other hand, operate better in a competitive environment. Gradual opening to competition is called energy sector liberalization. Liberalization in electricity power industry should be implemented by adopting following steps: sector restructuring, introduction of competition in wholesale generation and retail supply, incentive regulation of transmission and distribution networks, establishing an independent regulator and privatization (Jamasb, T., Politt, M., 2005b). These main steps are summarized in table 1-1.

**Table 1-1: Main steps of liberalization**

| | |
|---|---|
| Restructuring | Vertical unbundling of generation, transmission, distribution, and retail supply activities<br>Horizontal splitting of generation and retail supply |
| Competition and Markets | Wholesale market and retail competition<br>Allowing new entry into generation and retail supply |
| Regulation | Establishing an independent regulator<br>Provision of third-party network access<br>Incentive regulation of transmission and distribution networks |
| Ownership | Allowing new private actors<br>Privatising the existing publicly owned businesses |

Source: Jamasb, T., Politt, M. (2005b)

## 1.1. European liberalization of the electricity markets

Liberalization of electricity power industry is one of the main objectives of the European energy policy. The aim of liberalization in the European Union is creation of a single European electricity market. Essential acts of the European Union concerning electricity market are called Energy packages, of which three have been implemented so far.

The EU's first Energy package laid out instruments for the gradual harmonization and liberalization of electricity markets. Directive 96/92/EC regulated the sector and set common rules for the market. To liberalize that market, the Directive set two options for EU member states' non-discriminatory access to the power grid: contractual relation or regulated access. The contractual relation gave the producers room to negotiate with transmission or distribution grid operators. Regulated access gave entitled customers the chance to tap into the power grid at previously specified, publicly released tariffs. The Directive protects unentitled customers, those who could not choose their supplier, through the institute of a single buyer. The directive also required vertically integrated undertakings to unbundle their accounts and make them transparent. The Directive's aims were the creation and liberalization of a single electricity market.

The member states disagreed sharply during the Directive's implementation as a result of its overly general requirements, which left little room for its incorporation in the member states' national legislations. Its failure to set rules for cross-border transmission of electric power was seen as its biggest shortcoming.

The second energy package, accepted in 2003, deepened market liberalization. It included Directive 2003/54/EC of the European Parliament and of the Council of 26th June 2003, concerning common rules for the internal market in electricity; and Regulation (EC) No. 1228/2003 of the European Parliament and of the Council of 26th June 2003, concerning conditions for access to the network for cross-border exchanges in electricity. This set of provisions and directives set rules for coordinated cooperation between transmission system operators and deepened the requirements for separation between the production of electricity and its transmission and distribution.

A mechanism was set up to regulate cross-border electricity flows and financial flows, including how they could be used. Transmission system operators had to publicly release information about interconnection capacities. The package, unlike its predecessor and in line with the goals of liberalization, only allowed regulated access to transmission and distribution systems at previously published tariffs.

The measures and proposals of the second energy package were followed in 2006 with the European Union's Green Paper (2006): A European Strategy for Sustainable, Competitive and Secure Energy. The strategy responded to the contemporary state of the energy sector in the European Union and put forward six priority areas:

1. *Energy for growth and jobs: completing the internal electricity and gas market*
2. *Internal energy market and the security of supply: solidarity between Member States*
3. *Secure and competitive energy supply: the road toward a more sustainable, efficient, and diverse energy mix*
4. *An integrated approach to tackling climate change*
5. *Support for innovation: a strategic plan for European energy technology*
6. *Toward a coherent external energy policy*

The third energy package implemented measures in these priority areas. It expands unbundling and introduces separation at the levels of management (management unbundling) and commercial law (legal unbundling). This separates decision-making processes for both activities even in an integrated undertaking. The next chapter will deal with unbundling in more detail.

An independent regulatory authority is an important condition for the successful liberalization and non-discriminatory access to transmission networks. Other areas it should supervise include chiefly consumer protection and cooperation between national regulatory authorities. The Commission therefore presented its wish to establish a coordinated group of national regulatory authorities to secure the unified application of European legislation.

## 1.2. Third Energy Package

The newest push toward liberalization of electricity is the set of directives and regulations collectively called the Third Energy Package. Its purpose was to expand on the process the second package started and deepen the ongoing liberalization of electricity and gas markets, secure investments in the energy infrastructure, strengthen regulation at the EU level, and reinforce consumer protection. The member states and European Parliament agreed in March 2009 on the 13th of July. The third energy package consists of:

- *Directive 2009/72/EC concerning common rules for the internal market in electricity, repealing Directive 2003/54/EC*
- *Regulation (EC) No 714/2009 on conditions for access to the network for cross-border exchanges in electricity, repealing Regulation (EC) No 1228/2003*
- *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*

The package was supposed to be implemented in national legislations by March 3, 2011. However, not all countries met the deadline.

This paper deals with the three main priority areas of the third energy package, which directly or indirectly concern competitiveness and market integration and relate to the single electricity market: ownership unbundling in vertically integrated companies; strengthening the customer whom competition both benefits and endangers; and regulating the issues of the internal European market.

Unbundling is the separation of monopolistic activities from competitive activities. The first draft of the package included only two types of unbundling, direct ownership separation and independent system operator (ISO) arrangement. The European Commission and countries with already liberalized energy tend to prefer direct ownership separation. Countries which perceive direct ownership unbundling as a threat to the position of their own energy companies pursued the ISO arrangement, where an independent systems operator, established by the particular state's government, supervises those companies.

These arrangements were not satisfactory for Germany and France, which came up with a third path toward liberalization: the independent transmission operator (ITO). Similarly to the ISO, an ITO preserves both activities within one vertically separated company.

Production is left under the control of the parent company, whereas a subsidiary handles transmission and investment activities.

The third energy package strengthens the consumer's position against suppliers. This concerns not only the consumer's right to secure energy at reasonable and transparent prices, but also the issue of "energy poverty." It assumes a duty to secure energy delivery to vulnerable customers. The EU calls secure energy supply at transparent prices a universal service; governments may secure it for customers via the so-called "supplier of last resort" if the original supplier can no longer able deliver electricity or natural gas to supply energy and gas to households and small businesses. In the Czech Republic, local distributors fill this role for both electricity and natural gas.

The third energy package also reinforced consumer protection against unfair business practices which followed the rise in the number of energy supply companies in the liberalized energy market. Increased public awareness concerning consumption and the costs of related services should further be the goal as well as it is accessible and sustainable energy for households and small businesses. End consumers can thus use feedback to manage their consumption and control their costs through better energy efficiency. They can also react to changes in energy tariffs.

Regulation of the liberalized market is at least as important as the package itself; however, it must not infringe on market freedom. For this reason the Third Package pushes unification of the member states' regulatory authorities. In 2003 the European Commission established the European Regulators' Group for Electricity and Gas (ERGEG) to improve cooperation between individual regulatory authorities and the European Union.

To further consolidate the internal market, the Third Package also strengthens the regulatory environment within the Community. Regulation No. 713/2009 of the European Parliament and the Council (EC) of 2009 established an independent Agency for the

Cooperation of Energy Regulators (ACER) which began its activities two years later. The agency supervises internal energy markets and advises the European Commission.

Regulation (EC) No. 714/2009 includes the last area of concern of the Third Package: conditions for network access during cross-border exchanges in electricity, supporting cooperation between the individual transmission system operators in Europe. The ENTSO-E network now serves this purpose.

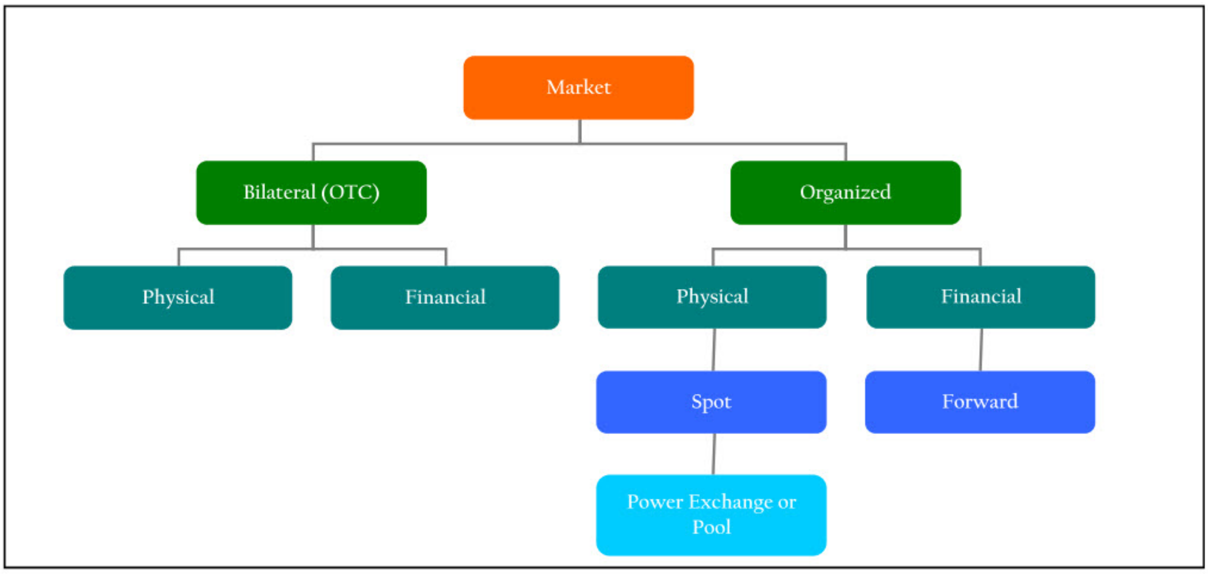
# 2. Organization of electricity markets

As mentioned above, a single European electricity market requires full liberalization at national market levels. This chapter's first part reviews the issues related to electricity trading, its second part deals with brief history of power exchanges.

## 2.1. Organization of wholesale market

Today, electricity trading can be divided into two basic types of markets: unorganized market (bilateral trading in over-the-counter markets) and organized market (trading in the power exchange markets).

Figure 3-2-1: Organization of wholesale market




Source: Karas, J., Sulamaa, P. (2013)

In the OTC market, two market participants make a trade. Product standardization allowed this market to welcome brokers, who mediate some contracts. Brokers earn their keep by giving a clear view of the market situation. The main reason for both direct and brokered OTC contracts is their flexibility: the scope of marketable products and trading unlimited by time. Individual trades follow standardized contract templates. In Europe, these usually involve EFET standards. The buyers and sellers themselves bear the financial risks.

In the power exchange market rules published in individual institutions' business conditions regulate change. The power exchange is the central party to all trades; trades concluded through it are anonymous. One major difference from bilateral contracts lies in trading security. Bilateral contracts only have contractual protection, whereas trading on the power exchange includes financial security. Trading is thus secure from financial risks, but requires greater financial participation of the market participants. Energy products traded in an organized market can be divided into spot contracts, which only physical delivery one day in advance, or future-term contracts, which can be settled physically or financially within periods ranging from one week to one year.

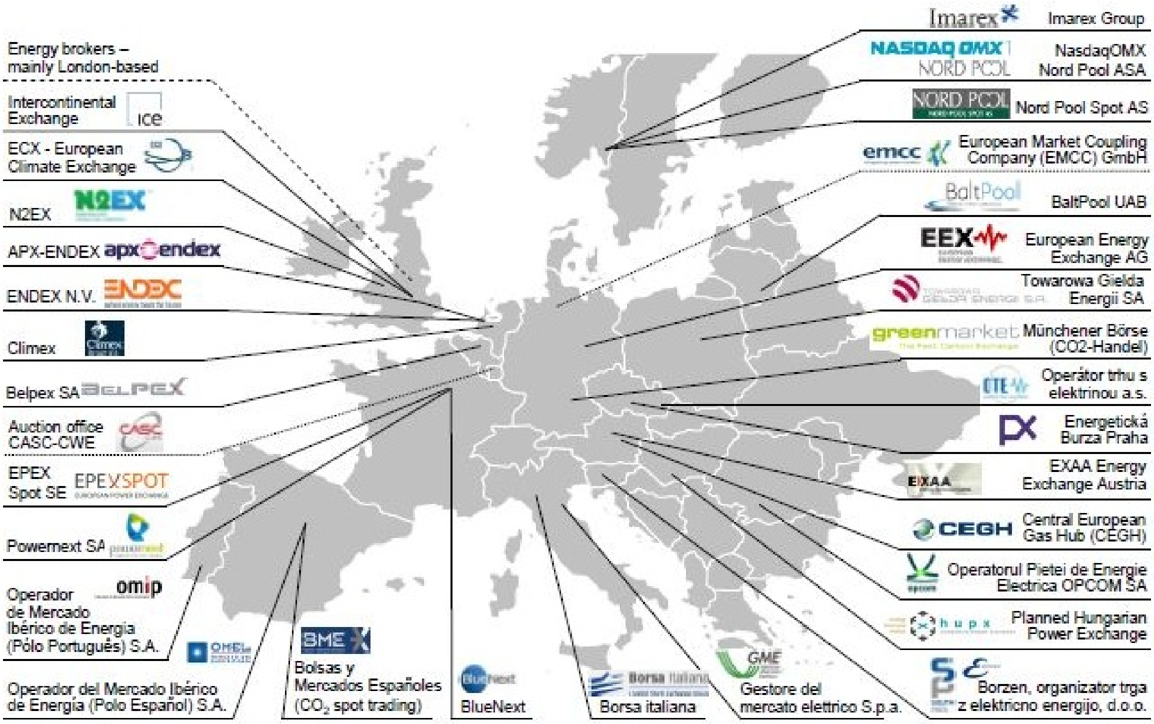
## 2.2. Development of power exchanges in Europe

During liberalization, physical electricity has become a commodity without government price control. Its price is created by supply and demand in the energy market. Similar prices of electricity in each EU country are a feature of a single European electricity market.[1]

Comparing electricity prices through energy exchanges should be relatively easy. However, this comparison encounters the problem that electricity traded in the power exchange may not constitute a large fraction of the overall volume traded. Especially in some eastern European countries, the energy exchange market represents only a small percentage of overall electricity consumption. Therefore, the price cannot be considered the market price, since OTC contract prices are likely to be very different.

[1] All information presented here are based on information available at internet portals each of the power exchange. All www addresses of internet portals are mentioned in Resources after last chapter of this thesis.

**Figure 2-2: Energy exchanges and other trading places for energy and related product**




Source: Karas, J., Sulamaa, P. (2013)

Despite these difficulties, the electricity market partly anticipated the laws, and some countries had liberalized their energy sectors even before the European Union began introducing energy packages. The oldest energy exchange in Europe is Nord Pool, a liberalized, integrated Scandinavian market which began trading electricity in the early 1990. By 2000, it traded electricity from Norway, Sweden, Finland and Denmark.

Great Britain also liberalized its electricity market in the 1990s, but until March 2001, it was based on the system of a single buyer. Normal power exchange trading began only in the year 2000. The APXGroup owns Great Britain’s exchange as well as energy exchanges in the Netherlands. It is also involved in exchange futures trading in Belgium.

The most important single-market energy exchanges are the French PowerNext and the German EEX, which began cooperating shortly after their founding. On May 30, 2008, representatives of both companies signed an agreement creating the new common energy exchange EPEX Spot SE for spot trading in the German, French, Austrian, and Swiss markets, the EEX Power Derivatives GmbH for trading in power derivatives in the French and German markets, and a common clearing center for electricity and natural gas.

The history of the Spanish energy exchange goes back to 1998, when the systems operator OMEL acquired responsibility for trading in the energy market. In 2004, an agreement between the Spanish and Portuguese governments led to the joining of their systems operators and energy markets.

The Italian energy exchange was founded in 2002 and began trading in 2004. The volume of trades in this energy exchange roughly equals Italy's overall electricity consumption in the corresponding period. The Prague energy exchange, founded in 2007, is among the younger energy exchanges in Europe. On October 1, 2008, it began trading in electricity from Slovakia and, on March 1, 2009, from Hungary. On February 1, 2010, it began trading in futures with settlement.

Poland also liberalized its electricity markets before the EU became involved. It took the first steps toward an energy exchange in 1999, but results were unsatisfactory due to low volume of trading and low market liquidity: in the Polish market, long-term delivery contracts between electricity producers and the systems operator are more popular than trading in the energy exchange.

The Slovenian energy exchange Borzen, founded in 2001, remains in state ownership. In 2008 it joined with Eurex to found the BSP regional energy exchange, which trades in Slovenian and Serbian electricity. The company now aims at including other countries in the region.

The Austrian energy exchange is not very important. The volume of electricity traded is roughly 1% of the overall consumption and its influence on electricity prices is thus negligible. Austrian electricity is mostly traded in the German EEX. Bulgaria does not have an energy exchange and its market liberalization is significantly delayed. Romania's OPCOM trades roughly one quarter of its electricity.

## 2.3. Integration of European power exchanges

To attract trading, an energy exchange's liquidity and trade volume should be high. Single countries' markets are rarely attractive enough. Therefore, energy exchanges cooperate and gradually harmonize their trading rules and business systems.

The pace of this process differs across Europe. Energy exchanges do not have equal influence in all EU countries. The newest EU members' energy markets are not liberalized enough to have exchanges at all. The road toward a perfect single electricity market is long. The first step will probably involve regional integration of groups of states, followed by increased cooperation between these stronger actors, following a path similar to the integration of stock exchanges. It will definitely benefit the common internal market.

NordPool and EEX are the clear leaders in integration, but other energy exchanges are working on expanding their activities. The integration of wholesale and exchange markets in electricity is called "market coupling." This term also generally describes market integration; however, it has special meaning in the energy sector. Cross-border trading in electricity involves the necessity to secure transmission capacity for electricity to the other market, which makes trading more difficult. In other words, market coupling means modifying business systems to include the limitations of cross-border transmission capacity in the process of buying and selling. If the capacity is insufficient, orders are coupled inside the individual markets; special auctions for cross-border transmission capacity are not needed. This should result in maximum price convergence, with only cross-border transmission capacity limiting the law of one price. Expanding this capacity enough will create a true common market with one price.

NordPool has already connected its system with the German EEX. Its connection with APX in Great Britain, Belgium, and the Netherlands is also approaching final stages. The resulting interconnected market will amount to 60% of EU consumption. NordPool is also active in the Estonian energy market, which trades 35% of Estonia's overall consumption and rising; and the Polish energy exchange, though the latter, as mentioned above, is not currently significant. The company expects deepening of cooperation and consolidation of energy exchanges in Europe, including mergers.

EEX and PowerNext also play an important role in integration, having joined in 2008 into EPEX, which now connects the markets of France, Germany, Switzerland, Austria and the Benelux countries. The EPEX price has become the reference price for OTC trading.

Among new EU member countries, the Prague energy exchange is the most significant, having already connected the markets of the Czech Republic, Slovakia and Hungary, and negotiating market coupling with Poland.

The Italian energy exchange has launched a pilot market coupling project with Slovenia. In its annual report, the Italian company, unlike integration leaders like EEX and NordPool, accentuates the preservation of a certain degree of national independence in energy exchanges. However, it is actively negotiating a single algorithm with other energy exchanges and full interconnection is expected by 2015, the deadline set by EuroPEX, the association of European energy exchanges.

The Slovenian BSP energy exchange is focused predominantly on Slovenia's neighbors, Serbia and Croatia. As non-EU states, Serbia and Croatia have slightly different energy markets. BSP will probably play an important role in the integration of these markets due to ongoing accession talks with the EU.

In November 2010, Romania and Bulgaria signed an agreement for future interconnection; however, since Bulgaria does not yet have energy exchange, successful market coupling in the region by 2015 remains doubtful.

# 3. Analysis of market integration

In previous chapter I have explained the importance of market integration and liberalization process. In this chapter I study market integration from empirical point of view. To do so I use two analyses, first correlation analysis and then convergence analysis. The aim of analyses is to study market integration, creation of internal market and influence of Third Energy package.

## 3.1. Literature review

Bower (2002), in one of the first studies of the unifying European electricity market, assessed its progress at the end of 2001, including fifteen European electricity markets. He used Engle & Granger cointegration analyses to show prices' integration at all locations, concluding that prices only correlated between Sweden, Denmark, and Finland. A cointegration test showed limited integration between Nord Pool and other locations, and Spain as poorly integrated with any other area.

Boisseleau (2005) examined market integration based on daily prices at power exchanges and OTC markets in six European centers: the Netherlands, Germany, France, United Kingdom, Nord Pool, and Spain. He used two kinds of tests to prove integration. First, he applied correlation analysis to the locations and the markets, using OTC and PX prices to study national and international correlation. He concluded prices were well correlated at the national level, but not at the international level, with the exception of France and Germany's link. In the second part of his study he applied linear regression analysis based on price OLS. His result showed the European electricity market as fragmented.

Haldrup and Nielsen (2004) developed a regime-switching model for long memory and thus fractional integration. They adapted this model to Nordic electricity spot markets and found out that Nordic electricity spot prices have a long memory and depend on congestion capacities exists across regions.

Higgs (2009) examined the interrelationships of wholesale spot electricity prices among the four regional electricity markets in the Australian National Electricity Market. Higgs created a “multivariate generalized autoregressive conditional heteroscedasticity model with time-varying correlations” to study.

One of the most recent papers concerning market integration is by Nepal and Jamasb (2011). They studied integration of the Irish single electricity market with European markets between 2008 and 2011. Nepal and Jamasb used a time-varying approach based on the Kalman filter. Their result suggested that in 2010 Irish single electricity market integration was low. And they made recommendations to boost it: increased trade and larger interconnector capacity. Autran (2012) and Pellinni (2013) performed similar market integration studies using Kalman filter. Pellinni used it at all European power exchanges and made classifications based on degree of convergence over time: clear evidence of convergence, mixed evidence of convergence, seasonal evidence of convergence and no evidence of convergence.

All the research above has concluded that the European electricity market is far from perfectly integrated but shows evidence of regional convergence.

## 3.2. Data description

The datasets consist of electricity prices for six European states and their markets: France, Germany, Great Britain, Netherlands, Spain, and Nord Pool, between 2004 and 2012. These are Europe’s most evolved and interconnected markets.

My research is in two parts: correlation analysis and convergence analysis. For the first I take into account power exchange and bilateral markets, but for the second I choose only power exchange markets, because my main research objective is analysis of power exchanges. Datasets vary slightly between parts of the study. For correlation analysis, I listed six power exchanges' daily average prices and base and peak prices during the weekdays to deal with daily and weekly seasonality, which could undermine results of my study. Thompson Reuters EIKON database supplied the prices at power exchanges. For bilateral markets, I have used OTC indexes assessed and calculated by Argus Analytics. Argus Analytics also differentiates between base/peak hours and weekly/weekend prices. At power exchanges, I picked base and peak prices during weekdays. For convergence analysis I used only prices based on daily average price at each power exchange during weekdays. Then I recalculated all prices as daily average prices in €/MW and transformed them into natural logarithms. More over the data collected in Table 5-1.

**Table 3-1: Data overview and sources**

| Location | Commodity | Data | Source |
|---|---|---|---|
| Great Britain | APX UK | Base/Peak | Thompson Reuters EIKON |
| | OTC | Base | Argus Analytics: UKOTC-B-1D=ARG/A |
| | | Peak | Argus Analytics: UKOTC-P-1D=ARG/A |
| France | EPEX FR | Base/Peak | Thompson Reuters EIKON |
| | OTC | Base | Argus Analytics: FROTC-B-NW=ARG/A |
| | | Peak | Argus Analytics: FROTC-P-NW=ARG/A |
| Germany | EPEX DE | Base/Peak | Thompson Reuters EIKON |
| | OTC | Base | Argus Analytics: DEOTC-B-1D=ARG/A |
| | | Peak | Argus Analytics: DEOTC-P-1D=ARG/A |
| Netherlands | APX NL | Base/Peak | Thompson Reuters EIKON |
| | OTC | Base | Argus Analytics: NLOTC-B-NW=ARG/A |
| | | Peak | Argus Analytics: NLOTC-P-NW=ARG/A |
| Nord Pool | System | Base | Thompson Reuters EIKON |
| Spain | Omel | Base | Thompson Reuters EIKON |
| | OTC | Base | Argus Analytics: ESOTC-B-NW=ARG/A |

## 3.3. Correlation analysis

Linear correlation analysis is a widely used technique to probe integration between two markets. This analysis aims to prove influence of the third liberalization package on market integration, using two time series: the years before adopting the package (2004-2008) and after (2009-2012). The assumption here is that the second time series will have higher correlation coefficients, because of better market integration.

Like Boisseleau (2005), I would like to examine market integration not just between countries but also within a national market. To do so I use prices at power exchanges markets and at bilateral markets. The second assumption is that national integration would be better than international integration.

Basic correlation coefficient is calculated as following equation:

$$\rho_{x,y} = \frac{Cov\ (X,Y)}{\sigma_x \cdot \sigma_y} \qquad (5\text{-}1)$$

where

$$-1 \leq \rho_{x,y} \leq 1 \qquad (5\text{-}2)$$

and

$$Cov\ (X,Y) = \frac{1}{n}\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y) \qquad (5\text{-}3)$$

Markets are perfectly integrated if the correlation coefficient is 1. If it is bigger than 0, the national or international markets have some degree of integration. Correlation analysis must be done carefully in the electricity market, which has a number of lags affecting the correlation coefficient. Lags could be daily or weekly seasonality. To deal with daily seasonality I use average base and peak prices for every day. And to resolve weekly seasonality I use only weekday prices. The results of correlation analysis are presented in table 3-2 for 2004-2008 and table 3-3 for 2009-2012.

## Table 3-2: Correlation analysis 2004-2008

| 2004-2008 | | France | | | | Germany | | | | Netherlands | | | | Great Britain | | | | Spain | | Nord-pool |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OTC base | PX base | OTC peak | PX peak | OTC base | PX base | OTC peak | PX peak | OTC base | PX base | OTC peak | PX peak | OTC base | PX base | OTC peak | PX peak | OTC base | PX base | System |
| France | OTC Base | | | | | | | | | | | | | | | | | | | |
| | PX Base | 0,87 (0,00) | | | | | | | | | | | | | | | | | | |
| | OTC Peak | 0,96 (0,00) | 0,91 (0,00) | | | | | | | | | | | | | | | | | |
| | PX Peak | 0,83 (0,00) | 0,97 (0,00) | 0,90 (0,00) | | | | | | | | | | | | | | | | |
| Germany | OTC Base | 0,90 (0,00) | 0,81 (0,00) | 0,88 (0,00) | 0,88 (0,00) | | | | | | | | | | | | | | | |
| | PX Base | 0,76 (0,00) | 0,75 (0,00) | 0,69 (0,00) | 0,73 (0,00) | 0,93 (0,00) | | | | | | | | | | | | | | |
| | OTC Peak | 0,84 (0,00) | 0,73 (0,00) | 0,85 (0,00) | 0,74 (0,00) | 0,97 (0,00) | 0,91 (0,00) | | | | | | | | | | | | | |
| | PX Peak | 0,67 (0,00) | 0,66 (0,00) | 0,63 (0,00) | 0,67 (0,00) | 0,78 (0,00) | 0,97 (0,00) | 0,88 (0,00) | | | | | | | | | | | | |
| Netherlands | OTC Base | 0,41 (0,00) | 0,43 (0,00) | 0,44 (0,00) | 0,46 (0,00) | 0,47 (0,00) | 0,45 (0,00) | 0,49 (0,00) | 0,46 (0,00) | | | | | | | | | | | |
| | PX Base | 0,35 (0,00) | 0,39 (0,00) | 0,38 (0,00) | 0,43 (0,00) | 0,43 (0,00) | 0,42 (0,00) | 0,45 (0,00) | 0,43 (0,00) | 0,89 (0,00) | | | | | | | | | | |
| | OTC Peak | 0,37 (0,00) | 0,38 (0,00) | 0,41 (0,00) | 0,43 (0,00) | 0,45 (0,00) | 0,42 (0,00) | 0,48 (0,00) | 0,44 (0,00) | 0,96 (0,00) | 0,90 (0,00) | | | | | | | | | |
| | PX Peak | 0,33 (0,00) | 0,37 (0,00) | 0,36 (0,00) | 0,40 (0,00) | 0,41 (0,00) | 0,39 (0,00) | 0,42 (0,00) | 0,41 (0,00) | 0,89 (0,00) | 0,99 (0,00) | 0,91 (0,00) | | | | | | | | |
| Great Britain | OTC Base | 0,62 (0,00) | 0,58 (0,00) | 0,65 (0,00) | 0,58 (0,00) | 0,47 (0,00) | 0,37 (0,00) | 0,44 (0,00) | 0,33 (0,00) | 0,45 (0,00) | 0,38 (0,00) | 0,41 (0,00) | 0,37 (0,00) | | | | | | | |
| | PX Base | 0,51 (0,00) | 0,51 (0,00) | 0,52 (0,00) | 0,49 (0,00) | 0,39 (0,00) | 0,35 (0,00) | 0,36 (0,00) | 0,31 (0,00) | 0,46 (0,00) | 0,49 (0,00) | 0,46 (0,00) | 0,49 (0,00) | 0,82 (0,00) | | | | | | |
| | OTC Peak | 0,55 (0,00) | 0,52 (0,00) | 0,59 (0,00) | 0,65 (0,00) | 0,43 (0,00) | 0,35 (0,00) | 0,33 (0,00) | 0,33 (0,00) | 0,46 (0,00) | 0,40 (0,00) | 0,45 (0,00) | 0,40 (0,00) | 0,95 (0,00) | 0,78 (0,00) | | | | | |
| | PX Peak | 0,49 (0,00) | 0,48 (0,00) | 0,41 (0,00) | 0,48 (0,00) | 0,37 (0,00) | 0,44 (0,00) | 0,46 (0,00) | 0,41 (0,00) | 0,48 (0,00) | 0,49 (0,00) | 0,49 (0,00) | 0,50 (0,00) | 0,90 (0,00) | 0,99 (0,00) | 0,78 (0,00) | | | | |
| Spain | OTC Base | 0,47 (0,00) | 0,51 (0,00) | 0,40 (0,00) | 0,44 (0,00) | 0,42 (0,00) | 0,38 (0,00) | 0,38 (0,00) | 0,33 (0,00) | 0,21 (0,00) | 0,21 (0,00) | 0,23 (0,00) | 0,31 (0,00) | 0,32 (0,00) | 0,35 (0,00) | 0,25 (0,00) | 0,32 (0,00) | | | |
| | PX Base | 0,31 (0,00) | 0,26 (0,00) | 0,27 (0,00) | 0,21 (0,00) | 0,26 (0,00) | 0,22 (0,00) | 0,26 (0,00) | 0,22 (0,00) | 0,29 (0,00) | 0,27 (0,00) | 0,32 (0,00) | 0,28 (0,00) | 0,32 (0,00) | 0,35 (0,00) | 0,31 (0,00) | 0,34 (0,00) | 0,85 (0,00) | | |
| Nordpool | System | 0,32 (0,00) | 0,31 (0,00) | 0,34 (0,00) | 0,37 (0,00) | 0,33 (0,00) | 0,34 (0,00) | 0,32 (0,00) | 0,34 (0,00) | 0,36 (0,00) | 0,29 (0,00) | 0,37 (0,00) | 0,28 (0,00) | 0,42 (0,00) | 0,35 (0,00) | 0,45 (0,00) | 0,36 (0,00) | 0,30 (0,00) | 0,45 (0,00) | |

National Correlation | International Correlation

Source: own calculations

## Table 3-3: Correlation analysis 2009-2012

| 2009-2012 | | France | | | | Germany | | | | Netherlands | | | | Great Britain | | | | Spain | | Nord-pool |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OTC base | PX base | OTC peak | PX peak | OTC base | PX base | OTC peak | PX peak | OTC base | PX base | OTC peak | PX peak | OTC base | PX base | OTC peak | PX peak | OTC base | PX base | System |
| France | OTC Base | | | | | | | | | | | | | | | | | | | |
| | PX Base | 0,89 (0,00) | | | | | | | | | | | | | | | | | | |
| | OTC Peak | 0,94 (0,00) | 0,93 (0,00) | | | | | | | | | | | | | | | | | |
| | PX Peak | 0,86 (0,00) | 0,94 (0,00) | 0,89 (0,00) | | | | | | | | | | | | | | | | |
| Germany | OTC Base | 0,91 (0,00) | 0,90 (0,00) | 0,89 (0,00) | 0,91 (0,00) | | | | | | | | | | | | | | | |
| | PX Base | 0,81 (0,00) | 0,87 (0,00) | 0,72 (0,00) | 0,75 (0,00) | 0,95 (0,00) | | | | | | | | | | | | | | |
| | OTC Peak | 0,86 (0,00) | 0,76 (0,00) | 0,87 (0,00) | 0,86 (0,00) | 0,97 (0,00) | 0,96 (0,00) | | | | | | | | | | | | | |
| | PX Peak | 0,67 (0,00) | 0,66 (0,00) | 0,63 (0,00) | 0,67 (0,00) | 0,91 (0,00) | 0,97 (0,00) | 0,97 (0,00) | | | | | | | | | | | | |
| Netherlands | OTC Base | 0,61 (0,00) | 0,54 (0,00) | 0,51 (0,00) | 0,61 (0,00) | 0,84 (0,00) | 0,87 (0,00) | 0,79 (0,00) | 0,85 (0,00) | | | | | | | | | | | |
| | PX Base | 0,51 (0,00) | 0,61 (0,00) | 0,51 (0,00) | 0,58 (0,00) | 0,81 (0,00) | 0,91 (0,00) | 0,74 (0,00) | 0,89 (0,00) | 0,96 (0,00) | | | | | | | | | | |
| | OTC Peak | 0,67 (0,00) | 0,55 (0,00) | 059 (0,00) | 0,51 (0,00) | 0,74 (0,00) | 0,81 (0,00) | 0,89 (0,00) | 0,73 (0,00) | 0,97 (0,00) | 0,98 (0,00) | | | | | | | | | |
| | PX Peak | 0,57 (0,00) | 0,53 (0,00) | 0,56 (0,00) | 0,57 (0,00) | 0,71 (0,00) | 0,88 (0,00) | 0,79 (0,00) | 0,92 (0,00) | 0,95 (0,00) | 0,99 (0,00) | 0,93 (0,00) | | | | | | | | |
| Great Britain | OTC Base | 0,63 (0,00) | 0,59 (0,00) | 0,63 (0,00) | 0,61 (0,00) | 0,73 (0,00) | 0,67 (0,00) | 0,74 (0,00) | 0,80 (0,00) | 0,82 (0,00) | 0,89 (0,00) | 0,91 (0,00) | 0,86 (0,00) | | | | | | | |
| | PX Base | 0,56 (0,00) | 0,57 (0,00) | 062 (0,00) | 0,56 (0,00) | 0,72 (0,00) | 0,75 (0,00) | 0,79 (0,00) | 0,75 (0,00) | 0,87 (0,00) | 0,92 (0,00) | 0,90 (0,00) | 0,93 (0,00) | 0,87 (0,00) | | | | | | |
| | OTC Peak | 0,63 (0,00) | 0,59 (0,00) | 0,65 (0,00) | 0,70 (0,00) | 0,80 (0,00) | 0,70 (0,00) | 0,71 (0,00) | 0,78 (0,00) | 0,89 (0,00) | 0,79 (0,00) | 0,83 (0,00) | 0,87 (0,00) | 0,95 (0,00) | 0,89 (0,00) | | | | | |
| | PX Peak | 0,67 (0,00) | 0,68 (0,00) | 0,62 (0,00) | 0,69 (0,00) | 0,73 (0,00) | 0,81 (0,00) | 0,86 (0,00) | 0,74 (0,00) | 0,87 (0,00) | 0,91 (0,00) | 0,90 (0,00) | 0,94 (0,00) | 0,98 (0,00) | 0,99 (0,00) | 0,92 (0,00) | | | | |
| Spain | OTC Base | 0,67 (0,00) | 0,61 (0,00) | 0,60 (0,00) | 0,64 (0,00) | 0,59 (0,00) | 0,66 (0,00) | 0,58 (0,00) | 0,54 (0,00) | 0,51 (0,00) | 0,53 (0,00) | 0,55 (0,00) | 0,63 (0,00) | 0,61 (0,00) | 0,63 (0,00) | 0,52 (0,00) | 0,65 (0,00) | | | |
| | PX Base | 0,53 (0,00) | 0,54 (0,00) | 0,57 (0,00) | 0,56 (0,00) | 0,58 (0,00) | 053 (0,00) | 0,56 (0,00) | 0,57 (0,00) | 0,56 (0,00) | 0,54 (0,00) | 0,59 (0,00) | 0,53 (0,00) | 0,57 (0,00) | 0,55 (0,00) | 0,57 (0,00) | 0,67 (0,00) | 0,91 (0,00) | | |
| Nordpool | System | 0,56 (0,00) | 0,67 (0,00) | 0,54 (0,00) | 0,52 (0,00) | 0,64 (0,00) | 0,61 (0,00) | 0,53 (0,00) | 0,56 (0,00) | 0,63 (0,00) | 0,62 (0,00) | 0,54 (0,00) | 0,53 (0,00) | 0,66 (0,00) | 0,68 (0,00) | 0,57 (0,00) | 0,56 (0,00) | 0,60 (0,00) | 0,55 (0,00) | |

National Correlation | International Correlation

Source: own calculations

## 3.4. Results of correlation analysis

Correlation coefficients between 2004 and 2012 in table 3-4 show high correlation at national level between bilateral markets and power exchanges in all countries studied. The national correlation coefficients are over 90% each. This also implies that power exchanges work at the national level.

In 2004-2008, international correlation coefficients are generally low (below 50%) and do not support the existence of one European electricity market. Exceptions from this are market pairs Germany/France and Great Britain/France. Germany and France average over 75% correlation. Germany and France are neighbors and so have good interconnections and can transfer a lot of electricity between them. The lowest market integration presents Spain and Nord Pool. Spain is very poorly integrated with any other market in Europe, with its best correlation between its bilateral market and the French base power exchange price. There is a geographical explanation of Spain and Nord Pool's low integration: both are far from central Western Europe.

Correlation coefficients between 2009 and 2012 in table 3-5, compared to 2004-2008, show rising correlation at both intranational and international levels. At the intranational level market integration is very high. The biggest change is at the international level. All countries express market integration with each other on same level. The best-integrated pairs are Germany/France again, Netherlands/Germany and Netherlands/Great Britain. The relationship between Netherlands and Great Britain and Germany and France seems to show good market coupling and support the existence of slowly creating a single European electricity market.

These results support the influence of the Third Energy Package adopted in 2009. All correlation coefficients have risen between the first and second time period.

## 3.5. Convergence analysis

Price convergence is one of the most important indicators of successful liberalization and market integration. In this chapter, I use Kalman filter approach to calculate time-varying convergence between six European power exchange markets.

But before I start filtering I need to find out if my data are stationary or non-stationary time series. Non-stationary time series could produce spurious results. To test stationariness I choose the KPSS test introduced by Kwiatkowski, Phillips, Schmidt and Shin (1992) with the Bartlett kernel explained by Hobijn (1998),

$$y_t = \alpha + \beta t + d \sum_{i=1}^{t} u_i + \varepsilon_t \qquad (5\text{-}4)$$

where

$$t = 1, \dots, T \qquad (5\text{-}5)$$

and

$$d \in \{0,1\} \qquad (5\text{-}6)$$

where $u_i$ and $\varepsilon_t$ are covariance stationary and short memory with mean zero and my null hypothesis is formulated as:

$$H_0\colon\ y_t = I(0) \qquad (5\text{-}7)$$

If KPSS stationary test proves that our data series are non-stationary I can continue applying Kalman filter. I use a simple convergence model based on Autran's (2012):

$$p_A(t) = \alpha(t) p_B(t) + \varepsilon(t) \qquad (5\text{-}8)$$

Where $p_A(t)$ and $p_B(t)$ are prices in country A and country B, $\alpha(t)$ is time varying unobservable coefficient, which must be estimated, and $\varepsilon(t)$ is a measurement error. Equation 5-8 is called the measurement equation.

$$\alpha(t) = \alpha(t-1) + u(t) \qquad (5\text{-}9)$$

Equation 5-9 is an autoregressive function with measurement errors and is defined as a state space model, where $\alpha(t)$ is the system state and $u(t)$ is measurement error. Equation 5-9 is called state equation.

For purposes of this thesis the state equation is vector$\alpha(t)$. The state equation defines the evolution of the time-varying coefficient. Vector $\alpha(t)$ defines the state of convergence and will receive graphic examination. Autran's state space model (2012) evolves smoothly over the time. More data about this model are in Appendix 2.

I will use the Kalman filter model described above with classification created by Pellinni (2013). Her classification is based on smoothed estimates of state vector $\alpha(t)$. She formed four groups according to proof of convergence: clear evidence of convergence, mixed evidence, seasonal evidence and no evidence.

I will use this to indicate the effect of adopting the Third Energy Package on the degree of convergence from 2009. My assumption is that there will be visible clear evidence of liberalization on convergence. The Kalman filter can be also used to examine existence of single European power exchange market.

## 3.6. Results of convergence analysis

My null hypothesis for the KPSS stationary test states that the series is stationary as is shown above in equation 3-7. From the result of KPSS test I can reject the null hypothesis at 5% and 1% level of significance as shown in table 3-6. The series is non-stationary.

After concluding that our series is non-stationary I did a Kalman filter with results shown in figures 5-1, 5-2 and 5-3 as a smoothed-vectors α(t) state for power market pairs. These estimates explain convergence between two markets. I study six power exchanges and thus sixteen pairs and have given them Pellinni's (2013) four categories.

**Table 3-4: Results of KPSS stationarity test**

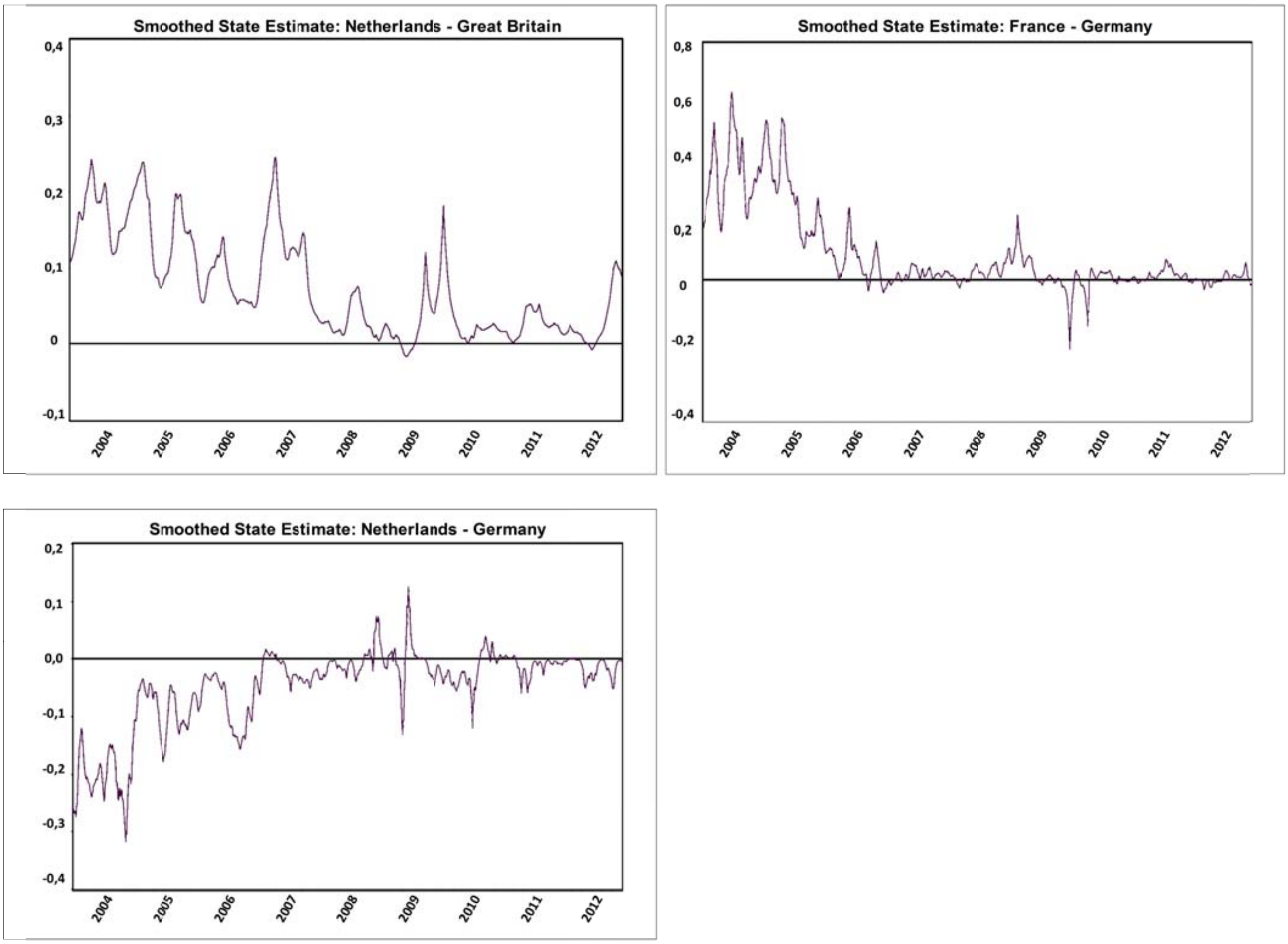
| | | |
|---|---|---|
| KPSS test for France<br>Test statistic = 1,274 | KPSS test for Germany<br>Test statistic = 2,228 | KPSS test for Netherlads<br>Test statistic = 2,689 |
| KPSS test for Great Britain<br>Test statistic = 3,728 | KPSS test for Spain<br>Test statistic = 3,141 | KPSS test for Nordpool<br>Test statistic = 4,923 |

Critical values: 0,743 for 1% level of significance, 0,462 for 5% level of significance

Source: own calculations

The first pairs show clear evidence of convergence. There are three of these out of 16: Germany/France, Germany/Netherlands and Great Britain/Netherlands. All these countries, again, have common borders, aiding their interconnections and high values of market coupling. The best-converged country appears to be Germany. The third energy has had a significant effect as an affirming and deepening variable. The estimates of vector $\alpha(t)$in this group are range -1 to 1 and during the visibly decrease range from 0. This is effect of deeper market integration.

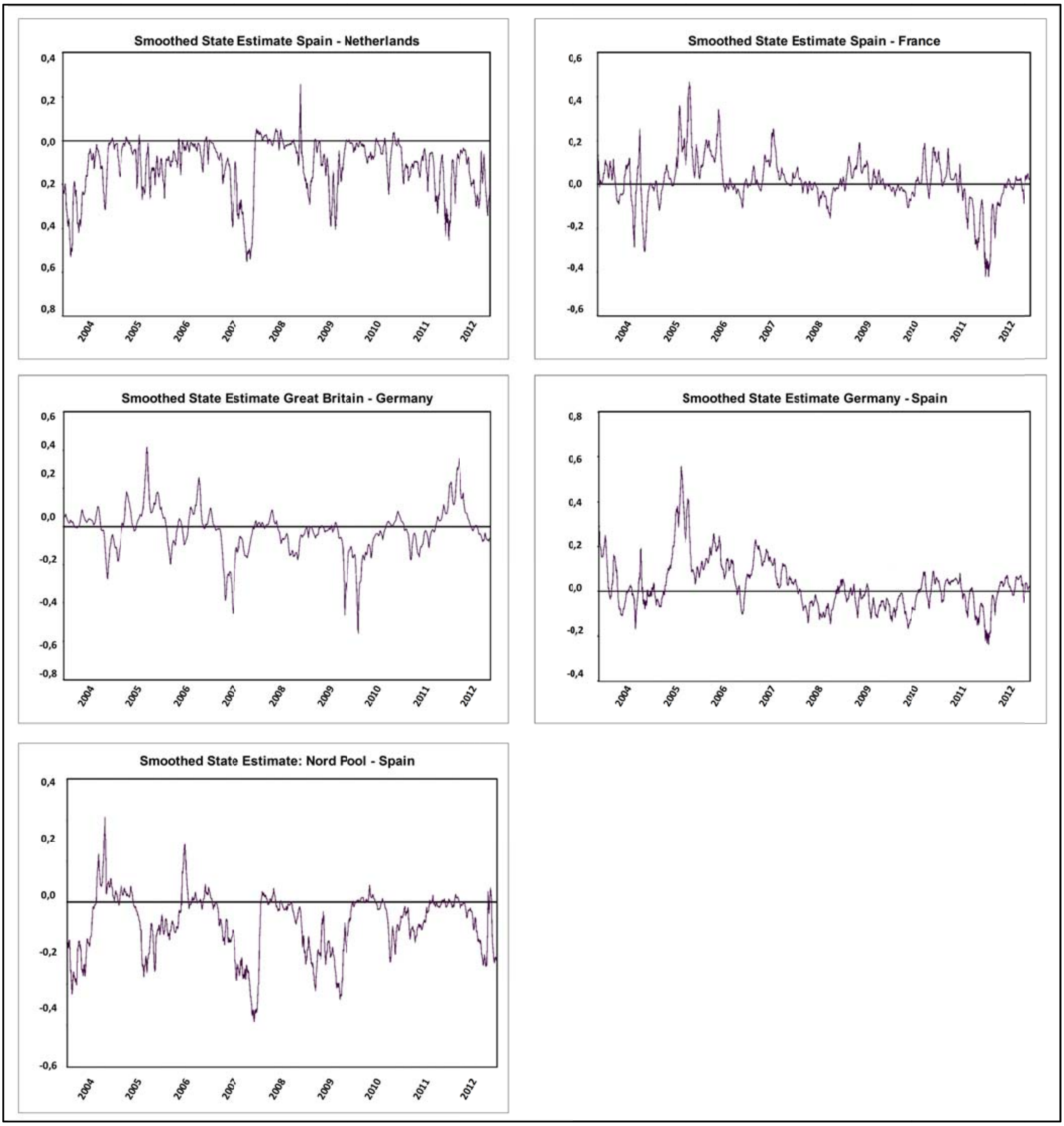
**Figure 3-1: Power exchange market pairs with clear evidence of convergence**




Source: Own calculations.

The second group, with mixed evidence of convergence, includes five pairs: Great Britain/Germany, Spain/France, Spain/German, Spain/Great Britain, and Spain/Netherlands. Some have a common border and some do not. Distant market pairs have similar power generation structure or market structure; therefore, external factors influencing them in the same way. The evidence of market liberalization's effect on integration is here not so evident. The estimates of vector $\alpha(t)$in this group are range -1 to 1.

**Figure 3-2: Power exchange market pairs with mixed evidence of convergence**

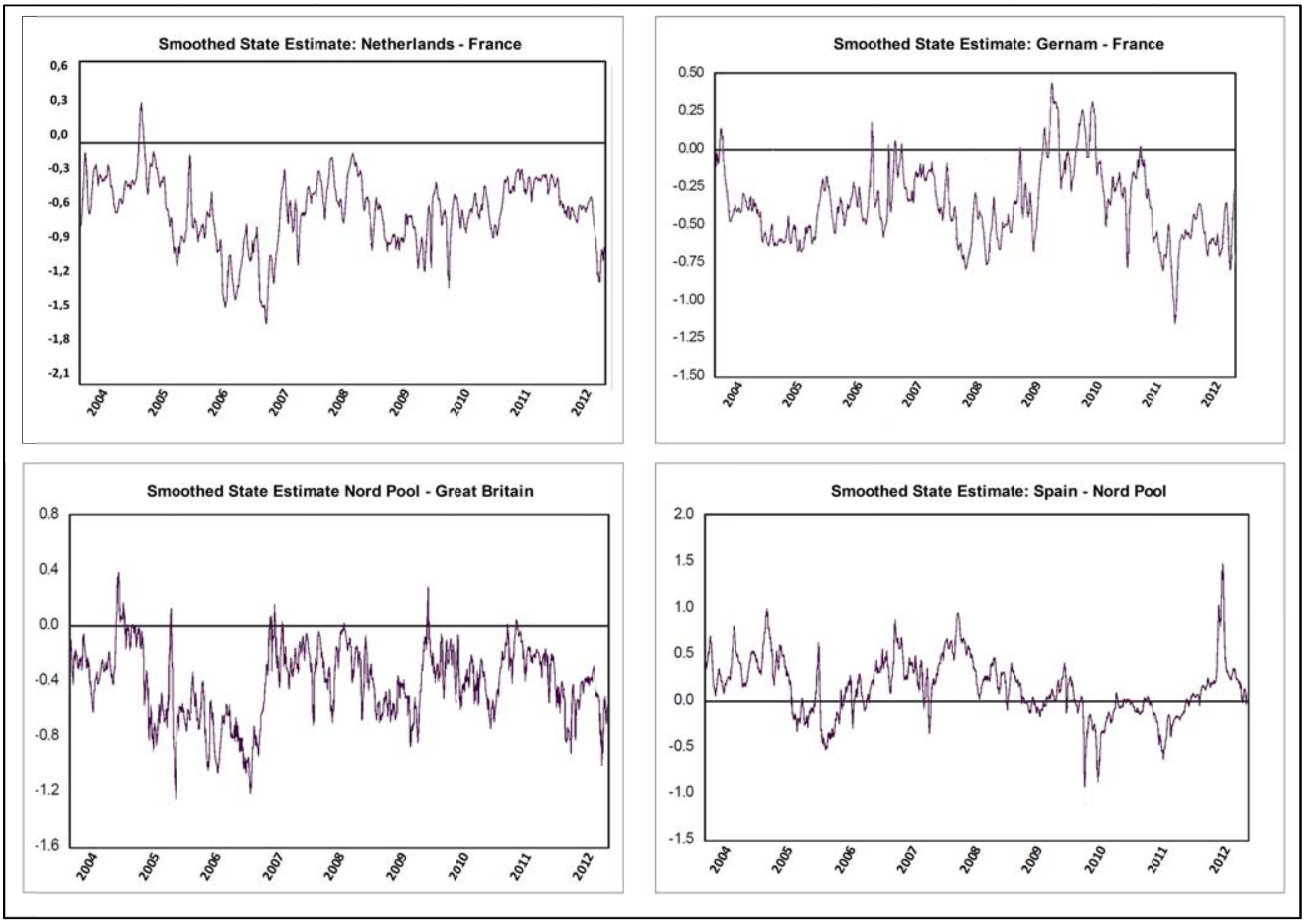



Source: Own calculations.

To the third group belong power exchange pairs with seasonal evidence of convergence. There is none according to results of Kalman filter estimations.

The last group shows no evidence of convergence, and comprises the remaining six pairs: Netherlands/France, Great Britain/France, and most of the pairs with Nord Pool. Nord Pool never seems to converge to another market except Spain's, which is not surprising, given its isolation from continental Europe. The estimates of vector $\alpha(t)$in this group are moving in wide range.

**Figure 3-3: Power exchange market pairs with no evidence of convergence**




Source: Own calculations.

These results do not confirm conclusions made in the previous chapter in correlation analysis. However, results of the correlation coefficient could be affected by the long time series of 2004-2008 and 2009-2012. The Kalman model estimates convergence on a daily basis and is therefore much more precise.

## 3.7. Future development of European power exchanges

The goal of European Union was achieving a single electricity market by the end of 2014. The main legislation act Third Energy Package was supposed to be implemented by March 2011. However the reality is far beyond the expectations because till now the implementation of Third Energy Package was not finished by all countries. But this didn't slow European institutions from creating and proposing new projects concerning a single European electricity market and European power exchanges. On September 26, 2013, the European Commission proposed a single European power exchange. The proposal doesn't mean canceling national power exchanges but creating one power exchange where could all members of European Union voluntarily participate. So this raises the question: What is the future of European power exchanges? In this chapter I summarize possible scenarios of future European power exchange market. To do so I use a study by Karas and Sulamaa (2013).

According to Karas and Sulamaa (2013), there are four scenarios of potential future development of European Power Exchanges. However, these scenarios are rather illustrative and should be taken as extreme outcomes. The reality will more likely be somewhere in between of those scenarios.

The first possible scenario predicts that both physical market place and market associations will be held in one single European legal entity. This is a highly centralized scenario. Financial markets would be completely separated business from power exchanges. Of course, we can identify pros and cons of this scenario. As potential advantage we can mention simplified structure and clarity of reference price. Liquidity would also increase. On the other hand, when something is centralized it is always hard to understand local needs. Therefore, preferences and needs of local customers might suffer. Drawbacks of monopoly structure could also take place: dominance might distort pricing and efficiency. Furthermore, lack of incentives to develop and innovate may occur. The reality will be inclined more likely to this scenario if there is continuing trend in mergers and acquisitions in power exchange market.

The next scenario, the EU ISO scenario, counts with power exchange market to become real-time market. System operators and power exchanges would be supposed to merge into one European independent system operator (ISO). Almost all physical volumes would be traded at delivery. Day-ahead and intraday markets are supposed to become forward markets, with price setting against real-time market prices. The market prices would result from demand and supply available at a node, while day-ahead nodal prices would become financial products. Financial trading of products would take place in different trading platforms in Europe. This scenario would give us an overview about investment needed between nodes. The ISO would be strictly limited in its operations because of regulation. This could be an opportunity for private entities setting up private trading platforms. Thanks to these, process of developing contracts that would ensure long-term contracts based on transparent prices would be facilitated. The question is, however, whether this scenario is not much complex and information-requiring to be implemented successfully.

The third scenario is a decentralized scenario. This scenario would be implemented in case European power exchanges are not gathered into one European market. Europe could be divided into several regions under this scenario, and these regions could voluntarily integrate price coupling. Also, responsibility for price coupling calculations would rotate among power exchanges. No separate legal entity would be introduced, as it would be for example in case of EU PX scenario. This model could be suitable if there are problems that are not possible to solve on the European level but rather require local solutions. Thanks to voluntary-based participation, implementation could be fast. Transmission planning would be more feasible on the region level than on EU level. Compared to EU PX scenario, decentralized scenario accounts for needs of local customers. However, this could also lead to drawbacks resulting from lack of competition. Also, rotating responsibility would require high level of organization and therefore relatively high costs.

Under the next scenario, European Market Coupling Operator (MCO) would be established. MCO would be subject to high level of regulation, would be operating at non-profit basis and would be owned by member states. MCO would implement auctions of congestion income and would have monopoly position on trades that would take place across biding zones. There would remain local power exchanges, just cross-border trades would be carried out via MCO. Therefore, monopoly position would be limited, ensuring competition of local power exchanges. More information about possible scenarios of future European power exchange markets are in Appendix 3.

What the reality will look like depends on many factors. Specific steps to creating new legislative or continuing natural tendency, currently to mergers and acquisitions seems to be a crossroad. Decentralized approach is probably the fastest and easiest way to reach day-ahead market coupling. On the other hand, if the current trend continues, meaning increasing numbers of mergers and acquisitions, it is more likely that single European power exchange becomes a reality.

# Conclusion

One of the goals of the European Union was to achieve a single electricity market by the end of 2014. The main legislation act Third Energy Package was supposed to be implemented by March 2011. However, the reality is far beyond the expectations. Till now the implementation of Third Energy Package was not finished by all countries. The legislation in its present form requires ownership unbundling of the generation, distribution, transmission systems, and deliveries of electricity. Not all countries prefer this model and especially countries such as Germany and France whose governments are unwilling to accept their weakening, which is why they have implemented steps ensuring the power generator can maintain a certain degree of influence in the transmission network.

Liberalization and integration of the European market require trading of electricity in energy exchanges. In some countries, energy exchanges are already well established, while in others they are yet to be formed. The most developed and successful energy exchanges in Europe are the Dutch, French, German, Scandinavian and Spanish power exchange.

To measure market integration between European electricity markets I use two analyses: correlation and convergence analysis. The purpose of correlation analysis is to estimate national and international integration of electricity markets in two time series 2004- 2008 and 2009-2012. These two time series were chosen to show influence of liberalization, especially impact of Third Energy Package. Results from correlation analysis imply that during period 2004-2008 there was a high correlation at national level between bilateral markets and power exchanges in all countries studied. On the contrary, the correlation at international level was rather sporadic and took place only between market pairs Germany/France and Great Britain/France. Results from period 2009-2012 showed dramatic increase in correlation at international level between both bilateral markets and power exchanges.

From the results I can make a statement that adopting Third energy Package has had positive influence in accelerating liberalization process of European electricity markets. Furthermore, I can conclude that in period 2004- 2008 there was no evidence of single European electricity market.

As a next step I studied market integration at European power exchanges by using convergence analysis. There are many ways of observing convergence and I selected Kalman filter approach to calculate time-varying convergence between six most developed European power exchange markets over the period 2004-2012. After applying Kalman filter I obtained estimations of degree of convergence for all power exchange market pairs and I used Pellinnis classification. The outcomes of this model are four groups of markets pairs. Each group implies different degree and type of convergence: clear evidence of convergence, mixed evidence, seasonal evidence and no evidence. This results in sixteen pairs of which three shows clear evidence of convergence, five mixed evidence and eight no evidence. This indicates market integration at regional level I central Europe but no existence of single European power exchange market. These results do not confirm conclusions made in the previous correlation analysis. However, results of the correlation coefficient could be affected by the long time series of 2004-2008 and 2009-2012. The Kalman model estimates convergence on a daily basis and is therefore much more precise. Also by visual inspection I can confirm the presence of the effect of Third Energy Package only in three power exchange markets with clear evidence of convergence. In these market pairs the visible integration existed before adopting the Third Energy Package and the Package was acting only as an affirming and deepening variable.

Lastly, I have examined four possible future scenarios of power exchanges. What the reality will be like depends on many factors. Will there be specific steps taken to create new legislative or will the development be rather natural, meaning inclining to mergers and acquisitions, as it is shown nowadays? Implementing decentralized approach is probably the fastest way of reaching day-ahead market coupling. On the other hand, if the current trend continues, meaning increasing numbers of mergers and acquisitions, it is more likely that a single European power exchange becomes a reality.

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# Appendix 1: Kalman Filter

The Kalman filter is a statistical approach which principle is to correct the model trajectory using observations and the information contained in the model in order to minimize the error between the true state and the filtered state.

For a stochastic state representation:

$$X_{k+1} = M_k X_k + B_k u_k + G_k W_k$$

With $M_k, B_k$ two linear matrices, $u_k$ an external input vector (that can be null), $G_k$ the noise entrance matrix and $W_k$ a white noise vector with covariance matrix $Q_k$ which symbolises the state model error.

The state is observed through an observation equation:

$$Z_k = H_k X_k + V_k$$

With $H_k$ a linear observation matrix and $V_k$ a white noise representing the error made on the observation (the measurement error) with covariance matrix $V_k$.

To obtain the state $X_k$, we combine the observations $Z_k$ and the information given by the state model. We determine the conditional density probability of the state $X_k$, knowing $Z_1, \ldots, Z_i$.

Source: Autran (2012)

This iterative process is divided into two steps:

## 1 The prediction step:

First a prediction of the state is calculated through the state equation:

$$X_{k|k-1} = M_k X_{k-1|k-1} + B_k u_k$$

And the covariance matrix of the system is updated:

$$P_{k|k-1} = M_k P_{k-1|k-1} M_k^T + G_k Q_k G_k^T$$

Calculation of the filter optimal gain $K_k$ :

$$K_k = P_{k|k-1} H_k^T (H_k P_{k|k-1} H_k^T + R_k)^{-1}$$

## 2 The Correction step:

The predicted state is corrected using the new observation $Z_k$ :

$$X_{k|k} = X_{k|k-1} + K_k (Z_k - H_k X_{k|k-1})$$

And an update of system covariance matrix:

$$P_{k|k} = (I - K_k H_k) P_{k|k-1}$$

This requires an initialisation stage, therefore values for $X_0$ and $P_0$ have to be given. If not defined, E-views automatically gives initial values usually small for $X_0$ and large for $P_0$ which are, stage after stage, getting closer to the real values. This is why the very first stages can be more imprecise than the following.

The parameters such as the covariance of the state model error and the observation error are scarcely known but they can be estimated through Expectation Maximisation Algorithm (algorithm used by Eviews and using maximum likelihood estimation but not described here).

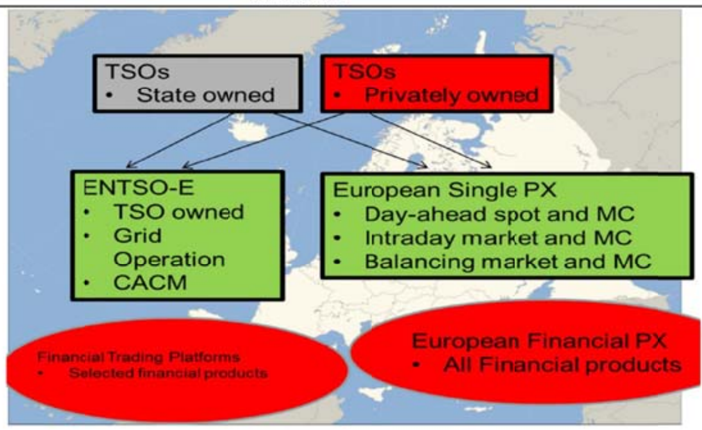
Source: Autran (2012)

# Appendix 2: Future scenarios of European power exchanges

**EU PX Scenario**

| Plusses and minuses of this scenario | |
|---|---|
| + | Simple structure |
| + | Seamless process |
| + | Clear reference price |
| + | Liquidity |
| - | Local understanding of customer needs may suffer |
| - | No option to de-coupling |
| - | Monopoly and dominance may harm the development and pricing of the service, efficiency, innovation and dynamics may suffer |
| - | TSO ownership may hinder structural development based on markets' need |

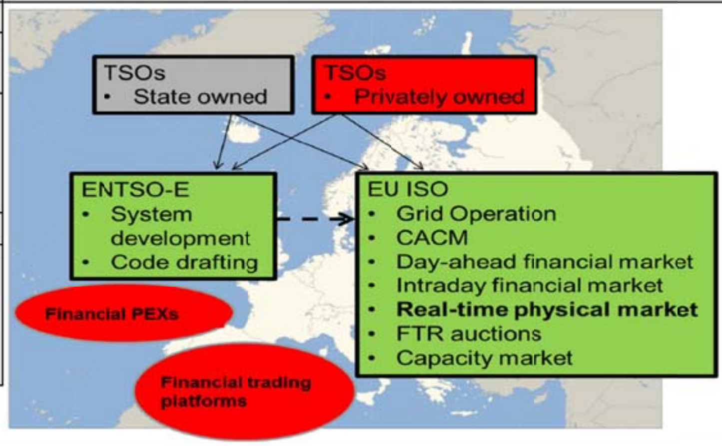
Structure




**EU ISO Scenario**

| Plusses and minuses of this scenario | |
|---|---|
| + | Takes into account the reality of transmission |
| + | Gives indication of transmission investment needs between nodes |
| + | As a regulated entity, the ISO has strict limitations on its operations which are primarily focused on financial transmission rights, day-ahead financial market, intraday financial |
| - | The nodal model is complex and difficult to understand |
| - | It requires huge amount of information. a European level central dispatch would be difficult task. Number of various products in the market would be at range of tens of thousands (USA example) |

Structure

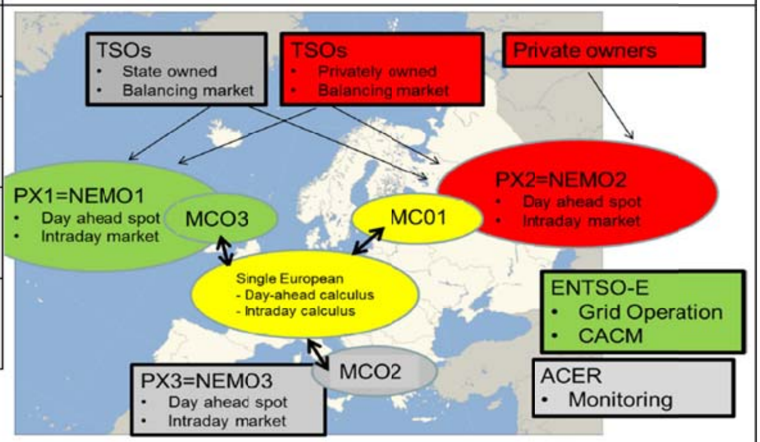



**Decentralized scenario**

| Plusses and minuses of this scenario | |
|---|---|
| + | As no EU regulation is needed and the co-operation is based on voluntary co-operation, implementation could be fast. |
| + | The scenario may be the easiest to command/control/regulate as the total market is split into regions. |
| - | Regional solution misses the potential efficiency gains that the whole market solution would bring about (less competitive market). |
| - | There is the danger that market design regionally could yield solutions where the interregional transmission flows are not market based. |

NEMO = Nominated Electricity Market Operator,
MCO = Market Coupling Operator

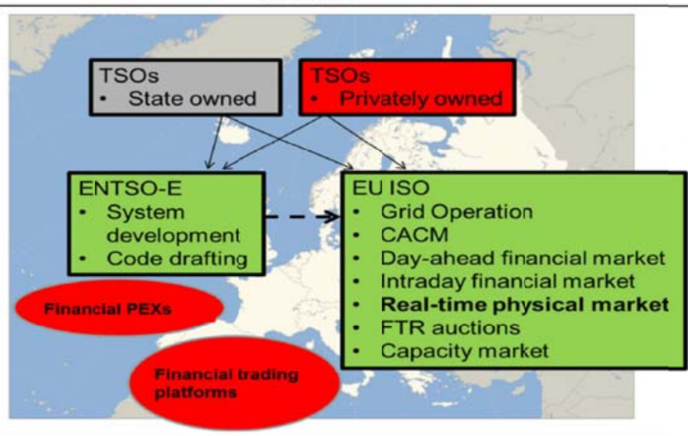
Structure

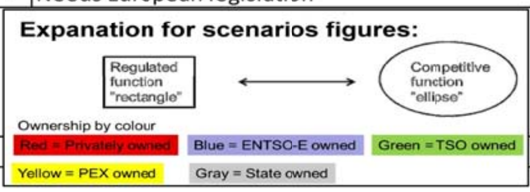



**EU MCO Scenario**

| Plusses and minuses of this scenario | |
|---|---|
| + | Monopole activities limited to minimum and separated from competitive functions |
| + | Gives indication of transmission investment needs between nodes |
| + | Congestion income would be removed from TSOs |
| - | EU MCO may gain too dominant position in Europe |
| - | Central European market coupling function may be difficult to operate |
| - | No de-coupling option |
| - | Needs European legislation |

Structure




Source Karas and Sulama (2013)