D2.3 Report on the empirical case study analyses emphasising the challenges in the very short-term, short-term and long-term electricity markets in Europe with high shares of RES-E penetration

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Executive summary

Considering the recent supply mix shifts from fossil-fuel generation to renewable generation and the desire to improve energy security and economic efficiency, analyzing the design of the current integrated European electricity market that was designed based on technologies and policy objectives of the 1990s and investigating whether it is still well-optimised becomes key. Renewable sources of energy present in fact unique characteristics that create unique challenges in an Energy-only market, and influence the performance and outcomes of electricity markets.

This report assesses empirically the challenges and issues for the short-term, medium and long-term electricity markets through a selection of case studies that cover three different market regions with different RES-E penetration levels in the European electricity market (the Nordel system, Central-Western European system and the Iberian system).

The analysis reveals that with increasing shares of RES-E:

- **average spot and futures prices tend to fall** (phenomenon that can be explained by the "merit-order effect"). There appears to be a positive correlation between price trends and RES-E share percentage, though other factors are also important in setting spot and futures prices;
- **negative prices occur more frequently** on the spot market due to the intermittency of these energy sources. Germany for instance experienced 297 hours of negative prices on its day-ahead market (EPEXSPOT) since 2008, hitting a low of -500 €/MWh in 2009. Three major elements can explain the occurrence of negative prices: the high production subsidies and the lack of appropriate market incentives to address negative market prices, the limited flexibility of conventional power plants, the must-run conditions of conventional power plants;
- **price volatility tends to increase**;
- **RES-E curtailment is sometimes needed** to manage oversupply and system security. Spain in particular makes extensive use of curtailment due to its high wind production levels, lack of interconnection to neighboring markets (particularly France and Portugal), must-run conditions of some non-RES units, and low demand levels at off-peak times.

When looking at the impact of market coupling on electricity prices, it can be noticed that:

- **market coupling optimises the spot prices** and flows between interconnectors since generators benefit from increased export capacity and consumers from more import capacity. Moreover, there is a noticeable convergence of average monthly and yearly futures prices after the CWE market coupling announcement. Market coupling must however be paired with sufficient interconnection capacity to realise its full effect;
- **volatility on the spot markets increases when interconnectivity is low** and real price volatility decreases only come with huge investments in infrastructure. On the futures market, the analysis revealed that monthly futures price volatility within and between countries in the Central-Western European (CWE) region decreases after the market coupling in September 2010;

- **Interconnection capacity in addition to flexible operation units can help promote spot price stability** during high production periods. Increased RES-E with more interconnections tends to lead to lower and more stable prices. Higher interconnection capacity and average export volumes leads to lower monthly futures prices.

Finally, the analysis of nuclear maintenance and phase-out events and of the relationships of commodity prices reveals that:

- **building interconnection capacity is a key to ensuring security of domestic supply and stable spot price levels** during low production periods. The announcement of the shutdown of a nuclear plant temporarily drives yearly futures prices up, but other factors such as higher shares of RES-E and the possibility to import cheaper energy from neighbouring countries through interconnectors play a greater role in influencing prices in the long term;
- if there is some **observable correlation between the TTF Gas prices and the day-ahead market prices**, at least for the Netherlands, the correlation between the European Brent oil prices and day-ahead market prices is nearly not existent. Monthly futures natural gas prices are mostly positively correlated with the monthly futures power prices.

The last section of the report examines best practices in international markets of relevance and with transferability potential to the European market. Measures such as advanced RES-E forecasting techniques, wind participation enablement and shorter dispatch intervals for the short-term markets can be found in the United-States, California and Australia respectively to address the increasing renewable shares. Measures in the United-States to address market coupling and increase economic efficiency include nodal pricing systems, complex bids possibilities and the pool type trading system. Security of supply is addressed in California and Brazil through specific capacity remuneration mechanisms and in India through a pricing system linked to frequency.

To conclude, several measures can be used to better adapt markets for the modern environment such as increasing interconnection capacity, demand-side response, increasing the flexibility of the system, improving forecasting techniques and optimizing the interplay of intraday, balancing and day-ahead markets.

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Abbreviations

CWE	Central Western European
DAM	Day-ahead market
ENTSO-E	European Network of Transmission System Operators for Electricity
EPEXSPOT	European Power Exchange
FANC	Federal Agency for Nuclear Control
IDM	Intra-day market
MOE	Merit order effect
RE	Renewable energy
RES-E	Renewable energy sources for electricity
SWE	South-Western Europe

1 Introduction

Over the past decade, European electricity markets have undergone paradigm shifts. Markets of the past were designed around centralised fossil-fuel generation along national or regional borders. Now these individual markets shall be integrated into one single European electricity market with high shares of renewable generation. These changes give reason to contemplate the design of the current integrated European electricity market and investigate whether it is well-optimised for the evolving European energy environment.

The aim of this report is to assess the current status of the European integrated electricity market with respect to renewable penetration trends and other major events that are or have taken place on the market. The challenges and issues for the short-term, medium and long-term markets are analysed through a selection of case studies that cover three different market regions in the European electricity market (the Nordel system, Central-Western European system and the Iberian system). Relevant indicators, for example, the ratio of market prices with fuel prices and their correlation with renewable trends are developed and compared over the years across different countries.

This report is organised as follows:

- Chapter 2 briefly outlines the project methodology.
- Chapter 3 analyses events happening on the very short-term and short-term markets (balancing, intra-day and day-ahead).
- Chapter 4 identifies trends and events on the long-term markets (futures markets).
- Chapter 5 summarises successful electricity market design elements from international markets with potential transferability potential to the European electricity market. Some best-practises and lessons learnt are recommended.
- Chapter 6 concludes the current discussion of this report
- Chapter 7 lists all referenced material

The work presented in this report (Deliverable D2.3) contributes significantly to the foundation of work carried out in the Market4RES project. The empirical analysis supports the theoretical and regulatory discussions and analyses from WP2 and strengthens their conclusions. Moreover, they serve as a basis for the analysis of potential (new) market designs in work packages 3 to 6.

2 Methodology

In order to identify current challenges and issues of very short-term, short-term and long-term markets, several countries were analysed spanning different market regions in the European electricity market with varying RES-E penetration. These countries include:

- Central Western European (CWE) Region: Germany, France, the Netherlands, Belgium
- Iberian Region: Spain, Portugal
- Nordic Region: Norway, Sweden, Denmark, Finland

The countries have been selected based on the availability of the data and the presence of partners of those countries in the consortium.

Historical data was gathered from January 2006 until 31 December 2014 where possible through desk research and the involvement of partners. Table 1 summarises the main data sources that were used:

Table 1. *Key market data sources used in this project*

Region/Country	Generation/Consumption data	Spot and Futures Data
Belgium	Elia, ENTSO-E	Belpex, ICE Index
France	eCO2mix, ENTSO-E	EEX, ICE Index
Netherlands	Tennet, ENTSO-E	APX, ICE Index
Germany	Fraunhofer, ENTSO-E	EPEXspot, EEX
Iberian region (ES, PT)	OMIE	OMIE, OMIP
Nordic region((NO, SE, DK, FI)	ENTSO-E	Elspot, Elbas

Note that the renewable energy sources in this report include solar thermal and photovoltaic energy, hydro (tide, wave and ocean energy), wind, geothermal energy and biomass (biological waste and liquid biofuels). Renewable energy from heat pumps is also included for countries where this information was reported.

Major historical events happening in EU markets were analysed and indicators developed.

The relevant cases have been classified into three different categories:

- Events linked to the changing environmental policy: increasing renewables uptake
- Events linked to improving economic efficiency of markets: market coupling and interconnections
- Events linked to security of supply: conventional supply changes

3 Very short-term and short-term market analysis

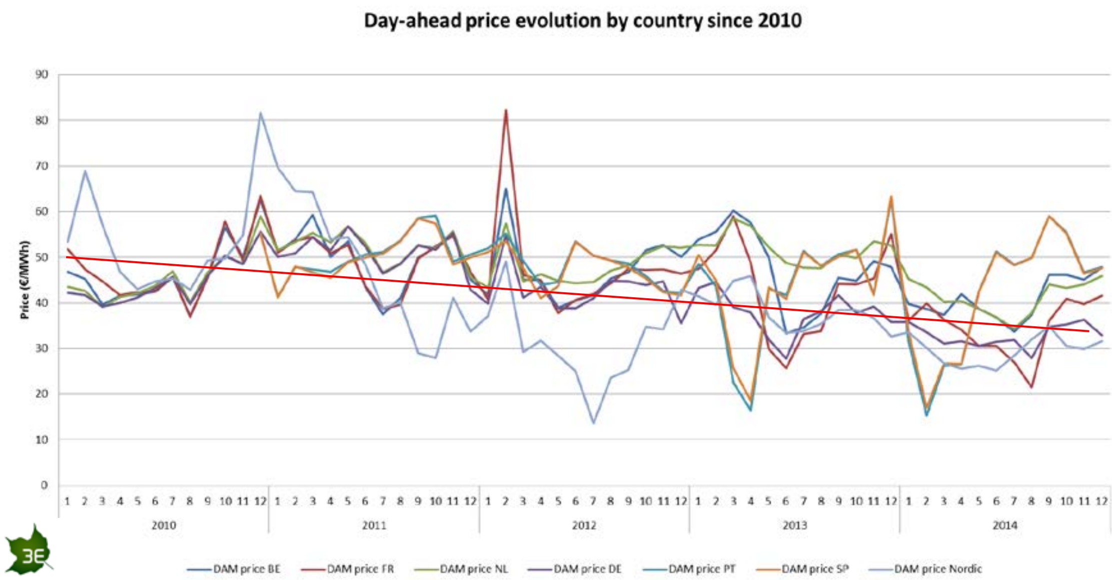
Price levels are influenced by several elements, such as the overall installed capacities compared to demand, the renewable energy share in individual country energy mix, and the capacity of interconnectors. As mentioned in deliverable 2.1, a major development shift in recent years has been the significantly increasing share of variable RES-E penetration in the electricity market.

In this chapter case studies on the falling electricity prices, negative short- term electricity price occurrences, RES-E curtailment, price volatility, price convergence, market coupling and increasing interconnections, nuclear shut-down and maintenance and the impact of commodity prices on the short-term markets, are analysed empirically and compared across the three market regions: the Central-Western European region, the Nordel region and the Iberian region.

3.1 Environmental policy: Increasing RES share

3.1.1 Case study 1: Falling electricity prices

Analysis of day-ahead market (DAM) prices of the countries studied confirms that there is on average a general trend towards falling electricity prices as illustrated in Figure 1.

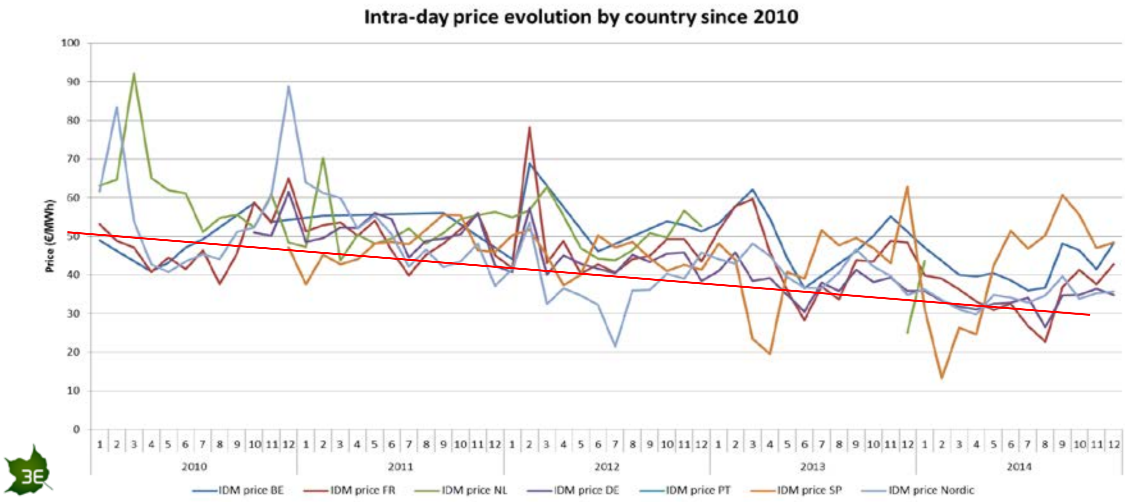


Source: APX, Belpex, Elspot, EPEXspot, OMIE

Figure 1. *Day-ahead market price evolution by country since 2010*

In the Central Western European region, the falling electricity prices on the spot markets have been most apparent in the Netherlands. Since autumn 2013, electricity prices on the Dutch market have dropped by nearly 30 percent, and in the first half of 2014, prices decreased by 11 percent. The DAM prices in Germany, Belgium and France have also decreased, but not as sharply. In the Nordel system, DAM prices decreased from January 2011 onwards.

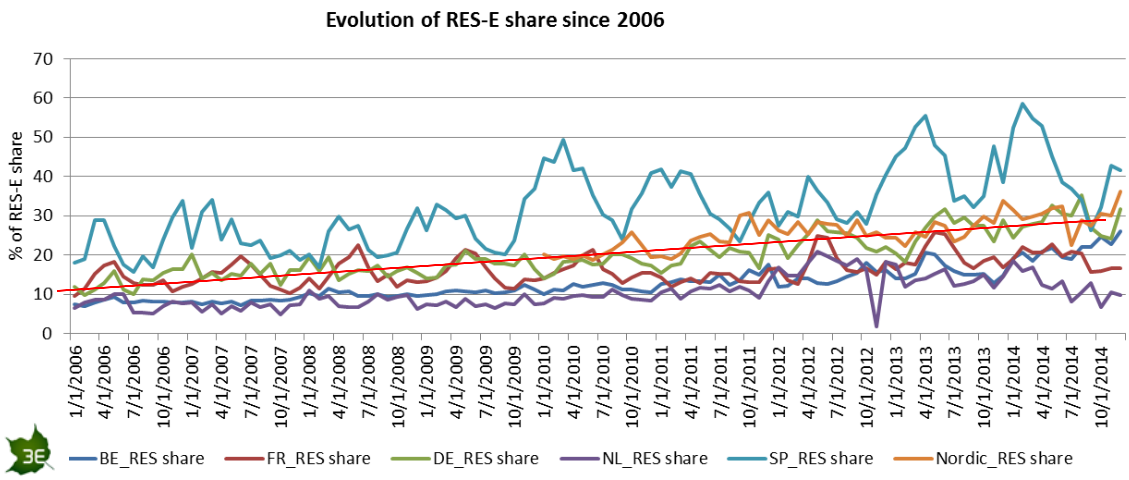
A similar pattern of decreasing price trends is seen for the Intra-day market (IDM) prices as illustrated in Figure 2.



Source: APX, Belpex, Elspot, EPEXspot, OMIE

Figure 2. *Intra-day market price evolution by country from 2010*

Simultaneously, domestic renewable energy share compared to total domestic electricity production has generally increased reaching back since 2006 as shown in Figure 3.

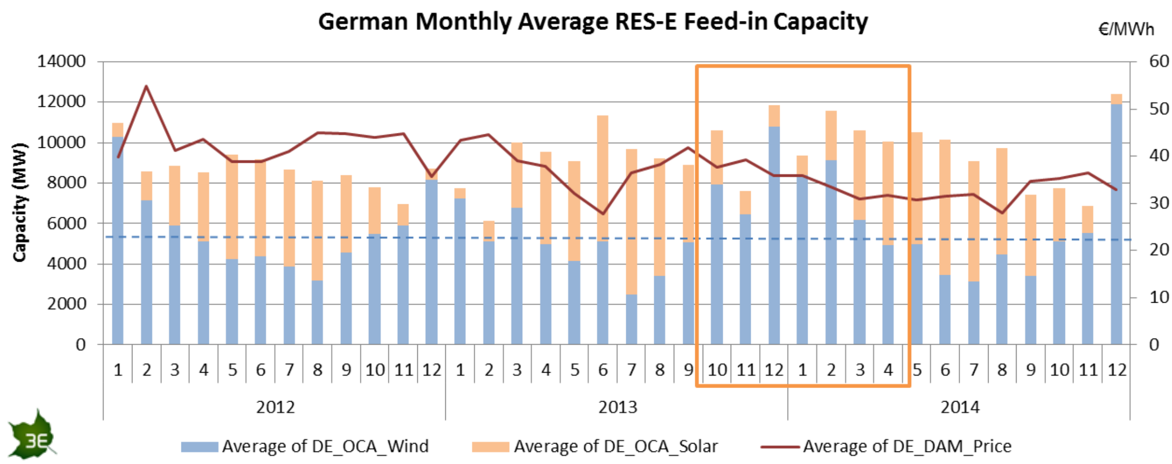


Source: ENTSO-E

Figure 3. *Evolution of RES-E share since 2006*

The falling electricity prices, at least in the short term, can be attributed partly to a steady increase of RES-E penetration. The phenomenon can be explained by the "merit-order effect". Wind and solar generation can directly reduce wholesale market prices at close to zero variable costs. These energy contributions replace more expensive fossil-fuel electricity production. When a certain injection of RES-E is predicted with an almost zero marginal cost, the bid curve reverses, with renewables dispatched ahead of conventional generation effectively lowering wholesale market prices.

Rates of decrease in power market prices are less pronounced in some countries than others; this is mainly influenced by the specific supply mix of the country and interconnection capacity. Spot prices in Belgium for example, with around 50 % share of nuclear, are much more affected by conventional production and imports than RES-E production. In Germany on the other hand, the increased uptake of intermittent energy sources on the wholesale market is a significant driver for price developments. At the end of 2013 and in the first quarter of 2014, a high above-average injection of wind power units can be observed (see Figure 4), contributing to the price decrease in the German market. In April and May 2014, higher-than-average solar radiation led to higher injection of solar photovoltaic power.



Source: Fraunhofer, EPEXspot

Figure 4. *Monthly average RES-E feed-in capacity in Germany*

In Table 2 a summary of the RES-E share increase in 2014 compared to 2006 (except in the Nordel system, where the comparison is done relative to year 2010 due to data availability), and the DAM price decrease in 2014 compared to 2006 is stated.

Table 2. *Share of RES-E compared to Day-ahead price decreases*

Trends	Belgium	France	Germany	Netherlands	Nordic	Iberian
RE share % (2006) *Nordpool (2010)	8.0%	13.4%	13.2%	7.6%	20.7%	22.9%
RE share (2014)	21.4%	19.3%	28.7%	12.3%	30.1%	43.1%
RE share % increase	**13.4%**	**5.9%**	**15.5%**	**4.7%**	**9.4%**	**20.2%**
DAM price €/MWh (2006) * Iberian (2010)	45.69	42.92	41.22	47.40	34.91	55.40
DAM price €/MWh (2014)	40.79	34.46	32.76	41.18	29.60	42.16
DAM price % decrease	**10.7%**	**19.7%**	**20.5%**	**13.1%**	**15.2%**	**23.9%**

Finally, Figure 5 compares the relationship of RES share percentage increase with DAM price increase for each studied country.

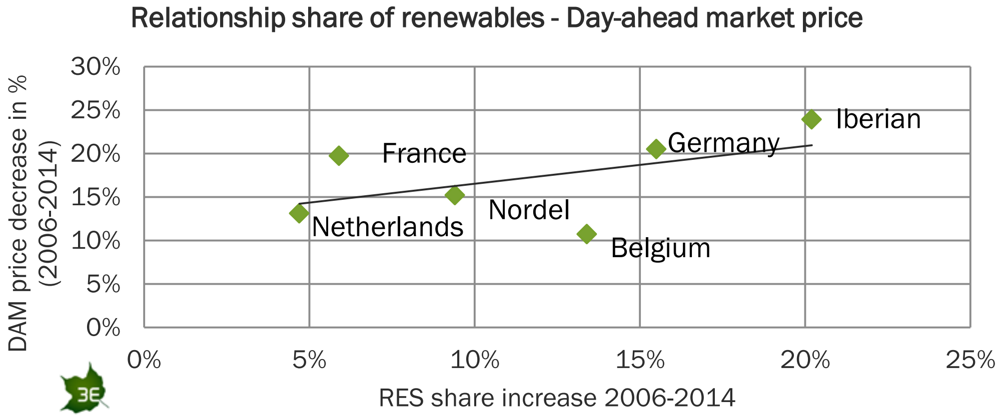


Figure 5. *Relationship between the shares of RES-E and the Day-ahead market prices*

There appears to be a positive correlation between price trends and RES share percentage. However, a causal relationship should not be ascertained too quickly. Prices are influenced by supply relative to demand at specific points in time and will only decrease if capacities are too high relative to demand or if the electricity mix and flexibility of the system do not correspond to the needs of the rising renewable shares and changing consumer patterns (Batlle et al., 2013). Renewable energy generation appears to be a key driver of the differences in wholesale spot prices, but this should be considered in relation to demand and export capacity which will be covered in later sections of this report.

3.1.2 Case study 2: Negative price occurrences

In recent years, several European electricity markets have seen that their prices turn negative when high shares of inflexible generation hit a low demand period. The price of electricity can become negative when the residual load (the total demand minus the production of electricity from renewable sources) is low. If export capacity is exhausted, then it may become necessary to reduce the production of base load power. However, it is usually quite expensive to stop and start-up these plants again. As a result, some producers may decide to continue to generate electricity with their base load power stations even selling at a loss since it is cheaper than stopping production temporarily. Renewable electricity producers, on the other hand, are generally less affected by negative prices as they sell their electricity at the purchase price and have low operational costs. They are also in many cases supported by subsidies, so they do not rely solely on revenue generated from the market.

Upward adequacy, i.e. the ability of power systems to meet peak demand, has historically been the point of attention of system operators, regulators and policy makers. However, downward adequacy, i.e. the ability of the system to cope with low demand periods is increasingly requiring attention in equal measures. Recent events have shown that system inflexibilities may lead to periods with excess power, challenging the operation of the power system. These inflexibilities include inappropriate incentive schemes for RES-E, not reflecting the needs of the system and market, priority dispatch and production support mechanisms, conventional generation facing techno-economic limitations in output variations, and must run conditions of power plants for system security reasons.

This issue is referred to as the "incompressibility of power systems" and is recently observed in Central Western European electricity markets such as Germany, France and Belgium, with hours showing negative electricity prices on day-ahead, intra-day and balancing markets (see Table 3).

Table 3. *Negative price occurrences in the period 2006-2014*

Period 2006-2014	Belgium	France	Germany	Netherlands	Nordic	Iberian
# hours of negative DAM prices	24	33	297	2	0	0
# hours of negative IDM prices	0	128	261	0	23	0
Lowest DAM value (€/MWh)	-200	-200	-500	-0.08	-37.65	-

Sources: APX, Belpex, Elspot, EPEXspot, OMIE

With the increasing share of RES-E such as wind and solar photovoltaic power, negative power prices are expected to become much more likely in the future due to the intermittency of these energy sources.

Different markets treat negative prices differently, some set a pre-defined price floor and others have no such intervention. For example, in Spain there are no negative prices and therefore no specific mechanisms to address it. In the Nordpool area, the price cap is -500 €/MWh. In the CWE area, the cap is -500 €/MWh. On the IDM, the floor for negative prices is -9999.9 €/MWh in the CWE region and 0 €/MWh in the Nordpool region. The extent to which these negative price limits should be extended or adjusted is unclear, but with higher shares of intermittent RES-E, some current price floor settings may be too low or the markets need to be evaluated to prevent such occurrences of very low prices. As pointed out by Eurelectric (2010), the lack of common market rules regarding negative prices will lead to distortions when joining bid offers in zones with different price boundaries (Glachant & Henriot, 2013).

While negative prices are mostly associated with an oversupply of wind energy, there are several additional structural reasons. In the German system, grid operators buy all renewable electricity in the electricity wholesale market regardless of price. Moreover, many plants on the system have limited flexibility and will only stop generating when negative prices are expected for a long period, since costs for ramping up and down the plant and the opportunity costs of minimum standstill times are more expensive than a short period of negative prices. Finally, plants must produce at a certain level to be technically able to offer balancing services when called upon (Andor et al, 2010; Brand-stätt et al, 2011). In the last week of December 2012 for instance, low demand in the holiday period together with high wind generation resulted in negative prices on the day-ahead hourly electricity market for Germany. Negative day-ahead prices dropped to nearly -222 €/MWh during the night of December 25th, and this problem reoccurred multiple times during the rest of that week.

Table 4 summarises the occurrences of negative prices in Germany for the period 2008-2014.

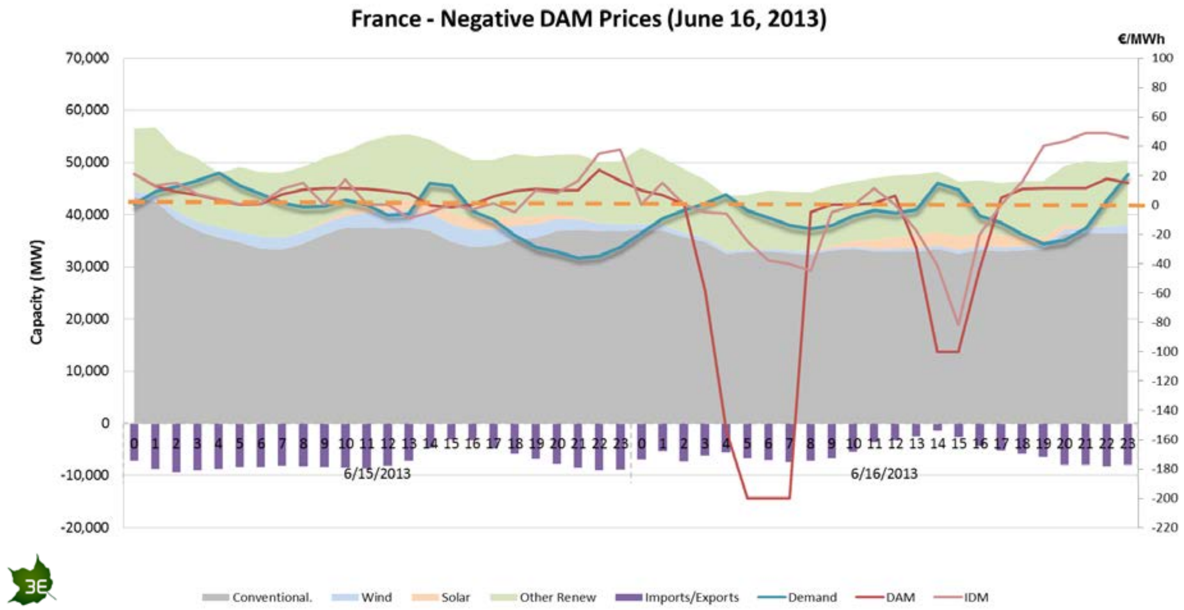
Table 4. *Negative price occurrences in Germany on the DAM in the period 2008-2014*

Year	2008	2009	2010	2011	2012	2013	2014
Number of hours	15h	71h	12h	15h	56h	64h	64h
Lowest price (€/MWh)	-101,52	-500	-20,45	-36,82	-221,99	-100,03	-65.03
Duration (hour)	1-6h	1-10h	1-3h	1-4h	1-9h	1-9h	1-10h
Most concerned months	October, December	May, October, December	January, March, December	January, February, December	January, December	March, June, December	March, May, December

Source: EPEXspot, CREG

In most countries, events where day-ahead market prices turn negative are nevertheless still rare. In the French day-ahead system for example, 56 hours with negative prices were observed in 2012, and these occurred over only 15 days. In Belgium, only 7 and 15 hours were observed in 2012 and 2013 respectively, in both cases for 3 days. Such events are nevertheless expected to increase in frequency in the years to come.

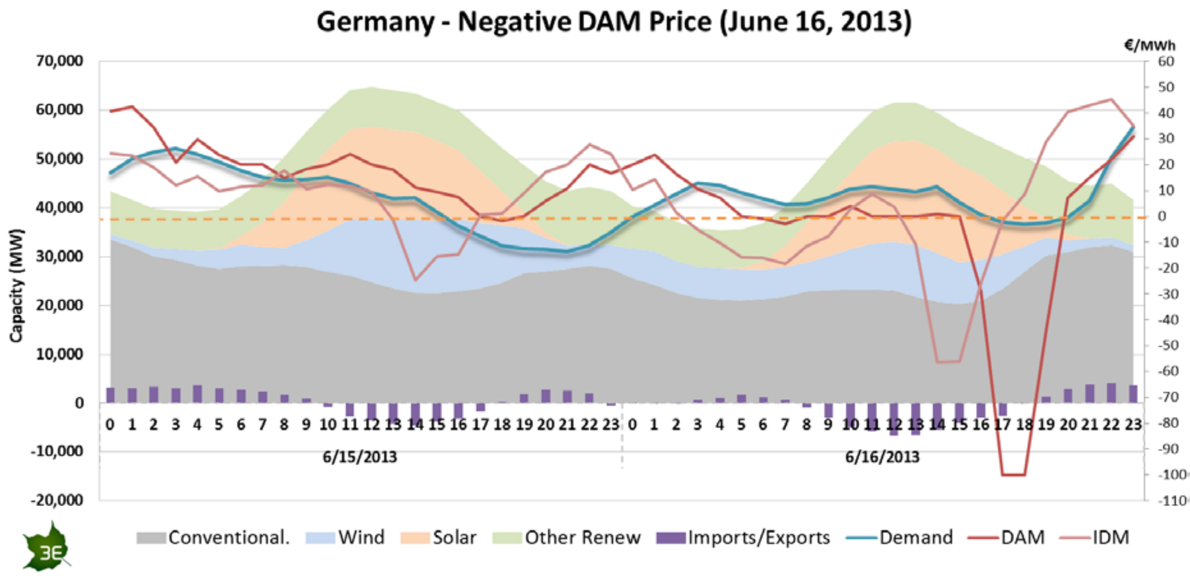
Since November 2010, negative prices have been permitted throughout the CWE region. In 2012, it was the first time that negative prices occurred in Belgium, France, the Netherlands and Germany simultaneously. This trend continued in 2013. In the weekend of June 15-16 2013 for instance, Belgium, Germany and France faced a regional low industrial and residential consumption on mild weather, and abundant inflexible generation driven by wind, PV, hydro and nuclear. As a result, France experienced a daily average price of -41 €/MWh and -20 €/MWh for base and peak demand periods respectively on the day-ahead market, and reached a minima of -200 €/MWh during the night as shown in Figure 6.



Source: EPEXspot, RTE, ENTSO-E

Figure 6. *Example of negative Day-ahead market price in France*

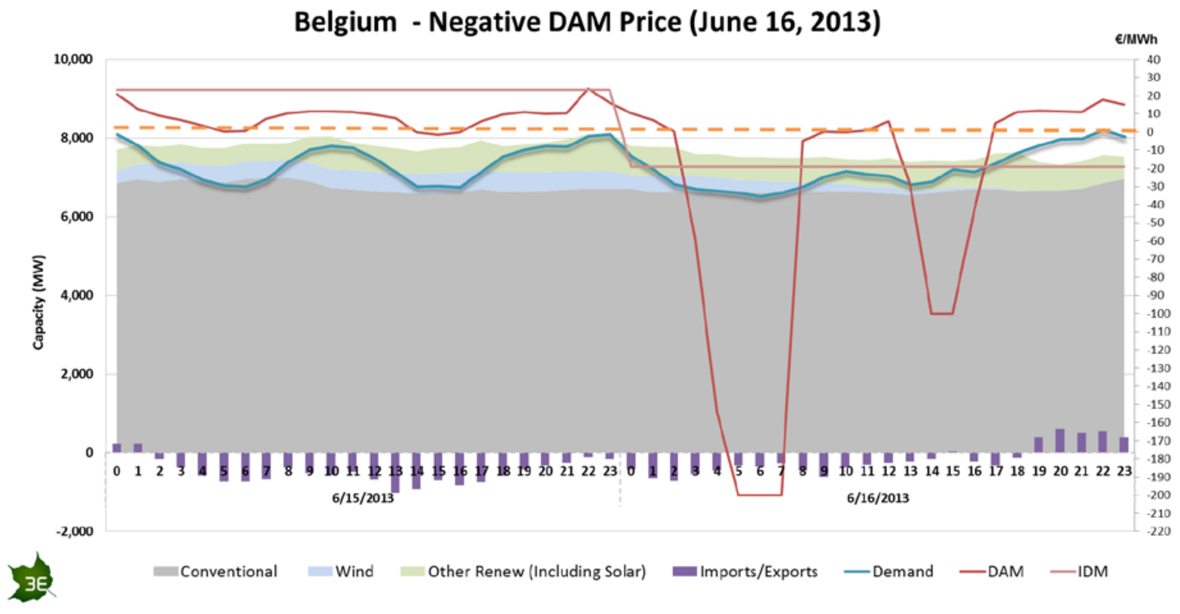
As the day-ahead electricity markets of France, Germany and Belgium are coupled, market prices are spread over the region, but they are buffered though by the available interconnection capacity. During the weekend of June 15-16 2013, average prices in Germany fell to roughly -20 €/MWh and 3 €/MWh for peak and base demand periods and reached a minima of -100 €/MW (see Figure 7).



Source: Fraunhofer, EPEXspot

Figure 7. *Example of negative Day-ahead market price in Germany*

Prices on the **Belgian** day-ahead market reached a low of -200 €/MWh on the same weekend (see Figure 8).



Source: Belpex, Elia

Figure 8. *Example of negative Day-ahead market price in Belgium*

In the Nordel system, negative prices occurred only a few times on the IDM during the 2006-2014 period. In the Iberian system, negative prices are not allowed, but zero-prices happened during 300 hours in Spain in 2010.

To sum up these observations, three major elements can explain the occurrence of negative prices (KU Leuven Energy Institute, 2014).

1. High production subsidies and the lack of appropriate market incentives to address negative market prices: they induce distorted price responsiveness of RES-E technologies, i.e. renewable generating units are willing to pay to inject power when not wholly needed.
2. Limited flexibility of conventional power plants: due to technological limitations such as start-up, shut-down and output ramping constraints. Negative prices can be avoided by incentivising the output control of must-run conventional generation sources or the reduction of minimum run levels of power plants. New sources of flexibility such as demand-response or storage technologies will likely play a larger role in the energy mix in the future for their flexibility advantages.
3. Must-run conditions of conventional power plants: in order to meet system security standards, conventional power plants have must-run conditions. To balance the prediction errors of RES-E, increase reserve capacity is needed. Improving forecast tools, or optimal sizing and allocation methodologies can alleviate this need.

To conclude, the occurrences of negative prices on the wholesale markets signal the need for more flexible electricity supply and demand through adaptation of systems components and reinforce the need for better integration of renewable generation sources to the power grid (Commission, 2014).

3.1.3 Case study 3: RES-E curtailment

"Curtailment" is an option that some system operators employ as a consequence of constraints in distribution and transmission grids to deal with overabundance of electricity production on the system. Electricity producers can also be shut down for certain periods of time to balance the grid and secure stability of the system when there is, for example, network faults. High RES-E generation coupled with low demand can create a need for curtailing renewable capacity. Curtailment results in economic losses, as the power that could be generated from RES-E at that time goes unused.

Table 5 below shows that Denmark, Portugal and Spain have maximum wind production levels that far exceed minimum consumption levels, indicating that generators in these countries are at a greater risk for curtailment. The "Penetration (%)" represents the maximum RES production level relative to the minimum consumption level. A maximum penetration level above 100 % indicates that renewable production could conceivable exceed demand levels and there would be a need to curtail, export or store part of the renewable energy generated in such a case.

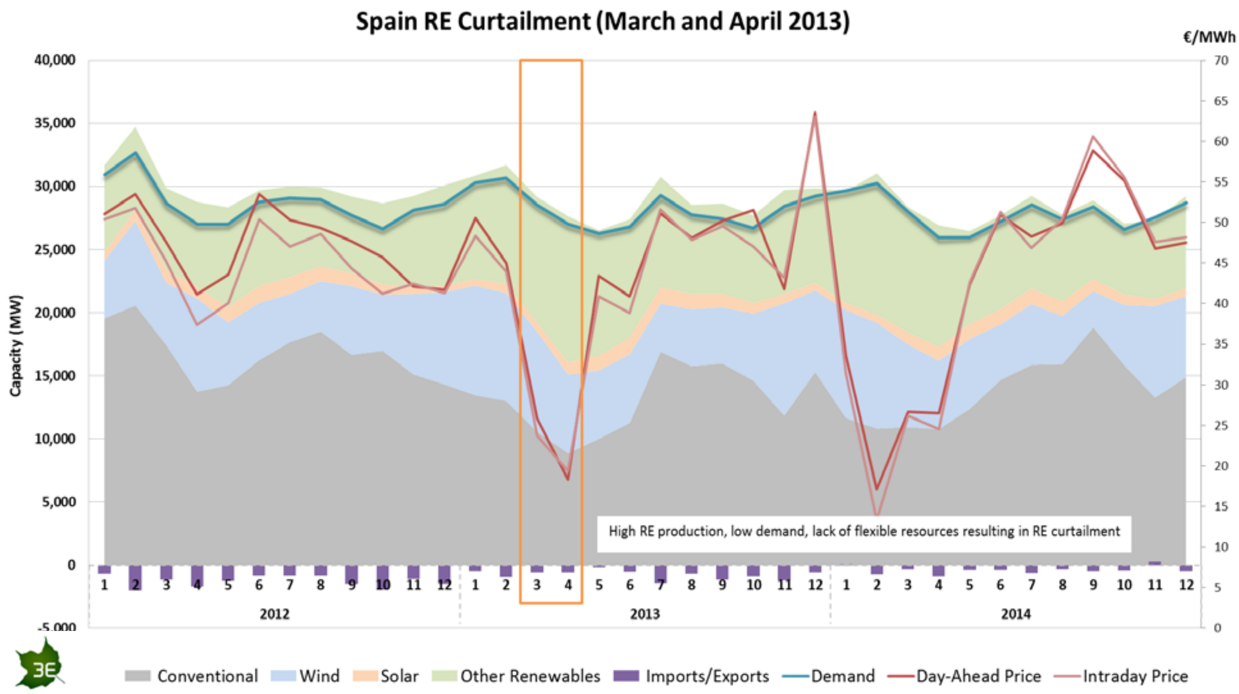
Table 5. *Renewable production relative to consumption levels (based on ENTSO-E data 2013)*

	Wind				
	Capacity (GW)	Max. production level (TWh)	Min. consumption level (TWh)	Penetration (%)	
				mean	max
Denmark	4.2	10.3	5.15	30	200
Portugal	4.2	10	7.86	20.4	127.3
Spain	22.4	48.5	38.3	18.2	126.6
Germany	30.9	46	47.8	8.5	96.3
Belgium	1.3	2.9	13.8	3.4	21

Spain in particular makes extensive use of curtailment due to its high wind production levels, lack of interconnection to neighboring markets (particularly France and Portugal), must-run conditions of some non-RES units, and low demand levels at off-peak times.

Even though RES-E has priority dispatch provisions in Spain, some non-RES units must be necessarily dispatched due to security or system constraints. Therefore, at any given time, the maximum RES-E production that can be fed into the system is limited. When RES-E available is higher than this limit, curtailment actions must be undertaken by the System Operator to maintain system security.

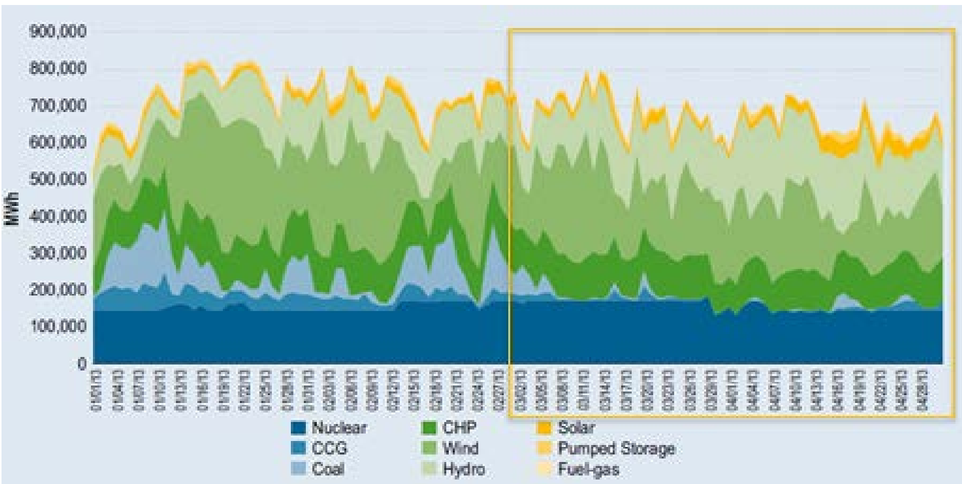
Since 2008, excess generation has already been observed in the day-ahead market when prices equaled zero and generation exceeded day-ahead demand. Figure 9 and Figure 10 show the lack of (scheduled day-ahead) flexible resources in March and April 2013, resulting in the curtailment of RES-E producers.



Source: OMIE

Figure 9. *Occurrences of RES curtailment in Spain*

Scheduled day-ahead generation by technology (Jan-April 2013) (MWh)



Source: CNMC

Figure 10. *Lack of flexible day-head generation in March and April 2013*

RES-E curtailment events have also happened several times in Germany, where wind power generation is important. Network congestion is managed by the national or regional TSO and curtailment is usually considered as a last resort measure that can be taken to ensure system security and safety in times of high production and low demand periods.

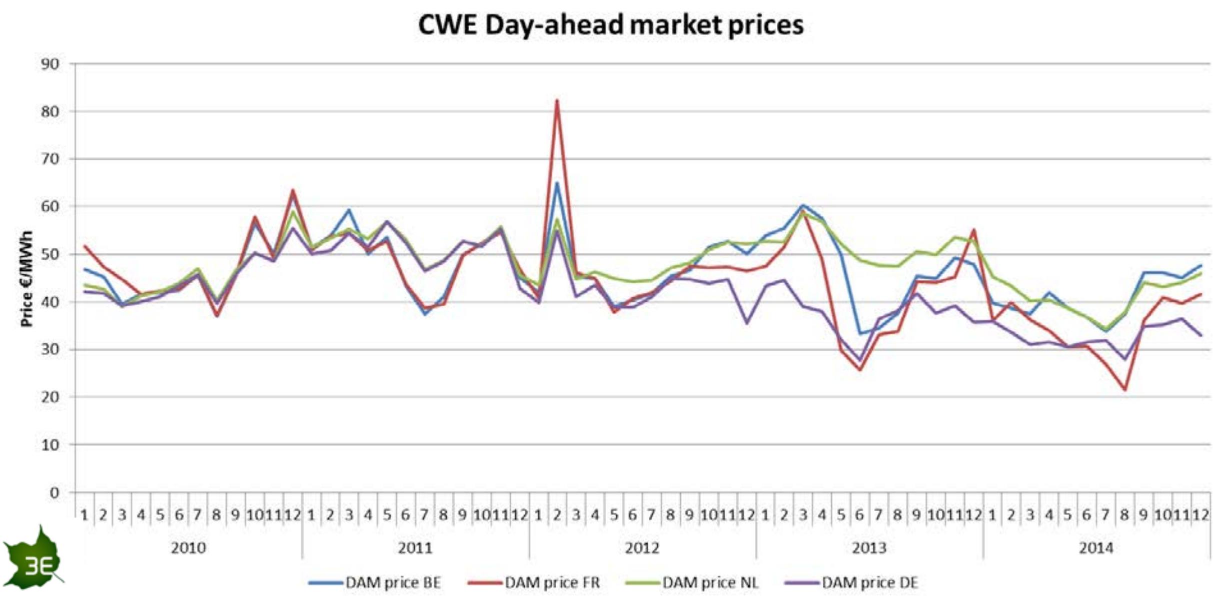
With higher RES-E integration in the market, curtailment will likely happen more frequently in some markets. In the future, balancing markets will likely play an increasingly important role. As argued by Glachant (Glachant & Henriot, 2013), the joint operation of balancing markets with other markets like the day-ahead market will become a key source of efficiency. Further, intraday markets and real-time balancing markets which allows trading after the day-ahead gate-closure, should gain in importance as the share of intermittent RES-E increases and there is a need to balance markets closer to real time at all hours of the day.

Moreover, some changes might have to be made to the present market design. In particular, Eurelectric argues that wind generators should be subject to the same scheduling and balancing obligations as conventional power plants. The share of wind power is reaching such levels that they should not be considered as neutral passive units: renewables must operate as other power plants and participate in maintaining power system stability.

3.2 Economic efficiency: Market coupling and interconnections

3.2.1 Case study 4: Market coupling and price convergence

In November 2010, the Central Western European Market Coupling (CWE) was launched, replacing the Trilateral Market Coupling of 2006. Despite the CWE market coupling, which theoretically implies that there can only be a price difference between the coupled markets when the capacity is fully utilised, prices seem to have followed a diverging path since 2012, as illustrated in Figure 11.



Sources: APX, Belpex, EPEXSPOT

Figure 11. *Day-ahead market price convergence during the period 2010-2014*

Significant decrease of price convergence occurred late 2012, when the convergence between Germany and France strongly decreased (except in April 2013). In fact, the percentage change in DAM price correlation between the period 2010-2011 and 2012-2014 in Table 6 clearly shows that the correlation of DAM prices in the period after 2012 was lower than in the period 2010-2011 in the CWE region. A negative value reflects a decrease in correlation.

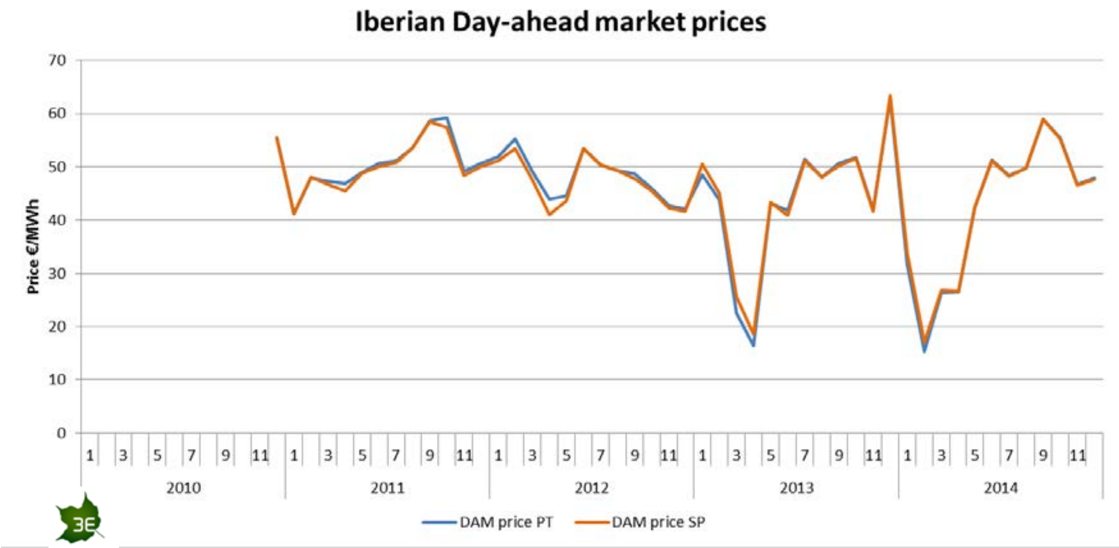
Table 6. *Percentage change in day-ahead price correlation between 2010-2011 and 2012-2014*

% change in correlation	Belgium	France	Netherlands	Germany	Portugal	Spain
BE	-	-	-	-	-	-
FR	-12.64%	-	-	-	-	-
NL	-2.23%	-0.17%	-	-	-	-
DE	-17.20%	19.66%	-41.33%	-	-	-
PT	73.26%	124.68%	75.57%	156.55%	-	-
SP	80.97%	124.51%	81.15%	149.71%	0.17%	-
Nordic	46.42%	4.06%	195.90%	73.25%	64.62%	64.98%

Price convergence patterns can vary within regions. Between Belgium and the Netherlands, and also between France and Germany, there are a high number of hours with full price convergence. For Germany and the Netherlands this is much lower. Converging prices between France and Germany in the summer months is a known seasonal pattern.

As shown in Table 6, DAM prices in the Nordic countries are more correlated to the DAM prices in the Netherlands for the period 2012-2014 compared to 2010-2011. A possible explanation is the availability of the new NorNed cable in 2014 connecting the Nordel system to the Netherlands.

In the Iberian market, day-ahead market prices have followed a steady trend; with the exception of an increasing number of up and down spikes from the end of 2012 (see Figure 12). The DAM prices in the Iberian region are much more correlated to the French and German DAM prices in the period 2012-2014 compared to the period 2010-2011, as illustrated in Table 6. This can be explained by the SWE market coupling that took place in 2014.



Source: OMIE

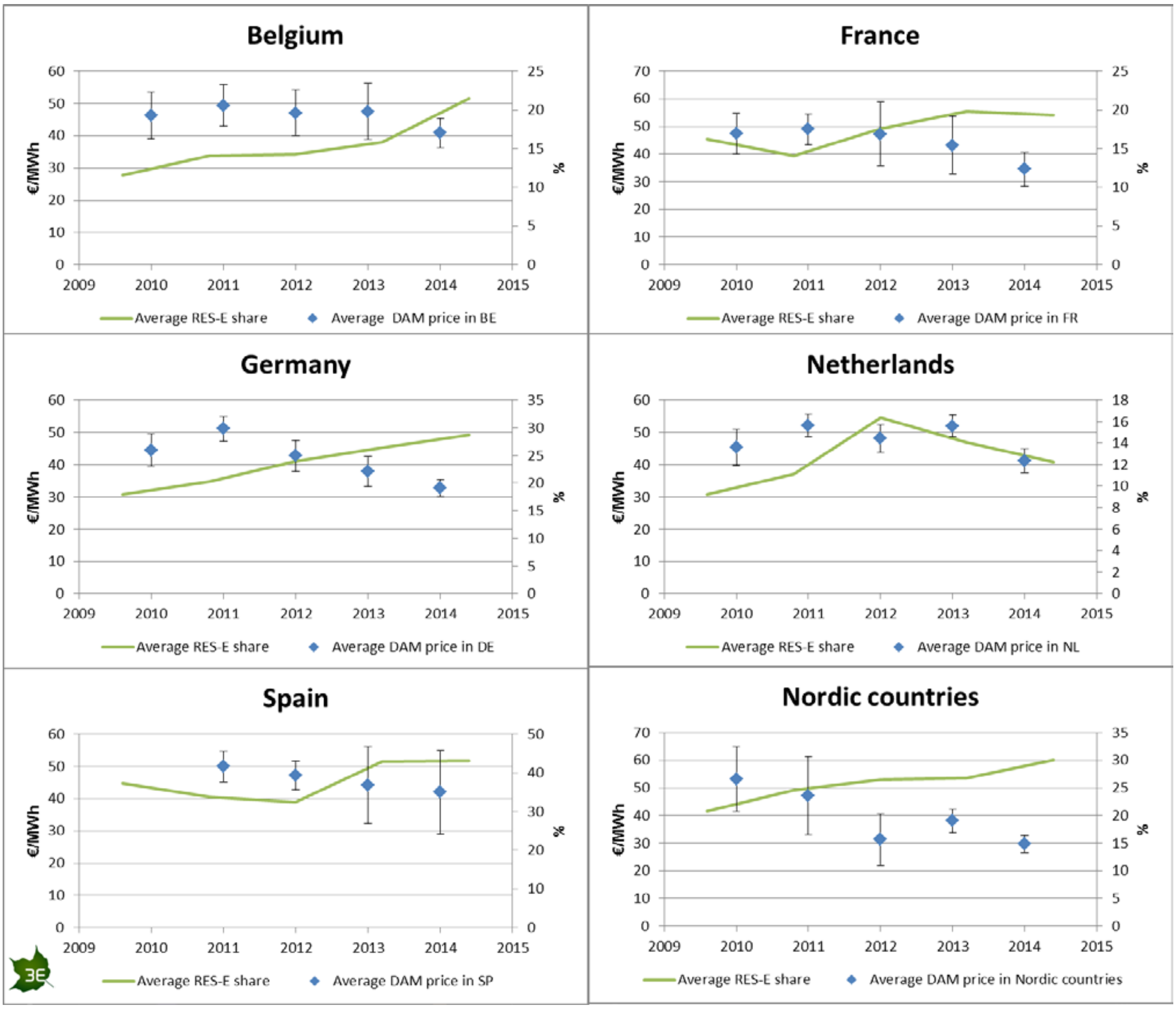
Figure 12. *Day-ahead market prices in the Iberian markets*

Market coupling optimises the prices and flows between interconnectors since generators benefit from increased export capacity and consumers from more import capacity. Economic efficiency is increased since lower cost generators are able to substitute higher cost generators in connected areas (consumer in initially lower cost areas do not benefit though).

3.2.2 Case study 5: Market coupling and price volatility

Volatility captures the amplitude of price movements for a given period of time. In general, price volatility depends on a large number of parameters such as fuel prices, availability of generating units, hydro generation production, demand elasticity and variations, network congestion and management rules of any specific electricity market. In this report, volatility is measured in terms of standard deviation, reflecting the degree of deviation of any individual price compared to the average price of the year. A low standard deviation corresponds to more stable price fluctuations, whereas a large standard deviation reflects high price fluctuations.

Figure 13 shows that DAM price volatility decreased in all CWE countries in 2011, after the CWE market coupling, but increased again in 2012 to stay steady or decline in 2013. In 2014, DAM price volatility decreased in all CWE markets except in the Netherlands. In Spain, DAM price volatility increased since 2012, whereas the Nordic countries saw the volatility of their DAM prices drastically decrease since 2011.



Source: APX, Belpex, Elspot, EPEXspot, OMIE, ENTSO-E

Figure 13. *Volatility of the base load price on the Day-ahead market*

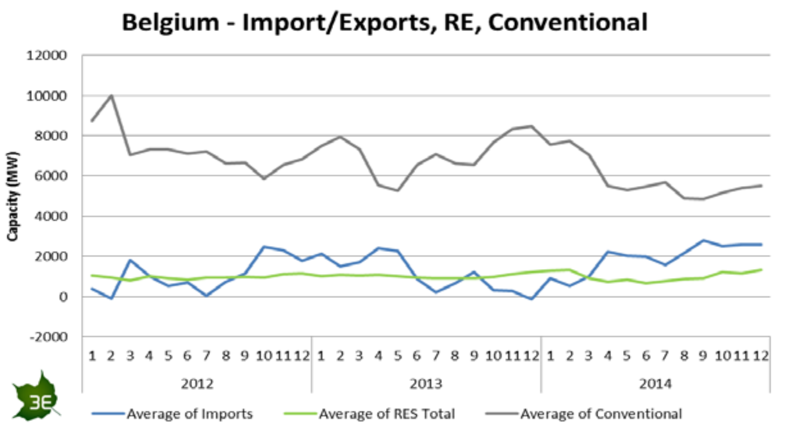
Though there is no clear correlation between the share of RES-E penetration and the DAM price correlation, it can nevertheless be concluded that volatility increases when interconnectivity is low (see Spain) and real price volatility decreases only come with huge investments in infrastructure (see Nordic countries). In the Nordic markets, short-term variations in the price of electricity have lowered as the share of easily regulated hydropower has increased.

Price volatility can be managed through more flexible system operations. In countries with a high share of intermittent RES-E, like Germany or Spain, there are already requirements for fault-ride through capacity provision of reactive power, frequency and voltage control, and incentives to minimise deviations exist. In Germany the provision of these services has become mandatory for new power plants. In Spain, there are financial incentives that drive the provision of these services (Glachant & Henriot, 2013).

3.2.3 Case study 6: Interconnection capacity and price stability

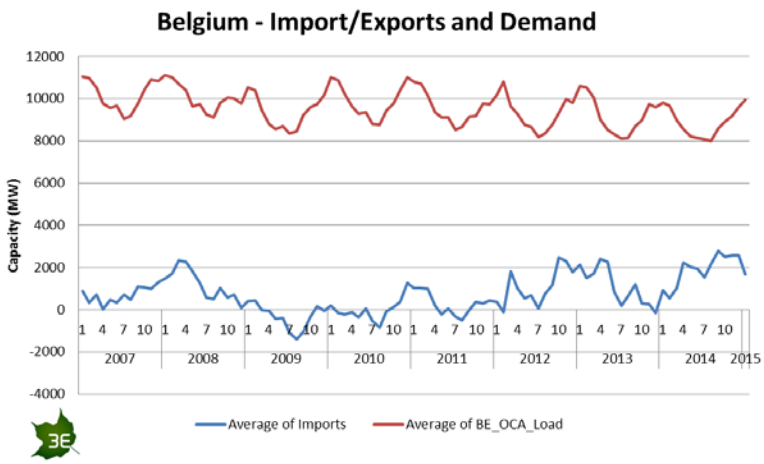
Interconnection capacity in addition to flexible operation units can help promote price stability during high production periods. Depending on the supply mix of a country and its existing interconnection capacity, interaction between imports, conventional and renewable production will vary.

In Belgium for example, imports are inversely correlated to the average production of conventional electricity (see Figure 14 and Figure 15)



Source: Elia, ENTSO-E

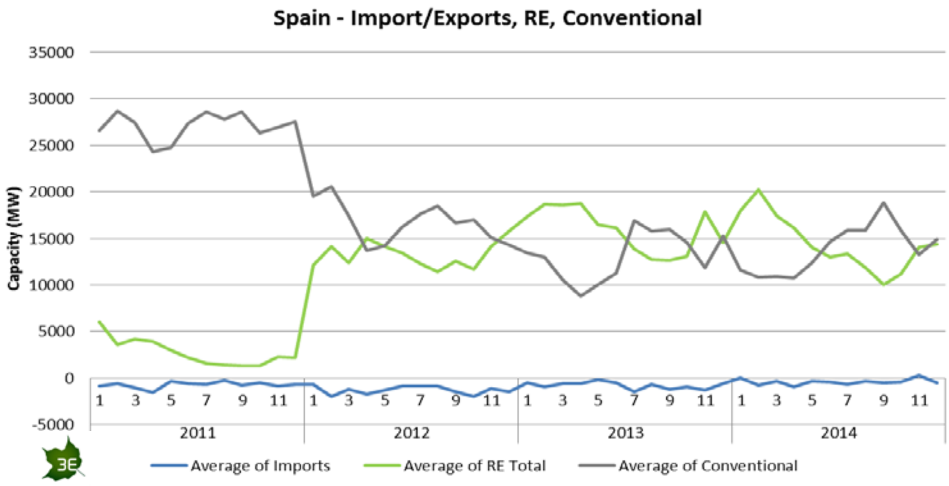
Figure 14. *Net imports, RES-E generation and conventional generation in Belgium*



Source: ENSTO-E

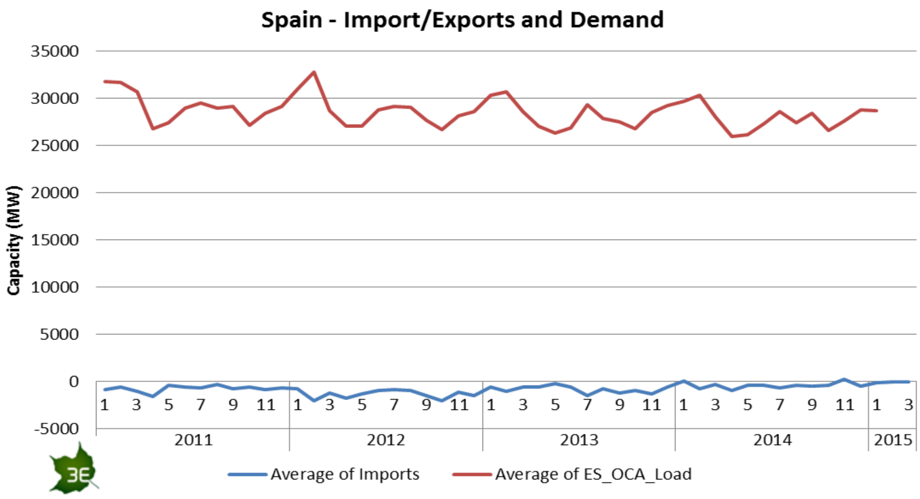
Figure 15. *Net imports and average electricity demand in Belgium*

Spain on the other hand has very limited interconnections and the average net imports do not seem to vary with changes in RES-E or conventional generation. When the production of RES-E increases, it is the conventional generation that is adapted or vice versa, as shown in Figure 16 and Figure 17.



Source: OMIE, ENTSO-E

Figure 16. *Net imports, RES-E generation and conventional generation in Spain*



Source: OMIE, ENTSO-E

Figure 17. *Net imports and average electricity demand in Spain*

As illustrated by the CREG (CREG, 2014), two markets will have the same price when the interconnection capacity between markets is not saturated.

- BE ≠ FR ≠ NL: two interconnections are saturated (congestion), therefore three different prices are in Belgium, France and the Netherlands
- FR = BE ≠ NL: interconnection with the Netherlands is full (congestion), resulting in the same price in Belgium and France, but a different price in the Netherlands;

- FR=DE=NL=BE the interconnections are not saturated in the CWE (no congestion), the same price is found throughout the CWE region.

In the Netherlands for instance, the NorNed subsea cable that was fully available in the first half of 2014 has contributed to more stable and lower prices as it enables the Netherlands to import large quantities of cheaper electricity produced by Norwegian hydropower plants. This development is a major factor explaining the price decrease on the Dutch market as mentioned in Section 3.1.1.

Table 7 shows that interconnection capacity relative to production is particularly low in Spain and Portugal, meaning there is little ability to export excess variable RES-E. The Nordic market in contrast, has high RES-E share and also high relative interconnection capacity.

Table 7. *Interconnection capacity and Day-ahead market prices*

Markets	% of installed electricity production capacity (2014)	RES Share (%) 2014	Avg price level €/MWh (2014)	Standard Deviation (2014)	Standard Deviation (2010)
Belgium	17	21.4	40.8	4.50	7.23
France	10	19.3	34.5	6.11	7.33
Germany	10	28.7	32.8	2.49	4.96
Netherlands	17	12.3	41.2	3.69	5.49
Nordic	33	30.1	29.6	3.20	11.61
Iberian	5	43.1	42.0	13.27	N/A

Therefore, as implied in Figure 18, more RES-E with more interconnections tends to lead to lower and more stable prices. The Nordic market has high RES-E shares, but low price variability because of its relatively high interconnection capacity, whereas Spain and Portugal have high price volatility due to high RES-E production and relatively low interconnection capacity to export excess electricity production.

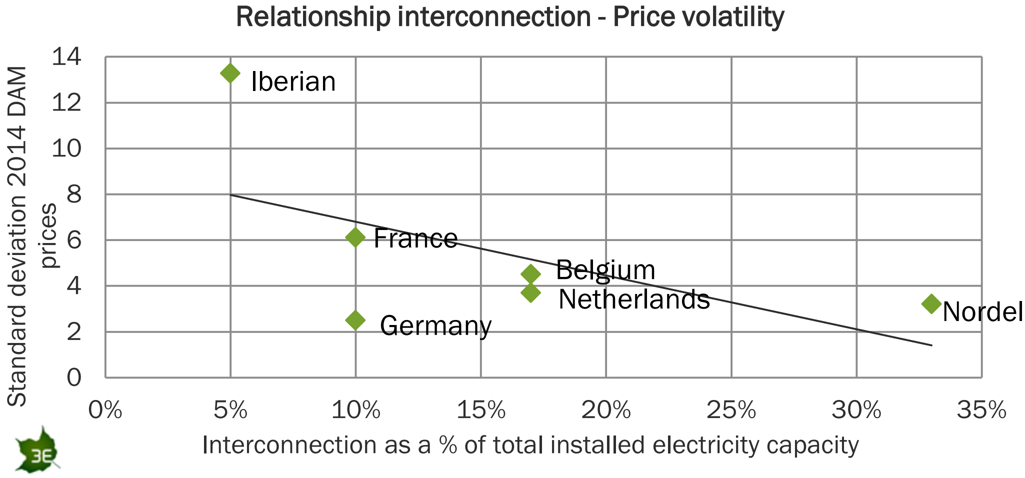
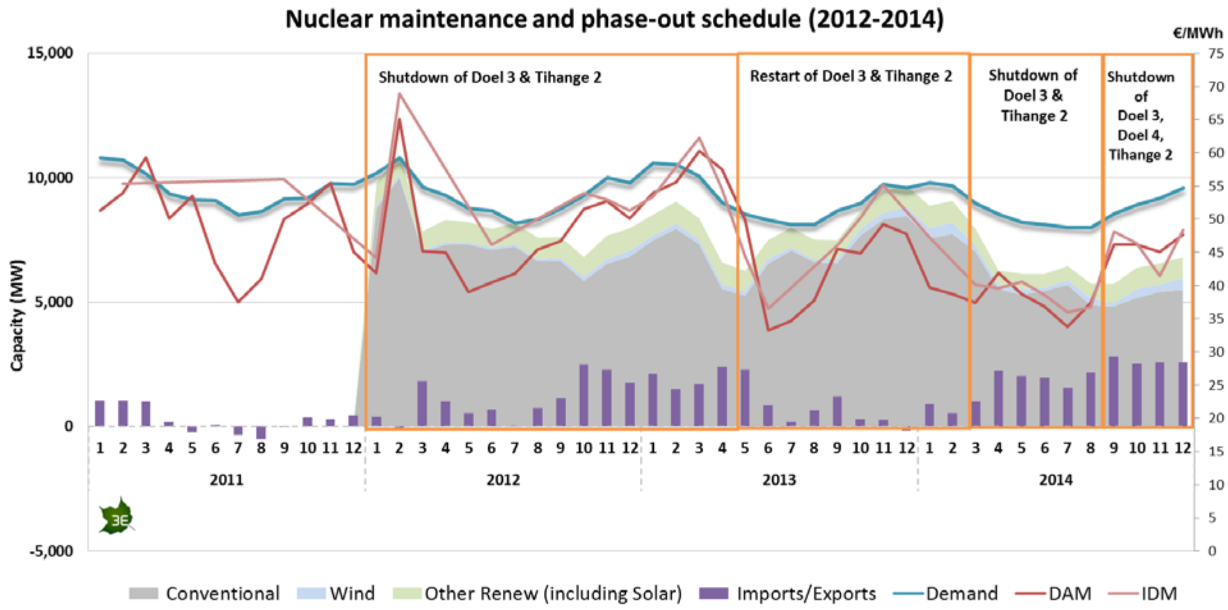


Figure 18. ***Relationship between interconnection capacity and volatility***

3.3 Security of supply: Conventional supply changes

3.3.1 Case study 7: Nuclear maintenance and phase-out events

Building interconnection capacity is also a key to ensuring security of domestic supply and stable price levels during low production periods. The shutdown for maintenance of the nuclear reactors in Belgium Doel 3 and Tihange 2 in 2012 and Doel 3, Doel 4 and Tihange 2 in 2014 (see Figure 19) clearly shows that the increase import needs are correlated with nuclear shutdown schedule. Imports appear to be a key source of capacity to replace lost nuclear capacity. Moreover, price volatility during nuclear shutdown periods is notable. The price levels are likely to be dependent on a variety of factors including the cost of substitute generation or non-generation options during nuclear shutdown periods and spot prices in neighboring countries.



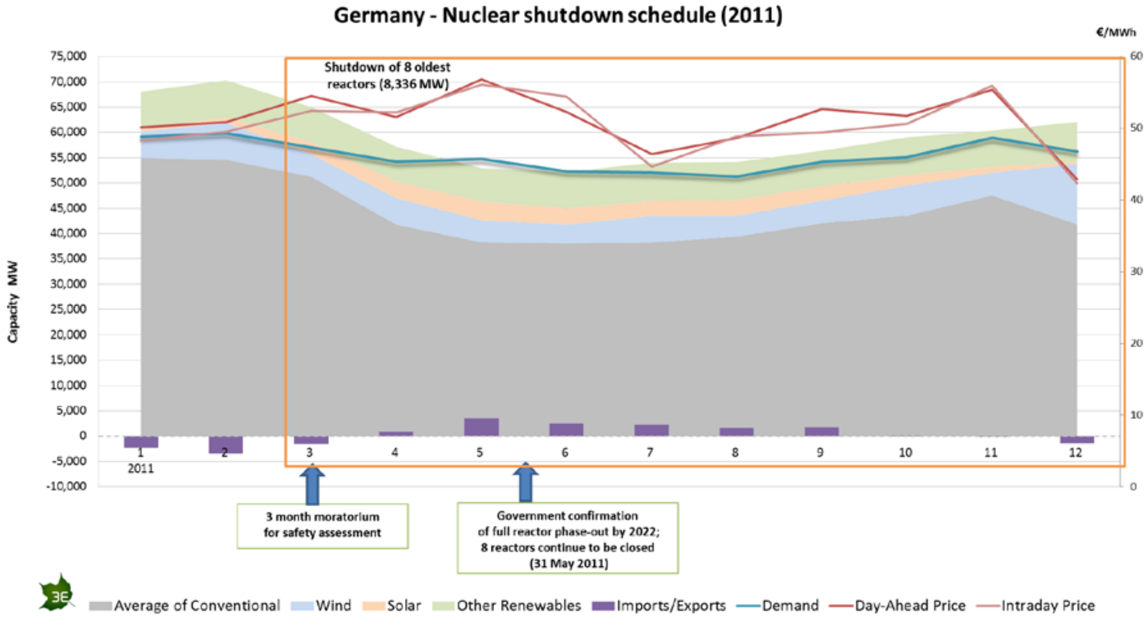
Source: World Nuclear Association, Belpex, Elia

Figure 19. *Nuclear maintenance in Belgium*

The CREG (CREG, 2014) hypothesizes is that Belgian's nuclear shutdown schedule and the need for increase imports is one cause for spot price volatility in Belgium, France, Germany and the Netherlands. Divergence in country prices is particularly noted in 2014, during a tight supply period for Belgium, with the shutdown of Doel 3, 4 and Tihange 2.

In Germany, a similar trend can be noticed. In March 2011 the government declared a three-month moratorium on nuclear power plants. The nuclear power reactors, which began operation in 1980 or earlier, were closed and were joined by another unit already in long-term shutdown, making a total of 8336 MWe offline under government direction, about 6.4 % of the country's generating capacity. As a result, the import needs increased and less capacity for exports was available after the nuclear shutdown.

Both houses of Parliament approved construction of new coal and gas-fired plants. This policy of replacing nuclear power with extra fossil fuel capacity and vastly expanding highly-subsidised renewables is known as the "Energiewende".

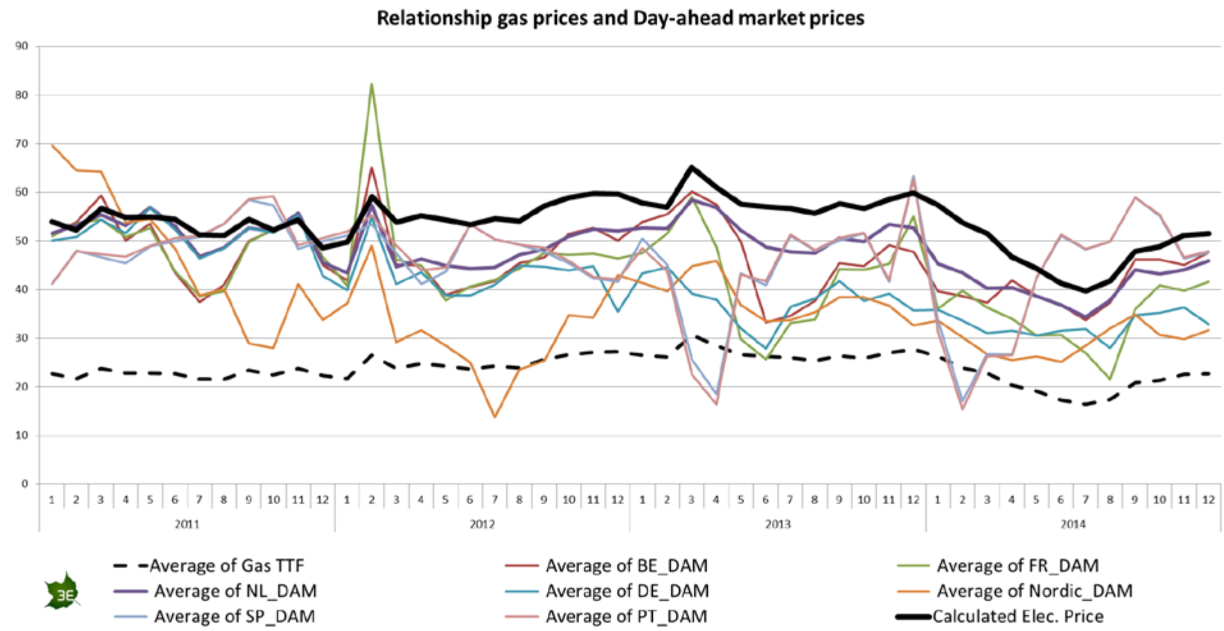


Source: World Nuclear Association, Fraunhofer, ENTSO-E, EPEXspot

Figure 20. *Nuclear shutdown schedule in Germany*

3.3.2 Case study 8: Commodity price relationships

In the Netherlands, gas-fired power plants account for a large proportion of Dutch electricity production facilities. As a result, the declining prices of gas quickly translate into significantly reduced electricity prices in the Netherlands. The same is true though to a lesser extent for Belgium. This can be seen in Figure 21 hereunder. If there is some observable correlation between the TTF Gas prices and the day-ahead market prices, at least for the Netherlands, the correlation between the European Brent oil prices and day-ahead market prices is nearly not existent (see Table 8). A plausible explanation for this is that oil is not usually considered a direct substitute for electricity and there is little oil used in the current production of electricity.



Sources: APX, Belpex, Elspot, EPEXspot, OMIE, ICE Index, EEX

Figure 21. *Correlation between commodities prices and Day-ahead market prices*

Table 8. *Correlation between commodities prices and Day-ahead market prices*

Correlation prices with: DAM	Belgium	France	Germany	Netherlands	Nordic	Spain	Portugal
Brent Oil (2010-2014)	0.10	0.07	0.13	0.34	-0.30	-0.03	-0.01
TTF Gas (2010-2014)	0.38	0.24	0.06	0.68	-0.23	-0.25	-0.26

Electricity prices are linked to gas prices through the following formula:

Electricity prices ~ Price gas/efficiency gas plant (55 % assumed) + CO_2 costs of gas + estimated OPEX costs of gas

Figure 22. *Formula linking electricity and gas prices*

The dark black line in Figure 21 represents the electricity price that would correspond with historic TTF gas prices using the formula in Figure 22.

Despite lower costs for CO_2 emission allowances, the generation costs of gas turbines went up during the period 2010-13 due to higher natural gas prices. Coal-fired generation plants on the other hand saw their coal costs decrease. As a result, the merit order of power plants in countries with a lot of gas power plants as in the Netherlands and with many coal-fired power plants as in Germany was influenced. The spread in generation costs between the fuels translates into a price spread between countries.

4 Long-term market analysis

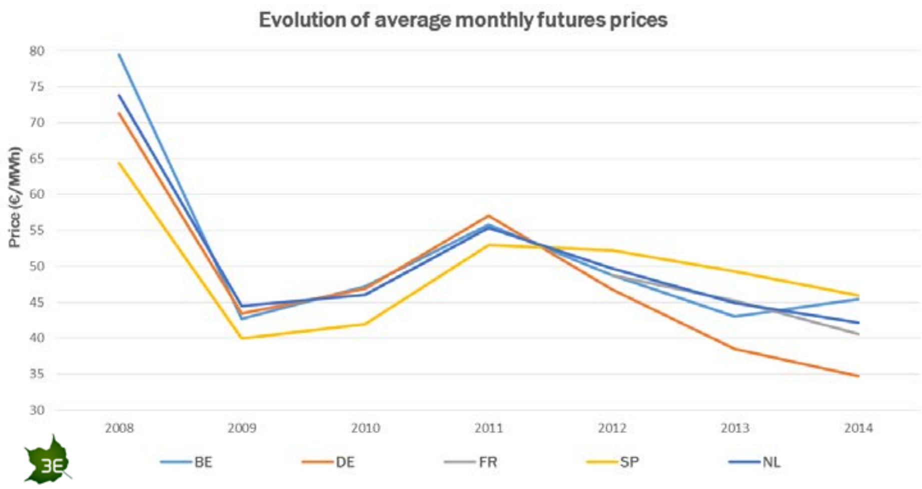
While spot prices reflect the momentary supply and demand situation, futures power prices are influenced by fuel prices, the structure and cost of new generation capacity (with an increasing importance for renewable energy technologies), capacity retirement, water reservoir levels, weather trends and interconnection capacities. Thus, asymmetries in futures prices in the different countries studied reflect market participant expectations of spot price differences that cannot be equalised in cross-border trade.

This chapter will focus on the challenges and issues of the energy only market for the medium and long-term markets (futures). Market participant expectations of future prices related to specific events are analysed. The details of specific events will be reviewed and compared across the following countries: Belgium, Germany, The Netherlands, Spain (futures market together with Portugal) and France. The Scandinavian futures market was not reviewed due to difficulties securing this data. Daily futures prices were gathered for the entire period 2008-2014 with the exception of France, where data for the period 2012-2014 was available.

4.1 Environmental policy: Increasing RES share

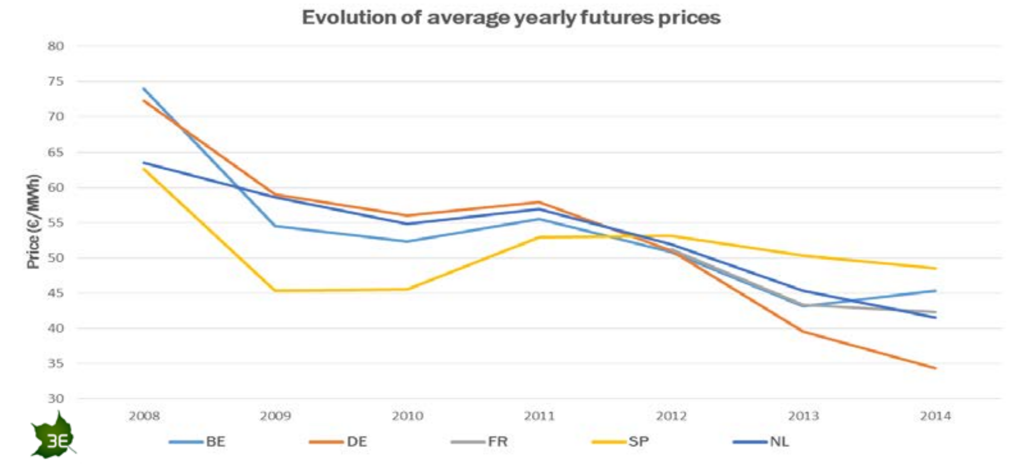
4.1.1 Case study 1: Falling futures electricity prices

Compared to short-term prices, Figure 23 (yearly average of monthly futures prices) and Figure 24 (yearly average of yearly futures prices) show that there is a general trend towards falling long-term electricity prices for the period 2008-2014. The daily published values of futures on different market platforms were used to calculate yearly averages.



Source: ICE, EEX, OMIE

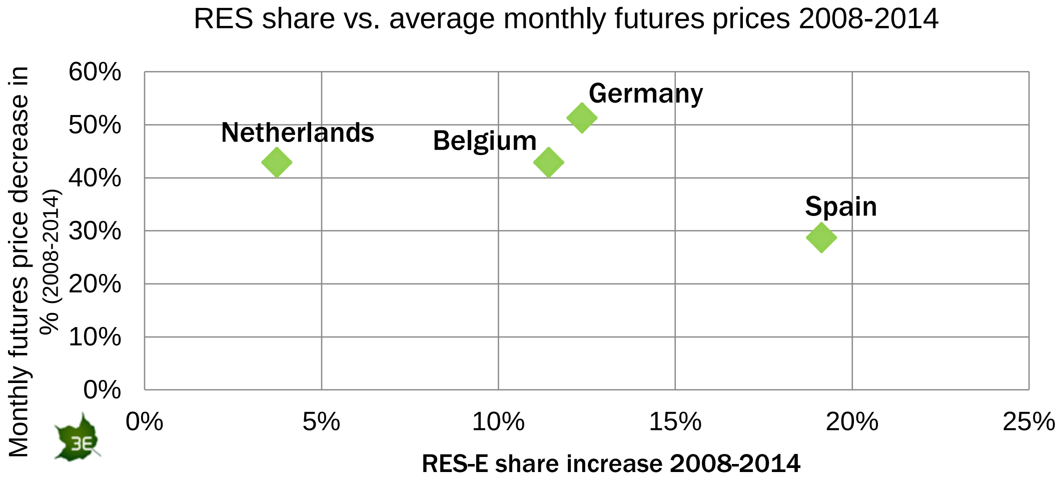
Figure 23. *Average monthly futures prices since 2008*



Source: ICE, EEX, OMIE

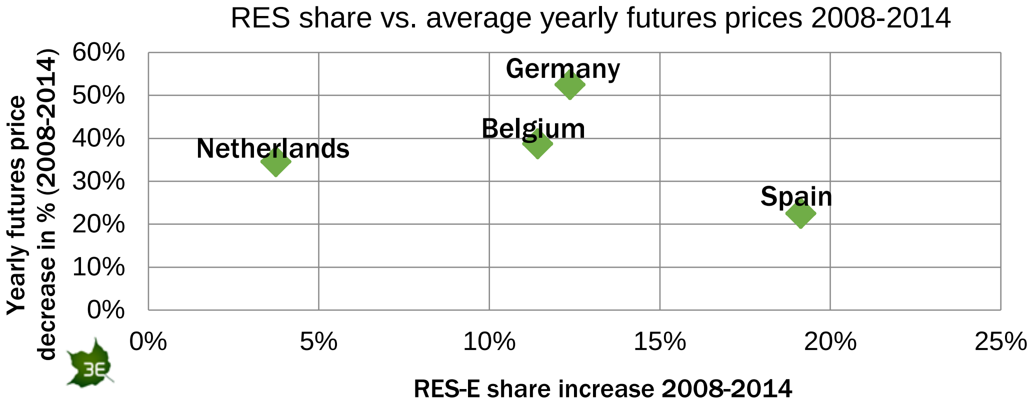
Figure 24. *Average yearly futures prices since 2008*

These figures show that RES-E penetration, which was increasing in all countries over 2008-2014, appears to have a negative impact on futures prices. However, there is no clear causal relationship between futures electricity prices and rising shares of RES-E, as was observed for the spot markets. This is illustrated in Figure 25 (relationship of monthly futures prices) and Figure 26 (relationship of yearly futures prices). For the period 2008-2014, shares of RES-E increased and futures prices decreased but higher shares of RES-E did not necessarily results in lower futures prices.



Source: ICE, EEX, OMIE, ENTSO-E

Figure 25. *Relationship RES share and average monthly futures prices*

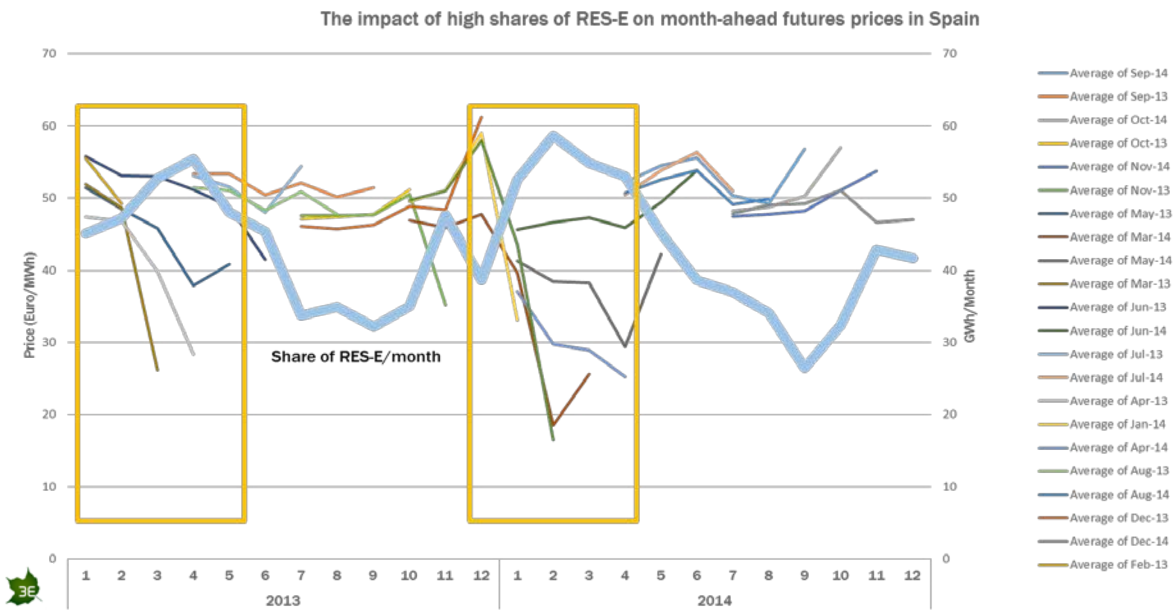


Source: ICE, EEX, OMIE, ENTSO-E

Figure 26. *Relationship of RES share and average yearly futures prices*

The following observations are worth mentioning:

- Price decreases are the highest in Germany and the lowest in Spain, both for monthly and yearly futures prices.
- The very high-penetration of RES-E can have a significant impact on month-ahead prices. The example of Spain, where this can lead to significant price jumps is illustrated in Figure 27. There is a significant month-ahead price decrease when the share of RES-E goes up during the first months of the year, both in 2013 and 2014. This price decrease is not as visible for the quarter-ahead and year-ahead futures prices.



Sources: OMIE, ENTSO-E

Figure 27. *Impact of high RES shares on monthly futures prices in Spain*

- Average monthly futures prices decrease more than yearly futures prices in Belgium, The Netherlands, and Spain, whereas yearly values decrease slightly more in Germany for the period 2008-2014. Market participants might thus expect RES-E penetration to have a higher impact in the long-run than in the medium-run in Germany whereas greater impact is expected in the medium-run for the three other countries. For France, only data for 2012-2014 is available and average monthly and yearly futures decrease approximately by the same percentage.
- Although the average yearly share of RES-E increased more in Spain than in all other countries over the period 2008-2014 (19.14 %), market participants expect prices to decrease less than in all other countries (28.71 % for average monthly futures). This might be explained by the fact that Spain suspended support for renewable electricity for new projects (measures approved by the government in January 2012) and applied retroactive measures to existing projects (approved by the government in July 2013) and has a low interconnection capacity (5 % in 2014).[1] This last aspect will be reviewed later in this chapter.
- Germany has a steadier growth of RES-E share compared to the other countries, the highest price decrease for the period 2008-2014 and the lowest prices in 2014. The steady versus erratic growth of RES might be a contributing factor to an attractive German futures electricity market.
- The Netherlands registered a decrease in share of RES-E in recent years (2012-2013) while average monthly futures prices have decreased more than in Belgium, France and Spain.

It can be concluded that RES-E penetration does contribute to lower prices in all analysed countries but other factors are also important in setting futures prices. Some of these factors will be the subject of the next chapters.

[1] Bloomberg New Energy Finance

4.2 Economic efficiency: Market coupling and interconnections

Increasing interconnection capacities in combination with market coupling are key elements towards building a harmonised European electricity market. They allow electricity to be exported when production volumes of wind and solar are very high or to import when these volumes are very low. In this section, two examples of market coupling and one example of interconnection are analysed. Since futures prices reflect price expectations of different market participants related to announcements of events, the following major events are examined:

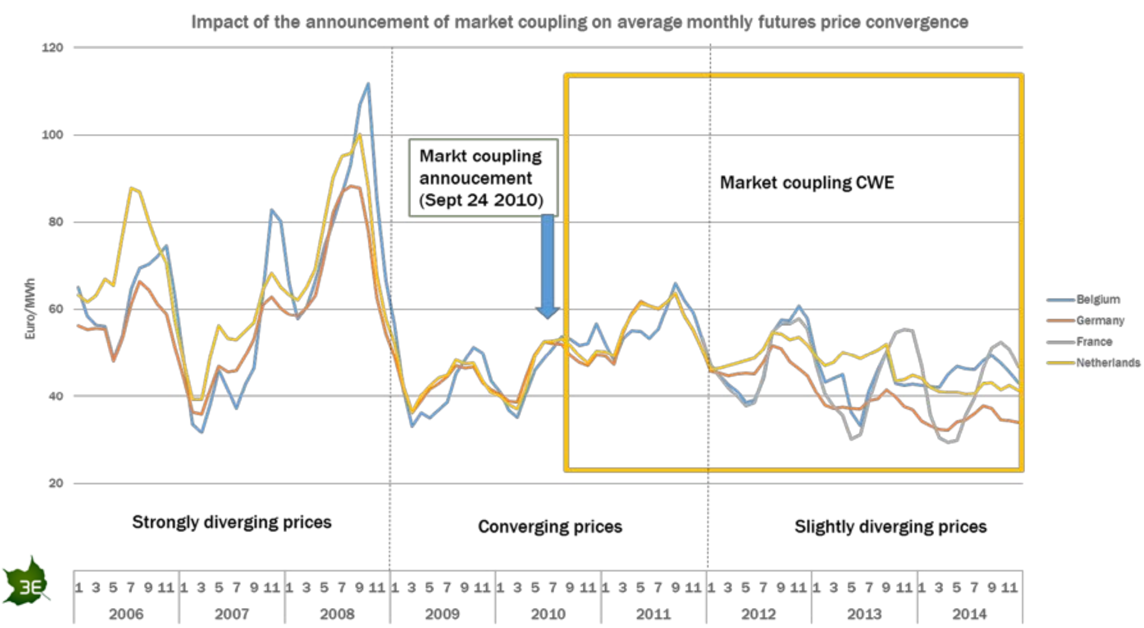
- The announcement of the Central-Western Europe (CWE) market coupling
- The announcement of the South-Western Europe (SWE) market coupling
- The Britnet interconnection between the United Kingdom and the Netherlands.

4.2.1 Case study 2: Market coupling, price convergence and price volatility

Impact of CWE market coupling on price convergence and volatility in neighbouring countries

Price convergence

Figure 28 displays the price convergence (yearly average of published monthly futures prices) in Central-Western Europe (CWE) after the announcement of the market coupling in September 2010. All data is available for Belgium, Germany and the Netherlands whereas data for France is only available from 2012 onwards.



Source: ICE, EEX

Figure 28. *Impact of the announcement of market coupling on price convergence in Central-Western Europe (CWE)*

While prices were strongly diverging before 2009, prices started to converge in April 2009-January 2012, the period leading up to market coupling. After market coupling was implemented, prices started to diverge again from the beginning of 2012 until the end of 2014.

Inefficient integration of renewable energy due to insufficient interconnections between the four States might be an explanation for the patterns observed above, as was the case for the spot markets.

On the whole, there is a noticeable convergence of average monthly and yearly futures prices after the market coupling announcement in 2010 (see Table 9). Therefore it can be argued that market coupling encourages price convergence on the futures market, but it must be paired with sufficient interconnection capacity to realise its full effect.

Table 9. *Price convergence of average monthly and yearly futures prices in CWE region for period 2008-2014*

Average price difference between monthly and yearly futures prices (Euro/MWh)	Belgium	Germany	France	Netherlands
2008-2010	-3.8	-8.6	N/A	-4.2
2011-2014	-0.5	-1.4	-0.6	-0.9

Price volatility

Table 10 and Table 11 demonstrate that both monthly futures price volatility within and between countries in the Central-Western European (CWE) region decreases after the market coupling in September 2010. The percentage standard deviation (standard deviation divided by average monthly futures prices) is used to calculate this price volatility.

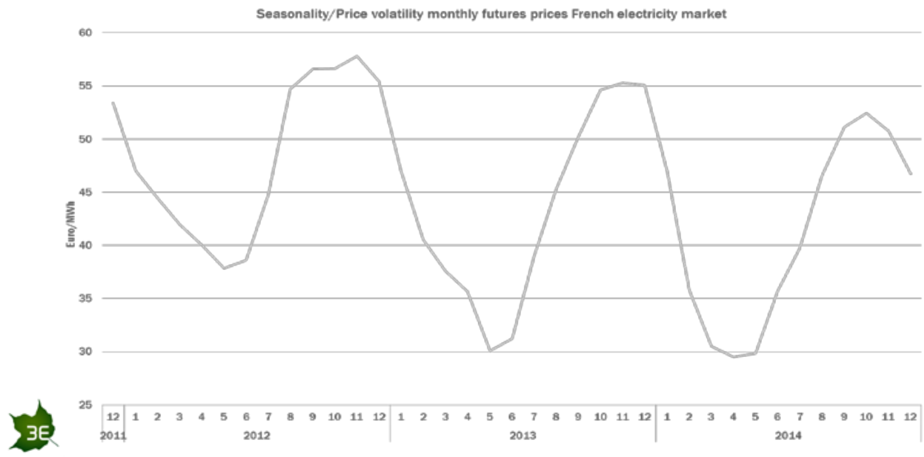
Table 10. *Intra-country price volatility of monthly futures prices for period 2008-2014*

Intra-country monthly futures price volatility before and after market coupling (% standard deviation)	Belgium	Germany	France	Spain	Netherlands
2008-2010	35.6	27.6	N/A	24.5	32.2
2011-2014	15.0	20.7	59.5	8.3	12.9

Table 11. *Inter-country price volatility of monthly futures prices for period 2008-2014*

Inter-country monthly futures price volatility before and after market coupling (% standard deviation)	Standard deviation prices BE-NL	Standard deviation prices BE-DE	Standard deviation prices BE-FR	Standard deviation prices NL-DE	Standard deviation DE-FR	Standard deviation NL-FR
2008-2010	33.7	32.0	N/A	30.0	N/A	N/A
2011-2014	13.9	18.3	16.7	17.6	18.2	15.4

The tables show that for the countries with complete futures data from 2008-2014 (Belgium, The Netherlands and Germany) price volatility clearly decreased over 2011-2014 compared to 2008-2010, both for inter-country and intra-country volatility. Price volatility between France and other countries is more or less at the same level of price volatility between other countries in the same region.[2] Price volatility within France is a lot higher than in the other countries because seasonal patterns play a very important role in the French power market (see Figure 29)



Source: EEX

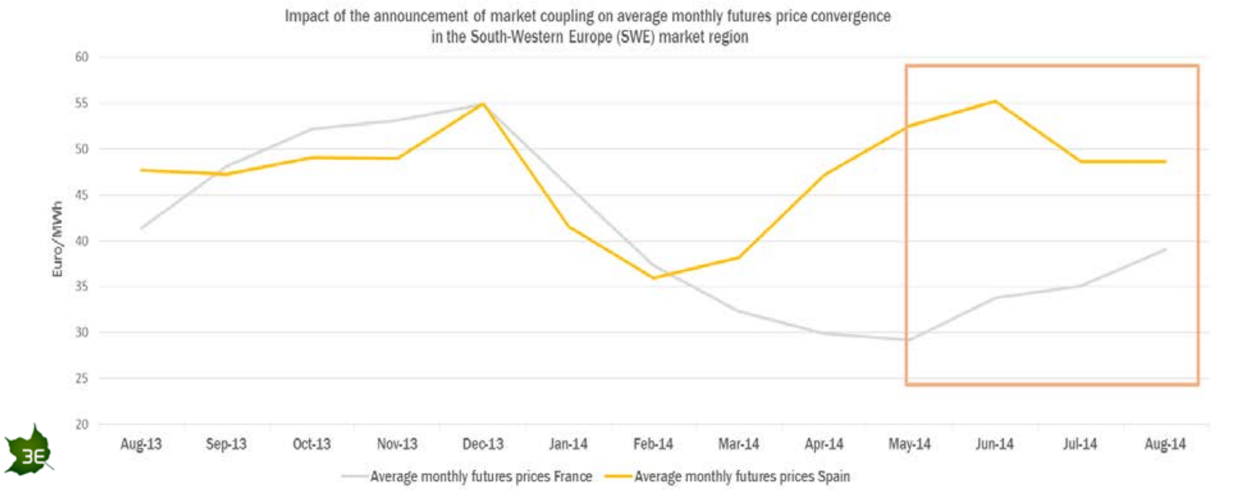
Figure 29. *Seasonality/Price volatility of monthly futures prices on the French power market*

Impact of South-Western European (SWE) market coupling on price convergence and volatility in France and Spain

Price convergence

Market coupling between Portugal, Spain and France was announced in February 2014 to be operational in May 2014. Figure 30 illustrates the impact of market coupling on price convergence between France and Spain.

[2] Only data for 2012-2014 is available for France.



Source: EEX, OMIE

Figure 30. *Impact of market coupling announcement on price convergence in South-Western Europe (SWE)*

Since market coupling between France and Spain is a recent event, it is difficult to ascertain at the moment the long-term effect of market coupling in the South-Western European (SWE) market region. At an initial glance, the average monthly and yearly futures prices appear to be converging after market coupling, similar to the CWE region (see Table 12).

Table 12. *Price convergence of average monthly and yearly futures prices in Spain and France in 2008-2014*

Average price difference between monthly and yearly futures prices (Euro/MWh)	FR	SP
2008-2010	N/A	-2.3
2011-2014	-0.6	-1.1

Price volatility

Monthly futures price volatility within and between Spain and France for the years 2013 and 2014 (period before and after the announcement of market coupling) are displayed in Table 13 and Table 14:

Table 13. *Price volatility of average monthly futures prices in France and Spain for 2013-2014*

Intra-country monthly futures price volatility before and after market coupling (% standard deviation)	France	Spain
February-December 2013	22.0	4.3
February-December 2014	22.2	10.6

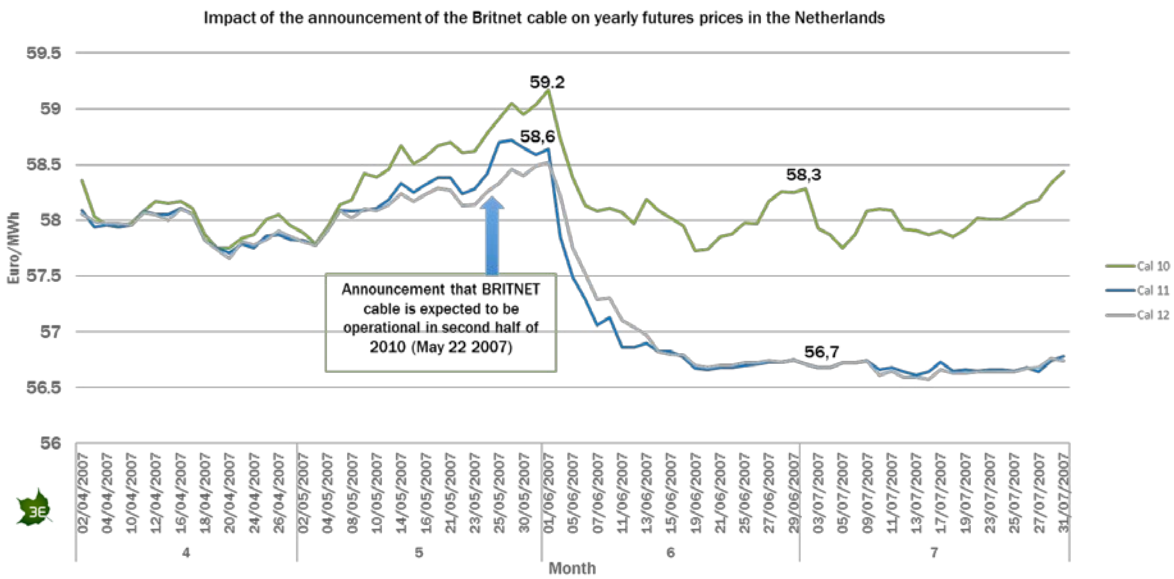
Table 14. *Price volatility of average monthly futures prices between France and Spain for 2013-2014*

Inter-country monthly futures price volatility before and after market coupling (% standard deviation)	FR-SP
February-December 2013	16.1
February-December 2014	17.9

Table 13 and Table 14 illustrate that futures price volatility (in and between countries) is not decreasing in the SWE region. An explanation and a consistent theme emerging from this futures price analysis is, that market coupling is, to a large extent, enabled by interconnections which is the next subject of analysis.

4.2.2 Case study 3: Interconnection capacity and average export volumes

As explained earlier in this report, the impact of the announcement of the Britnet cable development (capacity 1000 MW) between the United Kingdom and the Netherlands on futures prices in the Netherlands is worth analysing. It was announced in 2007 that the cable would be operational by the second half of 2010. The potential impact of this announcement on the yearly futures prices of 2010, 2011 and 2012 is illustrated in Figure 31. Note that monthly futures prices are not taken into account for this analysis as they are considered less relevant than annual futures prices to gauge market reaction to events that lie far out in the future.



Source: ICE

Figure 31. *Impact of Britnet cable announcement on yearly futures prices in the Netherlands*

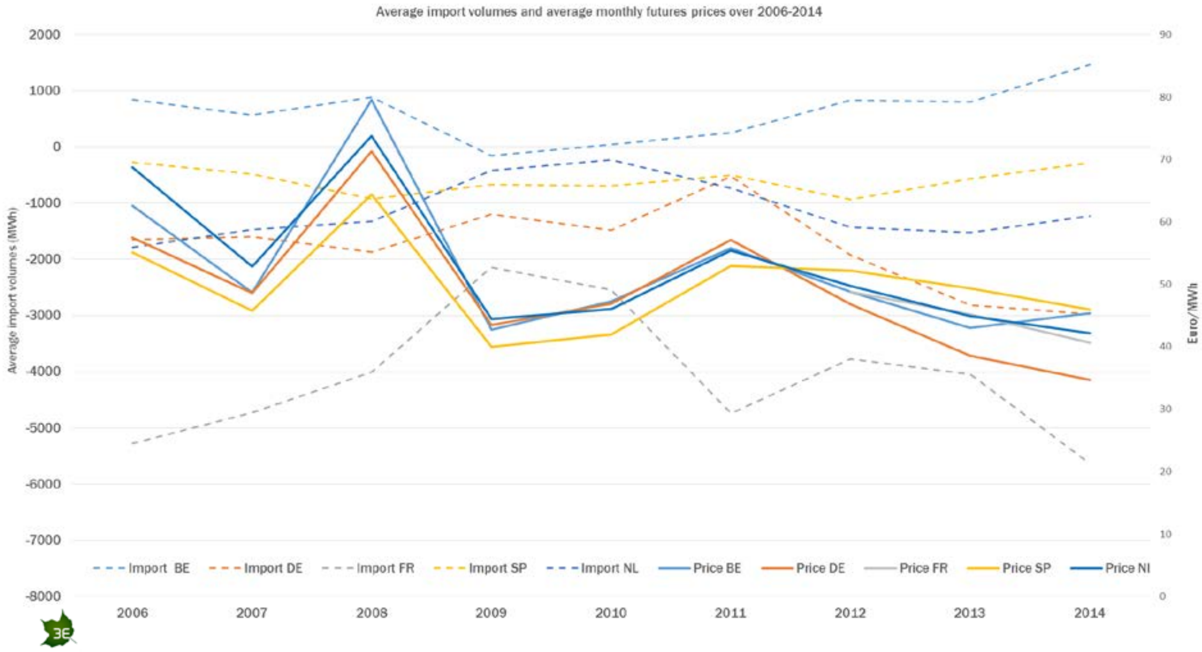
The announcement of additional interconnector capacity has a clear impact on yearly futures prices for the years 2011 and 2012. When the link was first announced, the new cable was expected to be operational in the second half of 2010. This is why yearly futures prices for 2011 and 2012, years when the cable was expected to be fully operational, are more than 1 euro/MWh lower than yearly futures prices for 2010. Moreover, the interconnection capacity announcement had a price decreasing effect during the entire year of 2007.

For other countries, the following observations related to interconnection capacity are worth noting:

- Germany and France have a relatively high interconnection capacity of 10 % (see Table 7 in Chapter 3) and the highest yearly average net export volumes of all countries in 2014 (France on average 5600 MWh, Germany on average 2970 MWh). These two countries have the lowest average monthly futures prices of all analysed countries in 2014. There is a strong correlation of around 95 % between average export volumes and monthly futures prices for both countries over 2011-2014 and export volumes were strongly increasing during this period.
- Spain is the country with the lowest interconnection capacity as a percentage of total installed electricity capacity (5 % in Table 7 in Chapter 3) and the second lowest average export volumes (on average 285 MWh) of all analysed countries in 2014. The country has, perhaps as a result, the highest monthly futures prices of all analysed countries. Average export volumes were significantly decreasing over 2012-2014 which translated into the highest monthly futures prices of all analysed countries in 2014 and lower price decreases than in Germany, France and the Netherlands for 2012-2014.
- Figure 25 and Figure 26 also show that yearly averages of futures prices were going up at the end of 2014 in Belgium. This increase will be explained further in a later section of this chapter on security of supply.

The emperical analysis thus concludes that higher interconnection capacity and average export volumes leads to lower monthly futures prices, which appear to be decreasing in recent years. Average import volumes and available prices for all analysed countries for the period 2006-2014 are shown in Figure 32.[3]

[3] Only data for 2012-2014 is available for France.



Source: ICE, EEX, OMIE, ENTSO-E

Figure 32. *Average import volumes and monthly futures prices studied countries for 2006-2014*

4.3 Security of supply: Conventional supply changes

4.3.1 Case study 4: Nuclear phase-out announcements

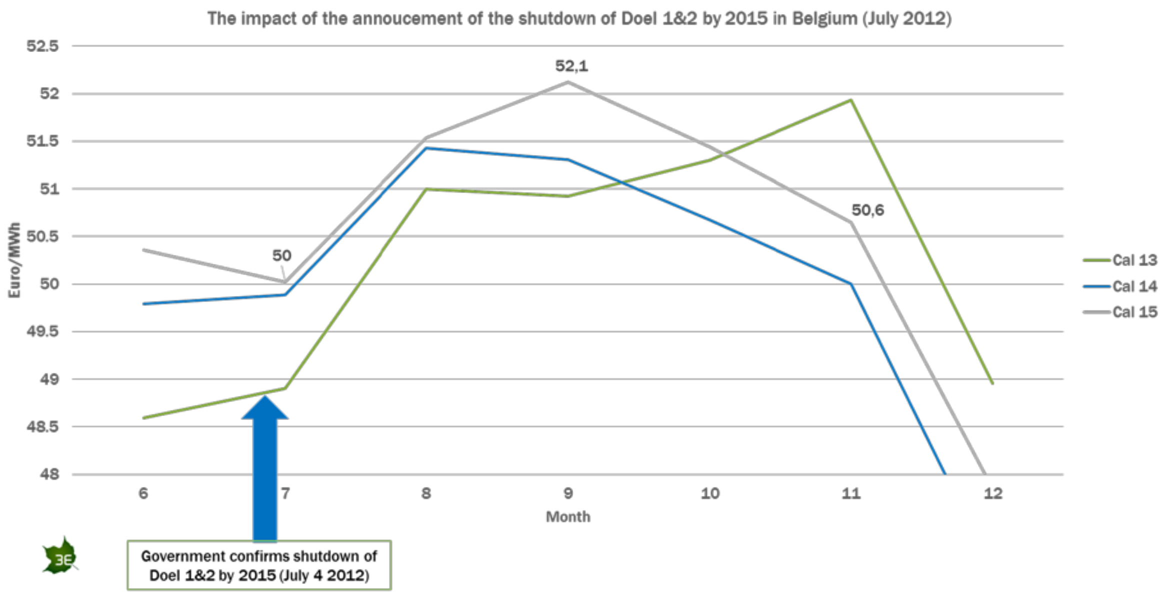
The following events will be analysed to determine the price impact of the announcement of the shutdown of nuclear plants on futures prices.

- The announcement of the Belgian government to shut down the nuclear power plants of Doel 1&2 by 2015 in July 2012
- The announcement of the German government to phase-out all nuclear power plants by 2022 in May 2011

Yearly futures prices are used because both events happen far out in the future. An important difference between the nuclear shutdowns in Belgium and Germany is that the Belgium governments announced to shut down specific nuclear reactors by 2015 (partial phase-out) whereas the German government announced to phase-out all nuclear parks by 2022 (complete phase-out).

Impact of the announcement to shutdown Doel 1&2 on yearly futures prices in Belgium

The impact of the announcement of the shutdown of Doel 1&2 by 2015 is illustrated in Figure 33.



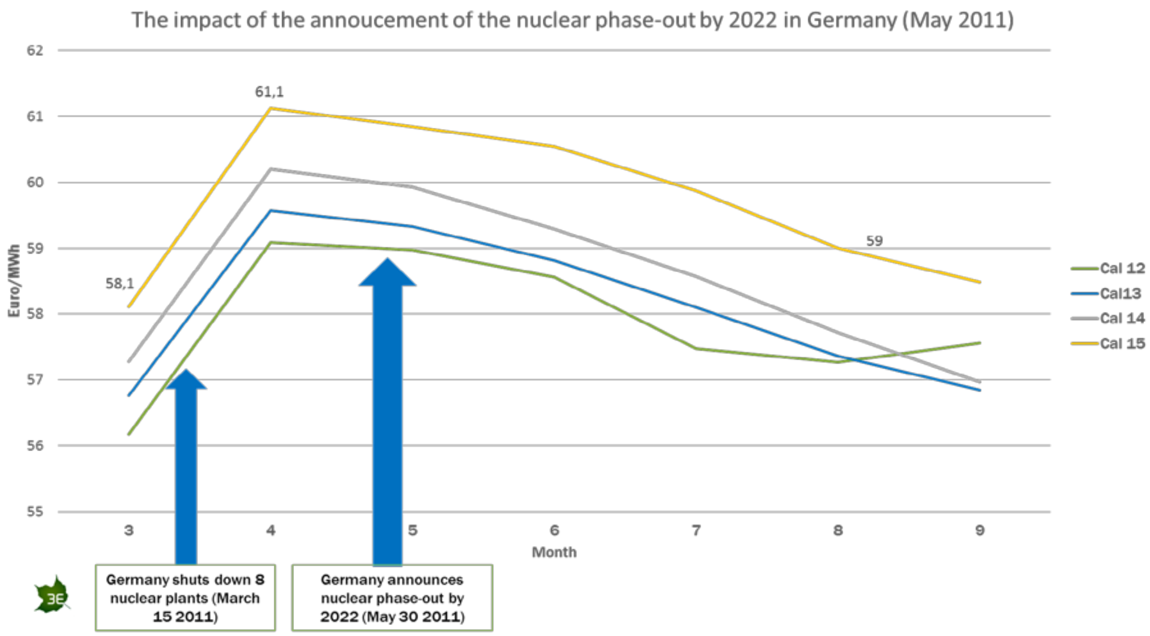
Source: ICE, Federal Agency for Nuclear Control (FANC), World Nuclear Association

Figure 33. *Impact of nuclear shutdown announcement on yearly futures prices for 2013-2015*

The figure demonstrates that from July 2012 onwards, yearly futures prices (2013, 2014 and 2015) initially increased for a few months and started decreasing in November 2012 to reach the price level of the beginning of July 2012 in December 2012. Moreover, prices continue to fall in 2013. One can conclude that the announcement of the shutdown temporarily drives prices up, but other factors such as higher shares of RES-E and the possibility to import cheaper energy from neighbouring countries through interconnectors play a greater role in influencing prices in the long term.

Impact of the announcement to phase-out all nuclear fleets on yearly futures prices in Germany

In May 2011, the German government announced plans to shut down all nuclear fleets by 2022. The government also decided to immediately shut down eight nuclear plants in March 2011. The impacts of both announcements on yearly futures prices from 2012 to 2015 are illustrated in Figure 34.



Source: EEX, World Nuclear Association

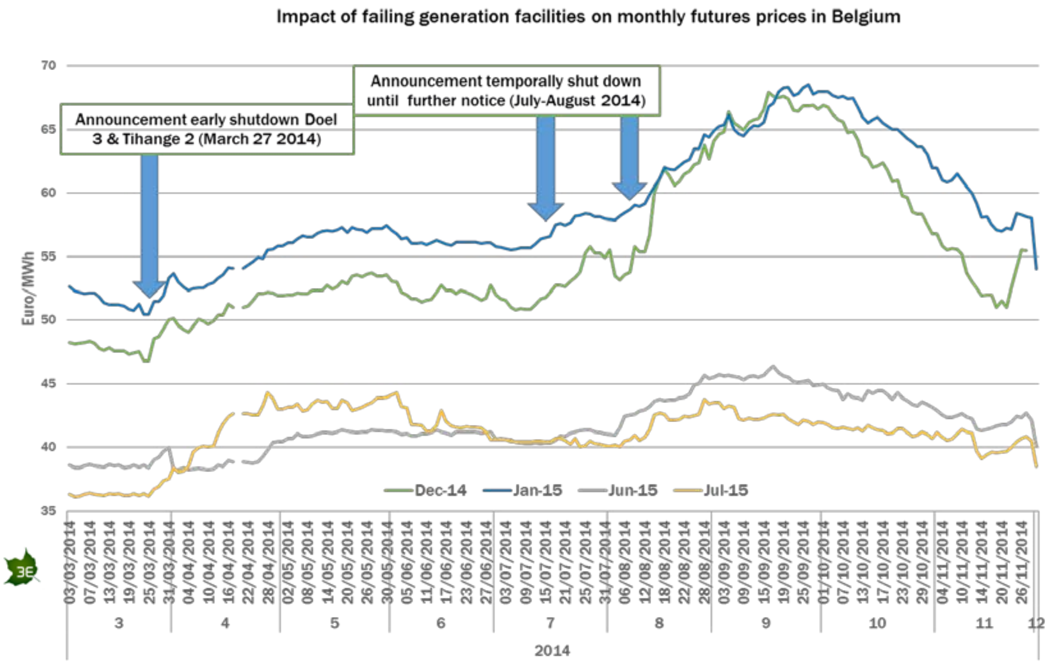
Figure 34. *Impact of nuclear phase-out announcement on yearly futures prices for 2012-2015*

Figure 34 shows that the announcement of an immediate shutdown of nuclear power plants has a higher impact on market expectations than the announced nuclear phase-out. From March 2011 onwards, prices go up by 2-3 euro/MWh for a few months to come back at the same level around August 2011 and prices continue to decrease in 2012. When the nuclear phase-out was announced in May 2011, yearly futures prices further decreased which demonstrates that other factors such as higher shares of RES-E and the possibility to import cheap energy from neighbouring countries through interconnectors are stronger price determinants than the announcement. The analysis also shows that reaction to the nuclear shutdown in Germany elicited a stronger reaction than in Belgium.

Finally, Figure 34 shows that the price difference between futures prices for 2015 and other years is increasing. This might reflect market participants' uncertainty with respect to long-term prices.

4.3.2 Case study 5: Failure of conventional generation plants

If important electricity generation facilities fail in a country, problems of security of supply can emerge. In Belgium, results of tests on the mechanical properties of the nuclear reactors Doel 3 and Tihange 2 indicate higher than expected risks for irradiation at the end of March 2014. As a result, outages of both plants have happened earlier than planned. In July and August 2014, the FANC (Federal Agency for nuclear control in Belgium) decided to keep both nuclear power plants temporarily offline until further assessment. The impact of these security of supply issues on monthly futures electricity prices is illustrated in Figure 35.



Source: ICE, Federal Agency for nuclear control (FANC)

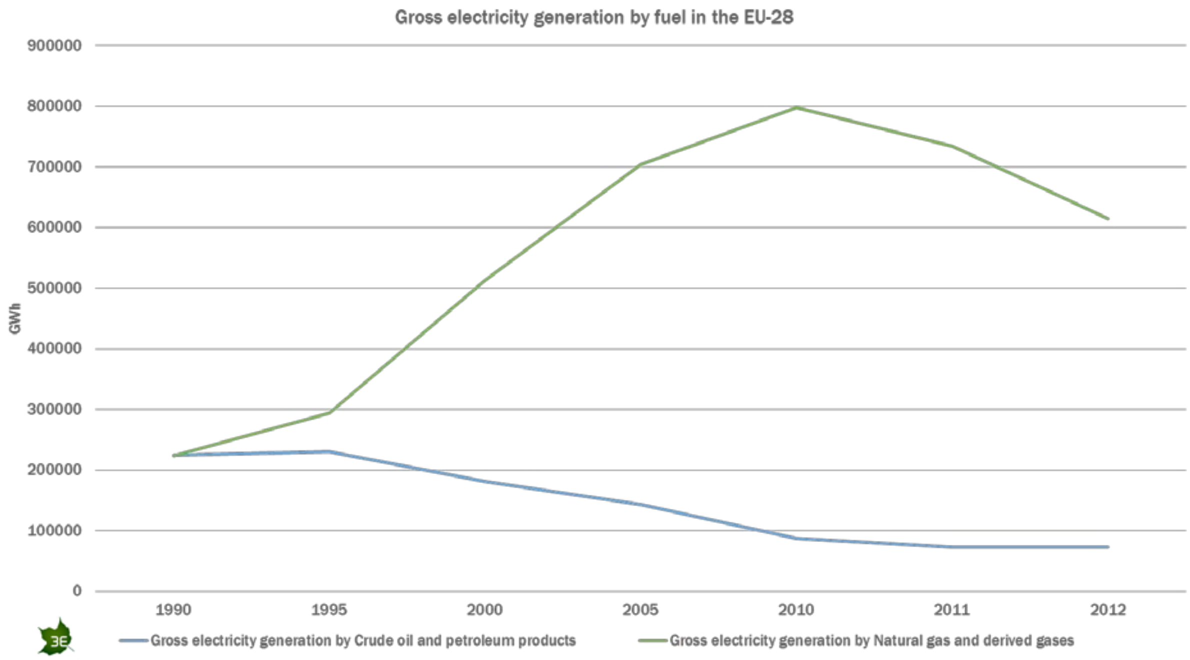
Figure 35. *Impact of failing nuclear generation facilities on monthly futures prices*

Figure 35 shows that the monthly futures price difference between winter and summer is becoming more important after the FANC announcement (difference increases from 10-15 euro/MWh to 15-20 euro/MWh). This can be explained by the fact that market participants are expecting energy supply risks in the winter because:

- Belgium imports a relatively high share of electricity (cf. Figure 32)
- ENTSO-E data shows that Belgium has limited interconnection capacity (3.5 GW) with neighbouring countries to import additional volumes, if necessary.

4.3.3 Case study 6: Commodity price relationships

Gas-fired power plants account for a significantly higher proportion of electricity production in some European countries than in others. Furthermore, the price of oil is historically tied to the price of natural gas in long term power contracts. Figure 36 shows that for EU electricity production, while crude oil and natural gas were used in equal measures in 1990, natural gas appears to be used six times more in 2012.



Source: Eurostat

Figure 36. *Gross electricity generation by fuel in EU-28*

Therefore in current times, one should expect a clearer relationship between electricity and natural gas prices than between oil and electricity prices. The relationship of futures Brent oil and TTF natural gas prices with power prices is illustrated in Table 15.[4]

Table 15. *Correlation between monthly futures prices of commodities and electricity*

Correlation (2010-2014) for published monthly futures prices of	Belgium	Germany	France (only 2011-2014 available)	Spain	Netherlands
Brent Oil	0.11	0.12	-0.09	0.49	0.42
TTF natural Gas	0.22	0.10	0.16	0.63	0.43

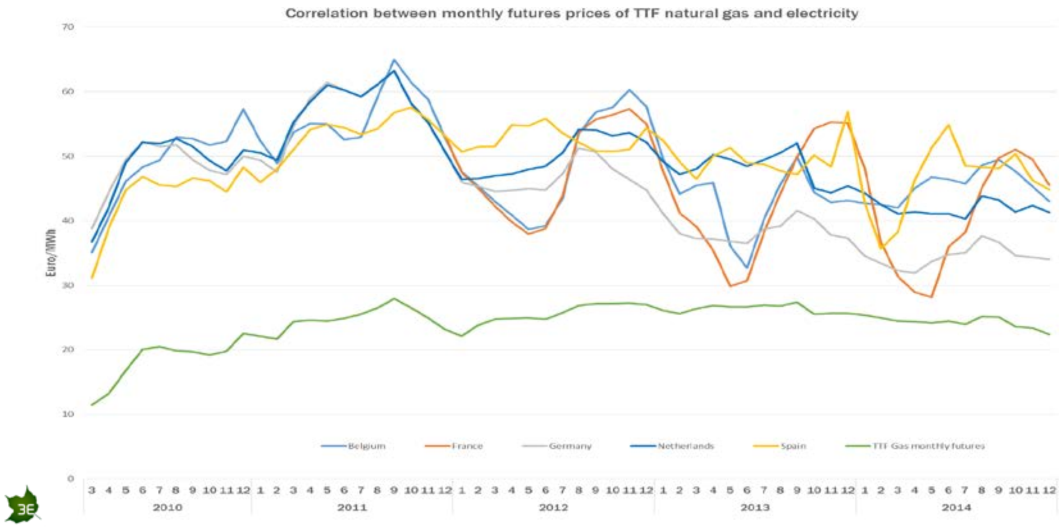
[4]For TTF gas, only the published value of the 15th day of the month was used for the period Oktober/2013-December/2014.

Correlation with TTF natural gas

Table 15 clearly indicates that monthly futures natural gas prices are positively correlated with the monthly futures power prices in Figure 32 for four out of the five countries. Spain (correlation 0.63) and the Netherlands (correlation 0.43) have the highest correlations among the countries studied. In these two countries, declining gas prices translate into significantly reduced electricity prices. As noted in Chapter 3, gas-fired plants account for a high share of electricity production in the Netherlands (63 % or 31 GW of production capacity in 2013). In Spain, gas accounted for 30 % or 30 GW of production capacity in 2013. Limited interconnection capacity, which restricted possibilities for power imports from neighbouring countries may be an explanation for the high correlation between domestic electricity needs and fuel prices.[5]

The country with the lowest futures prices, Germany, is characterised by the lowest correlation between natural gas and electricity of all studied countries. Other factors such as the share of RES-E, the use of coal and lignite and power imports/exports thus seem to play a more important role than generation by natural gas in this case.

Figure 37 shows the relationship between monthly futures prices of TTF natural gas and electricity in the different studied countries.



Source: ICE, EEX, OMIE

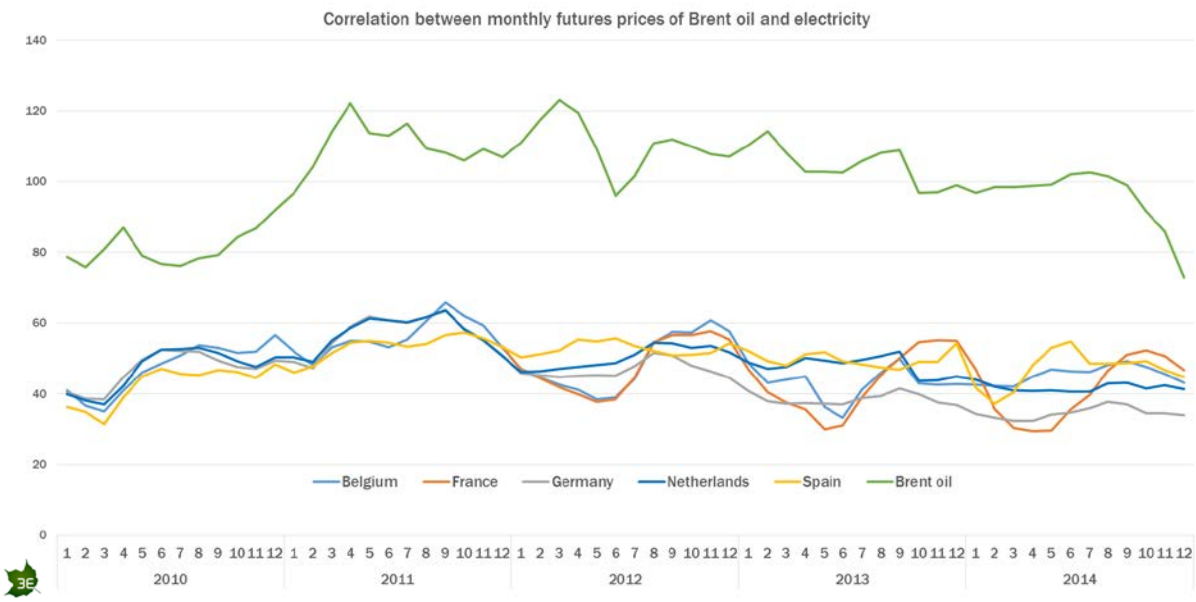
Figure 37. *Correlation between monthly futures prices of TTF natural gas and electricity*

[5] Source: Bloomberg New Energy Finance

Correlation with Brent oil

Table 15 demonstrates that the correlation between monthly futures Brent oil and electricity prices (see Figure 38) is lower than the correlation between monthly futures TTF natural gas and electricity. This is in line with the observations from Figure 32 (TTF natural gas volumes are six times greater than Brent oil for electricity generation). For Spain and the Netherlands, Table 15 indicates that there is a relatively strong relationship between natural gas and Brent oil which might be explained by the fact that gas contracts are tied to oil contracts to a certain extent but it is expected that natural gas prices will be decoupled or less influenced by oil prices in the coming years.

Figure 38 displays the relationship between monthly futures prices of Brent oil and electricity in the different studied countries.



Source: ICE, EEX, OMIE

Figure 38. *Correlation between monthly futures prices of Brent oil and electricity*

The correlation is stronger in Spain and the Netherlands than in the other countries.

5 International market designs: Best practices and lessons learnt

Increasing renewable shares, market coupling and conventional supply changes are not unique European trends. Other jurisdictions around the world are confronting similar challenges, but may be addressing them in different ways. This section examines best practices in international markets of relevance and with transferability potential to the European market. The list is non-exhaustive, but provides a basis for further analysis in the next work packages of the project. The different market design measures have been categorised under the three same categories used to analyse events in Section 3 and 4 on the very short term, short term and long term markets.

Environmental policy: Measures to address increasing renewable shares	
Advanced RES forecasting techniques	In the United States, several Independent System Operators (ISOs) are using advanced day-ahead weather forecasting techniques to optimise the integration and dispatch of renewables on the power system close to real-time. Most American ISOs now have centralised day-ahead wind power forecasts incorporated in their reliability commitment models which can be used to make better decisions for meeting forecasted demand (Cochran et al., 2013). In Europe, day-ahead weather forecast has become increasingly sophisticated in regions with high shares of renewables such as Germany and Spain.
Wind participation enablement	The Midcontinent Independent System Operator (MISO) has developed a “Dispatchable Intermittent Resources Program” which allows wind plants to submit offers for energy in the real-time market and update them based on sub-hourly forecasts (Cochran et al., 2013). In Europe, plants cannot bid in real-time markets. The California Independent System Operator (CAISO) has set up a “Participating Intermittent Resource Program” allowing individual wind plants to self-schedule according to shared forecasting techniques (Iec, 2009).
Shorter dispatch intervals for the short term markets	The National Electricity Market in Australia has sub-hourly (5 min.) dispatch intervals which enables system flexibility and improves forecasting accuracy. Short dispatch intervals reduce the need for regulated reserves and ramping, since changes in variable generation and load are more closely matched economically.

Economic efficiency: Measures to address market coupling	
Nodal pricing	The United States has a bidding zone configuration where different points of the system “nodes” are assigned distinct prices. This is also known as locational marginal pricing. Prices are set by taking into account differences in congestion levels (grid availability). These prices

	incentivise generators to adapt their production to minimise congestion which is costly for ISOs. (Neuhoff, 2011).
Complex bids	In the PJM market as well as in Texas and California, generators can submit complex, more nuanced bids which detail start-up costs, ramping constraints and energy costs. With this additional information, the market operator is more equipped to make better decisions that are more economic for all.
Pool type trading system	The PJM market is organised as a pool market. This is advantageous when having a high share of intermittent sources. The intraday market is more liquid, gate closure is late and the balancing and intraday markets are not differentiated, which supports the incorporation of improved generation forecasting of intermittent sources closer to real time (Borggrefe & Neuhoff, 2011). The ISO calculates closer to real-time an optimal dispatch based on firm schedules and flexible bids provided by market participants on the IDM clearing platforms. This fosters higher liquidity for the short-term optimisation of the system.

Security of supply: Measures to address conventional supply changes	
Capacity remuneration Mechanisms	In California, power generators have to bid a portion of their most flexible capacity into the market at all times. Moreover, a "Flexible Ramping Product" mechanism is in place, which incentivises generators to be offline during low-ramp periods (Marinot, 2015). In Brazil, where the power system is dominated by hydro generation, capacity auctions with long-term contracts have been implemented. These contracts support capacity adequacy over the long term and allows generators to hedge investment risks (hydro generation is highly susceptible to weather fluctuations). Auction winners normally receive long term contracts including a price for availability and electricity production (Cochran et al., 2013; Winkler, 2012).
Price curve linked to frequency	India benefits from an "Unscheduled Interchange" mechanism, a price curve linked to frequency by which generators deviating from their scheduled supply can either benefit or be penalised depending on whether the deviation is in the direction necessary to maintain grid frequency. Participants are therefore financially incentivised to maintain grid frequency (Cochran et al., 2013).

6 Conclusions

The current European electricity market was designed based on technologies and policy objectives that were predominant in the 1990s. However, with recent supply mix shifts from fossil-fuel generation to low carbon technologies and a desire to improve energy security and economic efficiency, European markets including day-ahead, intraday, balancing and futures, must adapt and modernise to work optimally under changing conditions.

In Sections 3 and 4, empirical case studies on the very short, short and long term power markets show that with increasing RES-E share:

- average spot and futures prices tend to fall
- negative prices occur more frequently on the spot market
- price volatility tends to increase
- RES—E curtailment is sometimes needed to manage oversupply and system security

There are several combinations of measures that can be used to better adapt markets for the modern environment.

Increase interconnection capacity. Building new interconnections to control price volatility, increase market efficiency and flexibility is the key to managing intermittent renewable sources. This equally applies when there is an over production of generation and when there is security of supply issues, for example, when nuclear plants go offline for maintenance or permanent shutdown.

Support demand management. Demand-side response (DSR) should be incentivised in order to better match supply with demand. DSR can shift consumer demand to off-peak periods during periods of high demand and incentivise consumption during high production and/or traditionally low demand periods. Technical infrastructure, such as smart meters, may be required to enable flexible demand.

Increase flexibility operations. There are several ways to increase flexibility of the system beside optimal use of transmission, for example, merging balancing areas, sharing flexible generation assets, sharing back-up reserves, etc. Having stand-by capacity that can ramp up rapidly can also provide more flexibility to the system.

Improve forecasting techniques. More sophisticated and accurate forecast of RES-E availability can reduce the need for back-up capacity. Another part of the solution is to decrease the lead-time for forecasts through intraday markets which would improve accuracy.

Optimise interplay of intraday, balancing and day-ahead markets. Intraday and balancing markets should be designed to make full use of the flexibility of the transmission system and the different generation technologies. For instance, lead time available to pursue system adjustments could be increased, gate closure delays reduced and it should be possible to reschedule power flows between countries more often.

Finally, this report looks beyond European borders by highlighting developments and best practices implemented in international markets with similar energy challenges to Europe. Solutions and measures that are relevant to the European context are described in the report, with the view to inform market design policies in Europe to better optimise RES-E integration on the electricity system. Europe can learn from the trials and tribulations of other markets. The changing energy/electricity environment and the effect on market prices, as described by the empirical studies, necessitate innovative measures to optimise the full potential of an integrated European electricity market.

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