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Wind power feed-in impact on electricity prices in Germany 2009-2013[1]

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Abstract

Until quite recently no electricity system had faced the challenges associated with high penetrations of renewable energy sources (RES). In this paper, we carry out an empirical analysis for Germany, as a country with high penetration of wind energy, to investigate the well-known merit-order effect. Our main empirical findings suggest that the increasing share of wind power in-feed induces a decrease of electricity spot price level but an increase of spot prices volatility. Furthermore, the relationship between wind power and spot electricity prices can be strongly impacted by European electricity grids interconnection which behaves like a safety valve lowering volatility and limiting the price decrease. Therefore, the impacts of wind generated electricity on electricity spot markets are less clearly pronounced in interconnected systems.

JEL classification: Q41, Q42, Q48

Keywords: RES, Electricity spot prices, merit order effect, volatility.

1. Introduction

Renewable energy is a key component of the EU energy strategy. It started with the adoption of the 1997 White paper and has been driven by the need to de-carbonise the energy sector and address growing dependency on fossil fuel imports from politically unstable regions outside the EU. To achieve this goal, the European Union has aimed to have at least 21% of its electricity coming from renewable energy sources.

Various RES supporting schemes are operating in Europe, mainly feed-in tariffs, fixed premiums, green certificate systems. The German Renewable Energy Act, "Erneuerbare-Energien-Gesetz" (EEG), a well known support scheme, has provided a favorable feed-in tariff (FIT) for a variety of renewable energy sources (RES) since the year 2000. It also gives priority to electric power in-feed from RES over power in-feed from conventional power plants, i.e., fossil- and nuclear-fuel thermal and already existing hydro-based power plants. Thus, all renewable sources combined made up 24 per cent of gross electricity production in 2013 and are Germany's second most important source of electricity generation after lignite (BDEW, 2013). Figure 1 summarizes the recent evolution of the electricity mix.

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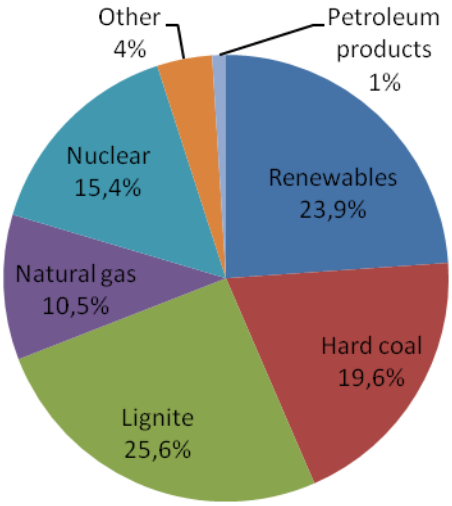
Carbon-intensive technologies clearly prevail in Germany, even though the system participation of renewables has grown significantly in the last few years (renewable production tripled from 40 TWh per year in 2001 to more than 150 TWh in 2013).

Figure 1. Share of gross electricity generation (2013).



(Author, source AG Energie bilanzen)

However, this success has led to many challenges to Germany energy system, thus raising doubts on RES future economic viability.

In this paper, we address a central question of the research agenda on renewable energy sources by exploring the impact of the RES on electricity prices (the merit order effect). Indeed, one of the central empirical finding in the literature on renewable energy is that an increase in RES generation would put a downward pressure on the spot electricity market price by displacing the conventional power plants with higher marginal cost.

The goal of this paper is to carry out an empirical analysis to investigate the well-known merit-order effect by using a data sample of daily electricity spot prices in Germany for the 2009-2013 period.

There are two main contributions of this study to the literature. Firstly, an AR-X- GARCH-X modeling is used with wind generation as an exogenous variable included in the mean and the variance equation. The goal is to assess the joint impact of intermittent renewable electricity generation on the electricity spot price level as well as on spot price volatility in Germany.

Secondly, in order to take into account the European grid interconnection, we have proxied it by the Germany-France prices differential (spread) and used it as an additional explanatory variable in our AR-X-GARCH-X model. The goal consists on assessing the market coupling on the RES impact on price level and price volatility.

Our main findings suggest that intermittent wind power generation does not only decrease the spot electricity price in Germany but also increases its price volatility. However, the downward effect of the feed-in of wind-generated electricity on spot prices and the upward effect on price volatility are limited by the possibility of exporting part of the surplus wind power to Germany's neighbours (including France).

The so-called merit order effect has gained increasing attention in the literature both on a theoretical basis and an empirical one. Indeed, Jensen and Skytte (2002) point out that RES generation enters at the base of the merit order function, thus shifting the supply curve to the right and crowding the most expensive marginal plants out from the market, with a reduction of the wholesale clearing electricity price.

Several papers have carried out empirical analysis on the impact of RES in electricity markets, finding evidence of the merit-order effect. Indeed, one of the central empirical findings in the literature on renewable energy (RE) is that an increase in intermittent sources generation would put a downward pressure on the spot electricity market price by displacing high fuel-cost marginal generation. RE installations, although they are very capital-intensive, have almost zero marginal generation cost and thus are certainly dispatched to meet demand. More expensive conventional power plants are crowded out, and the electricity price declines.

It is worth noting that several authors have explored this topic. For Germany, Bode and Groscurth (2006) find that renewable power generation lowers the electricity price. Neubarth et al. (2006) show that the daily average value of the market spot price decreases by 1 €/MWh per additional 1,000 MW wind capacity. Sensfuss et al. (2008) show that in 2006, renewables reduced the average market price by 7.83 €/MWh. Weigt (2008) concludes that the price was on average 10 €/MWh lower. Nicolosi and Fürsch (2009) confirm that in the short run, wind power feed-in reduces prices whereas in the long run, wind power affects conventional capacity, which could eventually be substituted. For Denmark, Munksgaard and Morthorst (2008) conclude that if there is little or no wind (<400MW), prices can increase up to around 80 €/MWh (600 DKK/MWh), whilst with strong wind (>1500MW) spot prices can be brought down to around 34 €/MWh (250 DKK/MWh). Jonsson et al. (2010) show that the average spot price is considerably lower at times where wind power production has been predicted to be large. Sáenz de Miera et al. (2008) found that wind power generation in Spain would have led to a drop in the wholesale price amounting to 7.08 €/MWh in 2005, 4.75 €/MWh in 2006, and 12.44 €/MWh during the first half of 2007.

Gelabert el al. (2011) find that an increase of renewable electricity production by 1 GWh reduces the daily average of the Spanish electricity price by 2 €/MWh. Wurzburg et al. (2013) find that additional RES generation by 1 GWh reduces the daily average price by roughly 1 €/MWh in German and Austrian integrated markets. Woo et al. (2011) carry out a empirical analysis for the Texas electricity price market and showed a strong negative effect of wind power generation on

Texas balancing electricity prices. Huisman et al. (2013) obtained equivalent results for the Nord Pool market by modeling energy supply and demand. Ketterer (2014) also examined wind power in German electricity markets and found that an additional RES generation by 1GWh led to a reduction of daily spot price by approximatively 1€/MWh.

The paper is organized as follows. Section 2 provides an overview of the merit order effect. In section 3, we carry out an empirical analysis and discuss the main findings. Section 4 provides some concluding remarks.

2. The merit order effect

In order to supply electricity, different power generation technologies compete with each other according to their availability of supply and their marginal cost of production (fossil fuels such as coal or natural gas, nuclear power, renewable energy sources like hydroelectric generators, wind or solar energy).

The electricity market operates according to day-ahead bidding. Indeed, the transmission system operators basically receives the bids from all power producers for the quantity and cost for each hour of the next day and then assigns the dispatch based on the lowest cost producer until demand is met. All producers who dispatch get the marginal price of the last producer that dispatched. As a result even if the last producer only produced theoretically one kWh then that is the price of the system. This conventional approach consists in ranking the power plants of the system in ascending order of their marginal cost of generation. This approach is called the merit order.

Traditionally, the hydroelectric power plants are the first to be dispatched on the grid. They are followed respectively by nuclear plants, coal-fired and/or combined-cycle gas turbines (CCGT), and then open cycle gas turbine (OCGT) plants and oil-fired units with the highest fuel costs.

Although power plants with the highest marginal cost correspond to the oil-fired gas turbines, gas plants are usually the marginal producers and as a result the cost of gas is very relevant to the wholesale pricing setting of electricity. But, due to EU ETS price weaknesses, carbon prices have plunged to record low prices making it more expensive to burn gas than coal. Moreover, The U.S. coal surpluses export due to shale gas revolution has lowered coal prices in Europe whereas oil indexation of gas contracts and geopolitical concerns have made natural gas more expensive. Therefore, the price competitiveness of more polluting coal-fired plants, allow them to be dispatched before the gas turbine and to be the key of electricity price setting.

However, a pricing based on marginal costs could never allow RES to recover their fixed costs. Indeed, the photovoltaic (PV) and wind power plants have a high average cost and their load factor is too low due to intermittency. Therefore, subsidising renewable energy sources by feed-in tariff scheme allowing their average costs to be recovered corresponds to a support mechanism outside the market. By granting an economic return above the market price, these supporting schemes have promoted RES development in several European electricity markets.

As the renewable energy sources (RES) have priority for grid access at zero marginal cost, i.e, have the privilege of priority dispatch, electricity from RES participating to the auction process at zero marginal cost replaces every other energy source with higher marginal cost. The decoupling of spot market prices and RES in-feed due to FIT support scheme results in lower average equilibrium price level on the spot market. This downward pressure on wholesale electricity prices is the so-called *merit order effect* (Sioshansi, 2013).

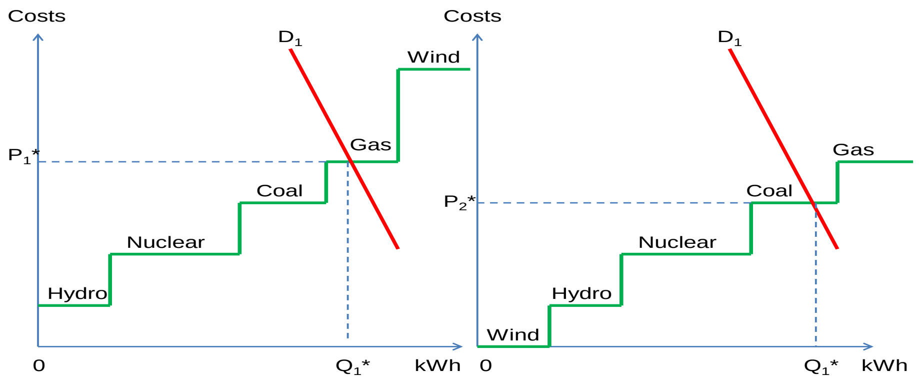
Indeed, during full and peak times, the marginal power plant is logically a combined-cycle gas-fired plant. However, as they have no fuel costs, RES have a zero marginal cost. Thus, electricity from RES makes the coal-fired plant becoming the marginal plant. The electricity market price is thus lower than it would be if there was no RES power in-feed. Lowering electricity spot prices causes a serious distortion to the electricity market.

Indeed, if the wind or solar power plants were not remunerated according to feed-in tariffs scheme they could never be profitable because the spot market price at full and peak periods would not allow them to recovery their fixed costs.

Furthermore, the insufficient dispatching of the flexible gas-fired plants jeopardises their profitability as they cannot be operated profitably because peak spot prices are too often below their marginal operation costs. Thus, the RES, by lowering equilibrium spot price level, will squeeze peak load power plants out of the market due to their comparatively higher variable costs.

The following Figure 2 shows the merit-order curve based respectively on average and on marginal costs.

Figure 2. Merit order based on average and marginal costs



Merit order **based on average costs (**Q_1^*; P_1^***)**

Merit order **based on marginal costs (**Q_1^*; $P_2^* < P_1^*$**)**

3. Empirical evidence

The total nominal power of wind farms climbed from 6.06 gigawatts (GW) in 2000 up to 33 GW by 2013 making Germany the third place in the international rankings behind China and the U.S. In this empirical section, we carry out an empirical analysis for Germany in order to explore this most evidenced stylized fact of RES impact on spot electricity prices: the merit order effect.

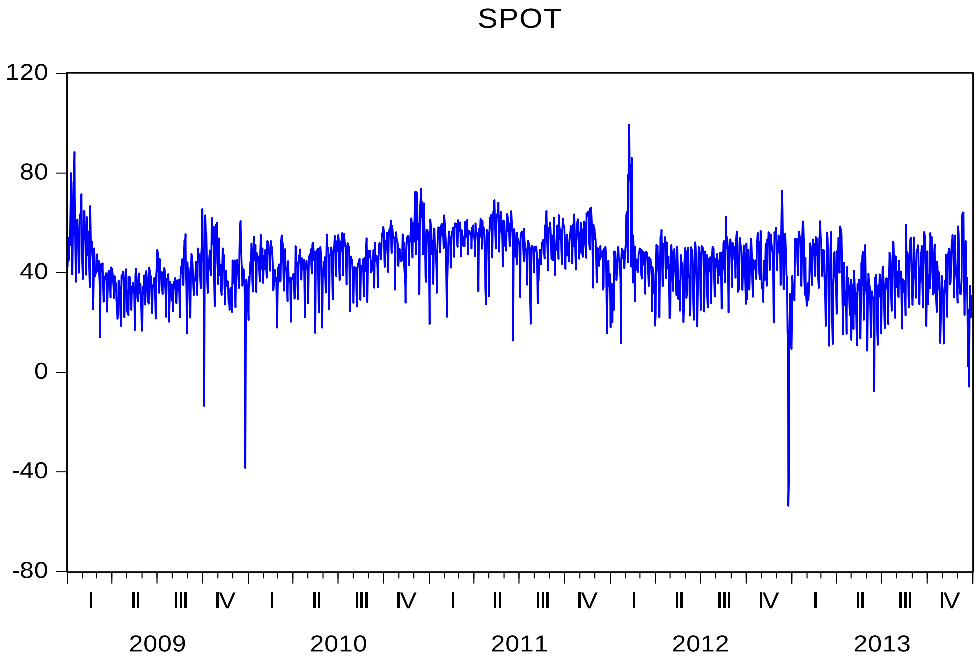
3.1 Data

The analysis is based on time-series data of the German power system as provided by the platform of the European Energy Exchange (EEX) .

The data is daily Phelix base load. The spot market is a day-ahead market and the spot price is an hourly contract with physical delivery on the next day. The Phelix Day Base is then calculated as the average, weighted price over these hourly contracts. The sample data covers the period going from the 1st January 2009 to the 31st December 2013, summing up to 1826 observations.

Figure 3 provides a plot of the data for the whole period. It is easy to see that the data exhibits the typical features of electricity prices and contains several periods of extreme volatility, price spikes and shows a mean-reverting behavior.

Figure 3. Daily EEX day-ahead spot prices (€/ MWh)



The descriptive statistics of German electricity spot prices summarized in Table 1 show that values of sample mean are close to 43.57 and a standard deviation of 12.10.

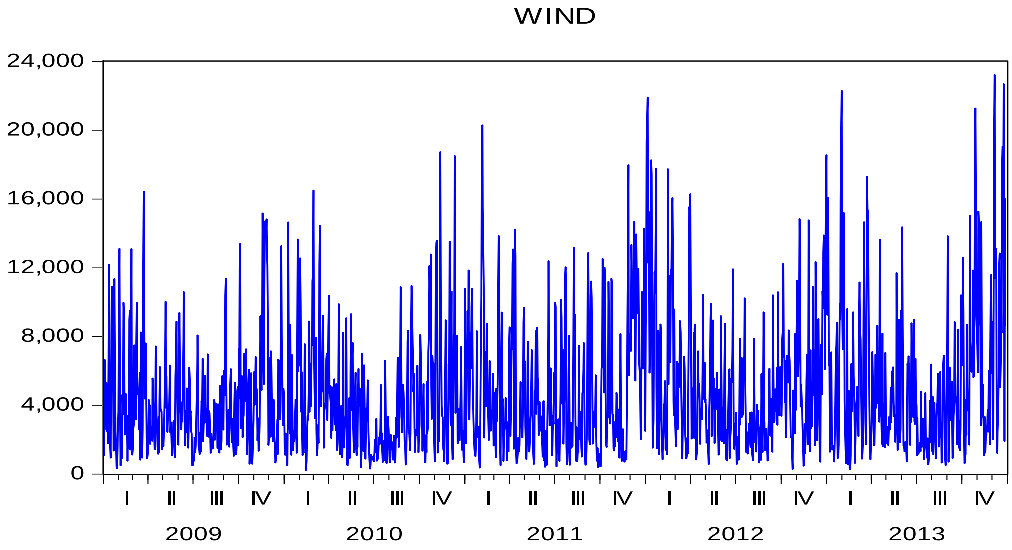
Table 1 Descriptive statistics of German electricity spot prices.

Observations	1826
Mean	43.50
Std.Dev.	12.10
Skewness	-0.84
Kurtosis	8.34
Jarque-Bera	2394.22
Prob.	0.0000

The sample kurtosis (11.50) is higher than 3, the kurtosis of a normal distribution, implying that price distribution exhibit fat tails. Furthermore, negative skewness indicates a greater probability of large falls in electricity price than large increases. By the Jarque- Bera statistic, the null hypothesis of normal distributions is also rejected.

For the wind power in-feed, we use daily forecasts for the full period as illustrated in Figure 4.

Figure 4 .Wind power feed-in (2009-2013)



These forecasts are made by the four German transmission system operators (TSO).[4] The descriptive statistics of wind feed-in reported in Table 2 show that the

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[4] The data are available in 15-minute format. For this study, 15-minute MW data are averaged for each hour and again averaged to MWh per day. There is four transmission system operators (TSO) in Germany and

Wind power forecasts fed into the grid has a mean of 4787 MWh per day but a high variability.

Table2. Descriptive statistics of wind feed-in

Observations	1826
Mean	4787.28
Std.Dev.	3795.48
Skewness	1.50
Kurtosis	5.52
Jarque-Bera	1171.47
Prob.	0.0000

The price distribution exhibits fat tails (excess kurtosis) and the null hypothesis of normal distribution is rejected according to Jarque-Bera statistic.

3.2 Empirical methodology: ARMA-X-GARCH-X model

In order to explore the link between daily electricity spot price and wind in-feed, we should carry out a linear regression using least squares method. As electricity spot prices deviates from the normal distribution due to more frequent large outliers, outliers should first be removed before conducting the regression analysis. In line with the literature, we remove values that exceed three times the standard deviation of the original price series. The outliers are then replaced with the value of three times the standard deviation.

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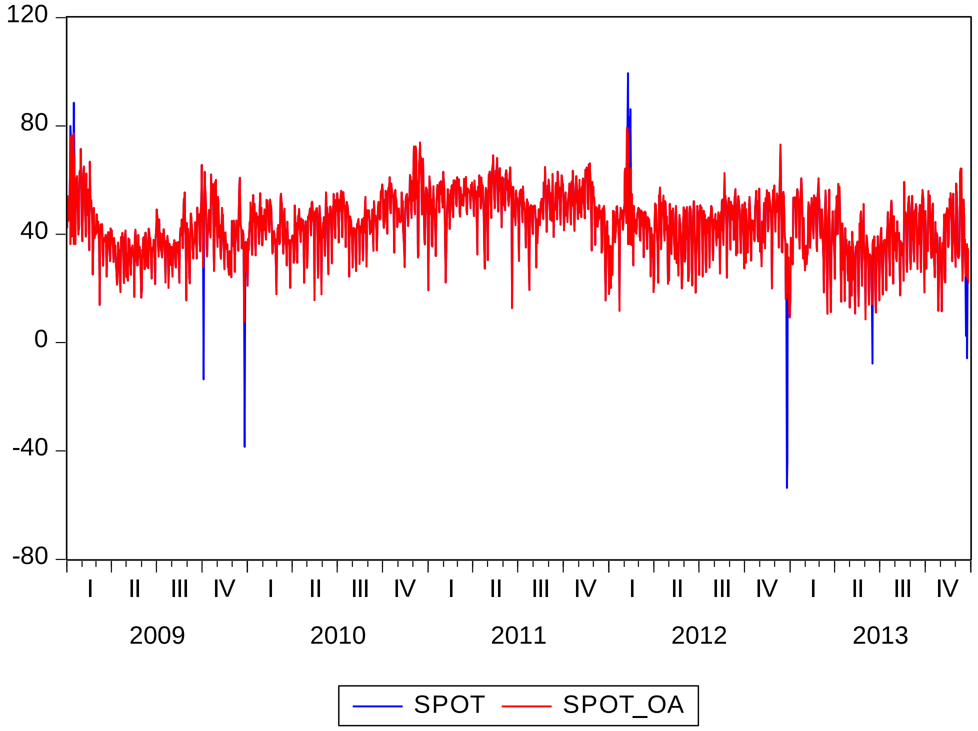
one TSO in Austria: *Amprion GmbH, TenneT TSO GmbH, 50hertz Transmission GmbH, EnBW Transportnetze*, and *APG-Austrian Power Grid AG*.

Figure 5. Outliers adjustment of spot electricity prices



Furthermore, the analysis of electricity spot prices correlogram shows a strong autocorrelation in lags 7,14,21,28 indicating a weekly seasonality. Indeed, electricity demand has a typical seasonal pattern as it varies throughout the day and during the week, as well as across the year. Therefore, models of electricity prices should incorporate seasonality by using dummy variables. For the weekly seasonality, dummy variables coefficients show a progressive lowering of electricity spot prices from the beginning to the end of the week. The lowest value occurs Saturday. For the monthly dummy variables, although some coefficients are not significant, we see a lowering of electricity spot prices during March, April, May, June, July and August.

After outliers removal and seasonal adjustment, we carry out an augmented Dickey-Fuller (ADF) test (Dickey and Fuller,1981) to test for stationarity properties of electricity adjusted spot prices.

Table 3. ADF unit root test on adjusted electricity spot prices

		t-statistic	**Prob.**
Augmented Dickey-Fuller	test statistic	-6.803016	0.0000
Test Critical Values:	1% level	-2.566233	
	5% level	-1.940998	
	10% level	-1.616582	

The ADF t-statistic is -6.8030 whereas the 5% critical value is -1.9410. The null hypothesis of a unit root is rejected, spot electricity prices are then stationary. As electricity is not storable, the price tends to spike and then revert (mean-reverting behavior) as soon as the divergence of supply and demand is resolved (Escribano et al., 2011).

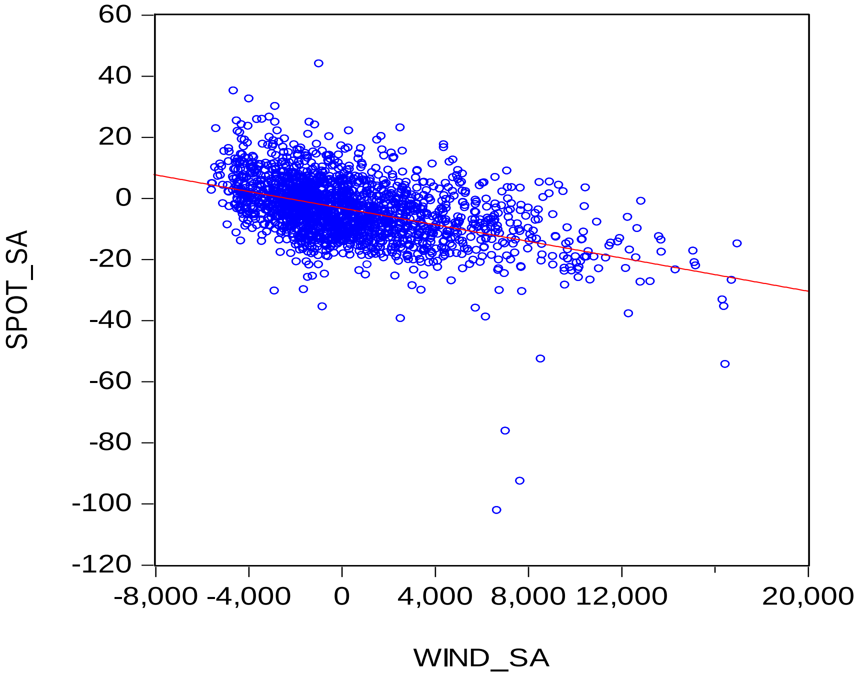
For the Wind power, the variable shows seasonal dynamics which could be accounted for by using dummy variables. The deseasonnalized time series called (wind_sa) is then tested using the ADF test which reveals their stationary behavior (the ADF t-statistic is -22.1589 whereas the 5% critical value is -1.9410).

Table 4. ADF unit root test on WIND_SA

		t-statistic	**Prob.**
Augmented Dickey-Fuller	test statistic	-22.15898	0.0000
Test Critical Values:	1% level	-2.566233	
	5% level	-1.940998	
	10% level	-1.616582	

The following figure 6 shows the negative impact of wind power on electricity spot price, the so- called merit order effect.

Figure 6. The merit order effect



Even after removing out seasonality and outliers, electricity spot prices still present high order serial correlation in its structure which could be filtered out by an autoregressive moving average(ARMA) filter (Box and Jenkins, 1976) . Therefore, the impact of wind-in feed on spot electricity prices is explored according to the following ARMA-X model where the wind feed-in considered as an exogenous variable X:

$$(spot\_sa)_t = \alpha_0 + \sum_{i=1}^{p} \alpha_1 (spot\_sa)_{t-i} + \sum_{j=1}^{q} \beta_j \varepsilon_{t-j} + \delta wind\_sa_t + \upsilon_t$$

The selection of autoregressive lag p could depend on AIC minimization, and q is assumed to be 0. According to the Akaike information criterion, the best choice was lag p=7 which corresponds to a weekly seasonality.[5]

The estimation results a reported in Table 5 (Column A) reveal a negative impact of wind power on the electricity price in Germany. Indeed, for each additional GWh of wind feed-in, the electricity price decreases by 1.23 €/MWh at the spot market.

This price decreasing effect of wind electricity generation in Germany is more pronounced than in Ketterer (2014), as we have used a more recent sample data.

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[5] The results of 7 autoregressive terms, not reported here, are available upon request.

Therefore, and given the average wind electricity generation during 2009-2013, the merit-order effect roughly corresponds to an average price decrease, in absolute terms, of approximately 6€/MWh.

Table 5. Wind feed-in impact on electricity prices

Dependant variable : electricity spot prices

Sample : 1.1.2009 31.12.2013

	(A)	**(B)**	**(C)**
		Mean equation	
Constant	-3.47 (0.0056)	-2.49 (0.0740)	-2.48 (0.0558)
Wind	-0.00123 (0.0000)	-0.0010 (0.0000)	-0.0010 (0.0000)
Spread			0.1316 (0.0000)
		Variance equation	
Constant		8.75 (0.0000)	11.93 (0.0000)
Alpha		0.39 (0.0000)	0.35 (0.0000)
Beta		0.31 (0.0000)	0.16 (0.0001)
Wind		0.000455 (0.0000)	0.000460 (0.0000)
Spread			-0.2617 (0.0000)
Adjusted.R squared	0.7125	0.7092	0.6930
AIC	6.2741	5.9693	5.9385
BIC	6.3013	6.0087	5.9839

Note: AIC and BIC stand respectively for Akaike and Bayesian information criterion, p-values are in parentheses.

The residuals of linear regression should then be homoskedastic according to least squares estimator hypothesis. Therefore, an ARCH-effect test following the procedure of Engle (1982) should be carried out on residuals. An ARCH effect in the residuals data indicates a time varying volatility dynamics. The parsimonious GARCH(1,1) specification (Bolleslev,1986) could be used to take into account the volatility of spot electricity prices.[6]

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[6] The GARCH (p,q) model was introduced by Bollerslev (1986). The conditional variance is expressed as $\sigma_t^2 = w + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2$ where $w > 0$; $\alpha_i \geq 0; i = 1,2,......p$; $\beta_j \geq 0,\ j = 1,2,.....q$ and [$\sum_{i=1}^{p} \alpha_i + \sum_{j=1}^{q} \beta_j$] < 1).The most used model in empirical litterature is GARCH (1,1) model where p=q =1 ; $\sigma_t^2 = w + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$.

Then, an ARCH-effect test following the procedure of Engle (1982) was conducted for the residuals time series. Results are reported in Table 6.

Table 6. ARCH heteroskedasticity test on regression residuals

F-statistic	120.83	Prob. F(1,1816)	0.0000
Obs*R-squared	113.41	Prob.Chi-Square(1)	0.0000

We conclude that the time series of residuals is heteroskedastic. We thus rely on the GARCH(1,1) to take into account the time-varying volatility feature.

As our goal consists in exploring the joint impact of wind in-feed on spot electricity price level and also on price volatility dynamics, the wind feed-in should be taken into account as an exogenous variable in the mean equation as well as in the variance equation. Therefore, our empirical analysis is based on ARMA(p,q)-X-GARCH(1,1)-X modeling where the exogenous variable X represents the wind in-feed. The empirical results based on AR(7)-X-GARCH(1,1)-X model are reported in Table 5 (Column B) .

The model parameters are positive and statistically significant at the 1% level. The sum of

$a + \beta$ is less than one. We can conclude that the introduction of wind electricity in Germany has not only reduced the electricity spot prices (-0.001098), but also induced an increase of their volatility (positive sign +0.000455 at the conditional variance equation).

Indeed, wind in-feed , due to the merit-order effect, not only reduces the electricity spot price level making them sometimes negative, but induces an increase of electricity price volatility, exacerbating risks in electricity markets.

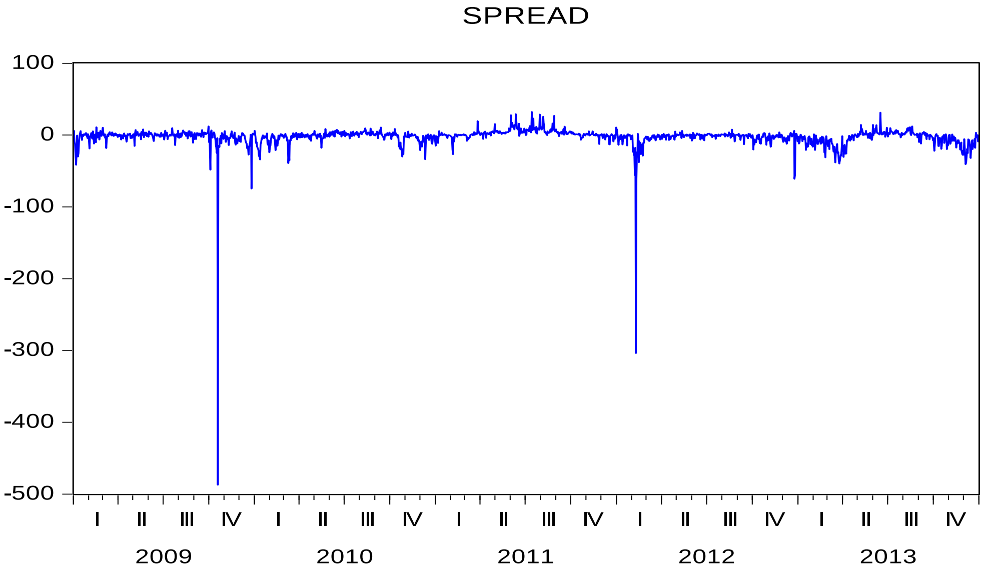
3.3 Impact of European interconnections

The Internal Electricity Market in Europe (IEM) consists in integrating all European electricity markets into one unique market. To reach this goal, the interconnections should play a central role by increasing efficiency of the interconnected systems. With the unused capacity, commercial exchanges are established taking advantage of the energy price differences between electricity systems. These exchanges make it possible for electricity to be generated using the most efficient technologies and allowing energy to be transported from where it is cheaper to where it is more expensive.

Germany has coupled its electricity markets respectively with Denmark in 2009, with Sweden in 2010. In November 2010, the countries of the CWE region (Belgium, France, Germany, Luxembourg and the Netherlands) and the Northern region (Denmark, Sweden and Norway) coupled also their electricity markets allowing flows of electricity toward and from neighboring countries.

For this study, we use the spread (price differential between Germany and France) as a proxy variable of market coupling and try to use it as an additional explanatory variable in our model (AR(7)-X-GARCH(1,1)-X model). The spread dynamics are shown at the following figure 7.

Figure 7. Spread of Germany-France electricity spot prices



In Table 5 (Column C), the reported results show that Germany-France electricity price spread not only increases the German spot electricity price but also lowers its volatility. Indeed, the coefficient of the spread is positive in the mean equation and negative in the conditional variance equation. With a better integrated electricity market, electricity export flows from Germany (low-price country) to France (country where demand and price are higher). Therefore, electricity exports are able to smooth the German spot price making it more stable, decreasing its volatility.

We can conclude that the introduction of wind electricity in Germany has not only reduced the electricity spot prices, but also contributed to an increase in their volatility. However, the challenge of a wind production excess in relation to low demand can be addressed by exporting the electricity production surplus to neighbouring countries.

Therefore, the interconnection of the European electricity grids behaves like a safety valve preventing the full effect of renewable power on the spot electricity price and its volatility.

The downward effect of the feed-in of wind-generated electricity on spot prices seems to be limited in comparison with the aforementioned empirical literature. But, it is worth noting that this literature considers a time period when the interconnections between the German transmission grid operators and their European neighboring counterparts were not developed as much as they are today.

Moreover, this downward effect is also partly offset by the shutdown of certain nuclear reactors, which modifies the merit order in favour of the more expensive thermal electricity. Furthermore, with time, grid managers are much better able to anticipate weather changes and control the feed-ins of wind or solar electricity (learning effect). Finally, the saturation of the grids is also a factor limiting the potential drop in spot prices, since part of the wind-generated electricity (offshore in particular) cannot be physically fed into the network for technical reasons.

4. Conclusion

The feed-in tariffs support scheme, consisting in buying intermittent electricity at a fixed price off-market considerably higher than the spot market price, has clearly induced a huge market penetration of RES.

The fact that this intermittent electricity has statutory priority on the grid and at the same time participates in spot market auctions at a zero marginal cost can have negative effects on the functioning of the spot market as it leads to a downward trend in the equilibrium price: the so-called merit-order effect. Indeed, each additional GWh wind (and RES in general) production of electricity will have a crowding effect on higher marginal cost power plants.

The purpose of the paper consists in quantifying the merit order effect of wind feed-in in Germany during the 2009-2013 period. One of the major findings is that the day-ahead electricity spot price fell by 1.23€/MWh for each additional GWh.

Moreover, the wind electricity generation has an increasing effect on the spot prices volatility.

However, all the negative effect of RES could significantly be limited by the interconnections of between Germany and neighbouring countries especially France, allowing it to export its surplus wind power. Therefore, the development of the renewable energy sources should be accompanied by a market coupling in order to address their challenges to European electricity system.

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