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Photovoltaic and Wind power feed-in impact on electricity prices in Germany

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Abstract

The goal of the paper is to quantify the impact of increasing renewable energy sources (RES) especially (wind generation and the photovoltaic feed-in) on the electricity prices in Germany, in order to investigate the well-known merit-order effect.

To explore this effect, we carry out an empirical analysis based on hourly historical data for the Germany electricity market between 2012 and 2016. Our main empirical findings suggest that the increasing share of wind generation and photovoltaic feed-in induces a strong decrease of electricity spot price level.

This merit order effect can have a negative impact on neighbouring electricity system. Moreover, the insufficient dispatching of the flexible gas-fired plants jeopardises their profitability and the fact that back-up is mainly done by coal plants creates a big challenge for Germany in its progress towards decarbonizing its energy mix.

Keywords: RES, Wind power, photovoltaic, Electricity spot prices, merit order effect.

JEL classification: Q41, Q42, Q48

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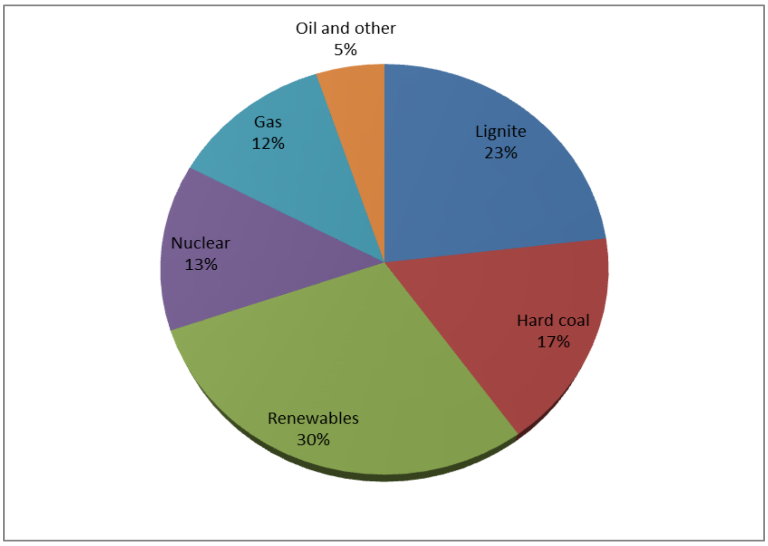
1. Introduction

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 to 30 per cent of gross electricity production in 2016 and are Germany’s second most important source of electricity generation after coal (BDEW, 2016). Figure 1 summarizes the recent evolution of the electricity mix. Carbon-intensive technologies clearly prevail in Germany, even though the system participation of renewables has grown significantly in the last few years.

Figure 1. Share of gross electricity generation (2016). (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 the paper is to quantify the impact of increasing renewable energy sources (RES) especially (wind generation and the photovoltaic feed-in) on the electricity prices in Germany, in order to investigate the well-known merit-order effect.

There are two main contributions of this study to the literature. Firstly, we take into account the joint impact of wind feed-in and solar photovoltaic on electricity price, with a more recent dataset allowing us to assess the learning curve of new technologies integration at the energy-mix of Germany.

Secondly, we carry out a multivariate regression along the 24 hours of the day using the seemingly unrelated regression (SUR) model in order to explore the joint impact of intermittent renewable electricity generation on the electricity spot price along the 24 hours of the day during 1827 days of our data sample. Therefore, the dynamics of the merit order effect is then assessed at an hourly resolution.

Our main empirical findings confirm that the increasing share of wind generation and photovoltaic feed-in induces a strong decrease of electricity spot price level. Moreover, this impact vary during the 24 hours of the day.

It is worth noting that 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.

The merit order effect was explored by several authors. For instance in 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. Cludius et al.(2014) have estimated the merit order effect of wind and photovoltaic electricity generation in Germany between 2008 and 2012. They showed that average specific effect (reduction of the spot market price per additional GW of renewable energy) lies between 0.8 and 2.3 €/MWh. and Benhmad et Percebois(2016,2017) also examined wind power in German electricity markets and found that an additional wind 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

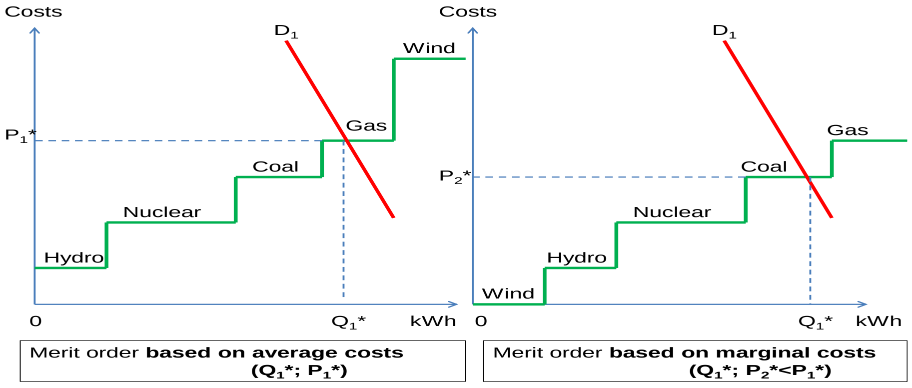
In order to supply electricity, different power generation technologies compete with each other according to their availability of supply and their marginal cost of production (fossil fuels such as coal or natural gas, nuclear power, renewable energy sources like hydroelectric generators, wind or solar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

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

Figure2. 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

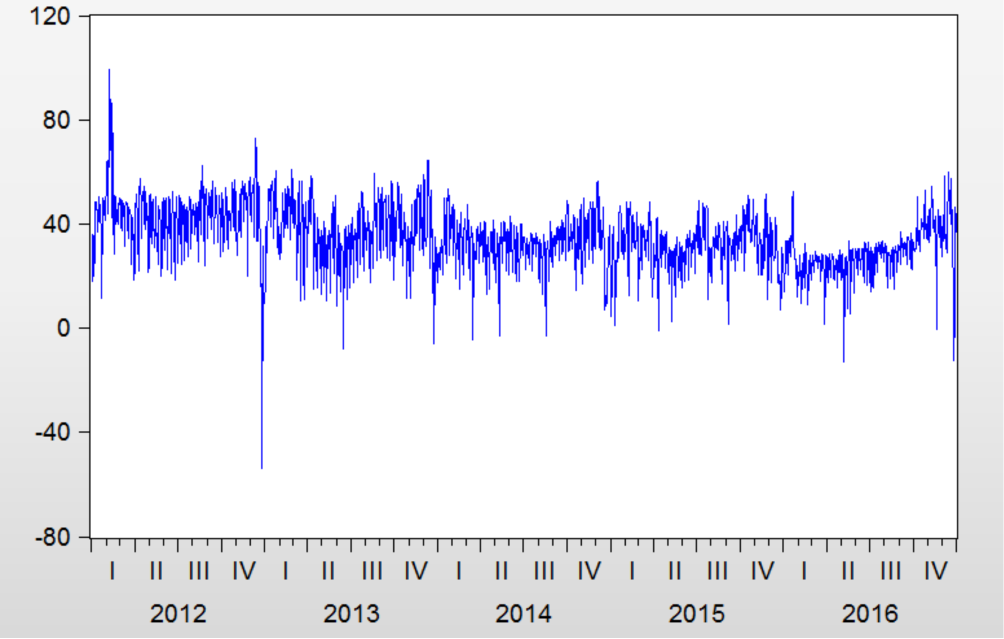
3.1 Data

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 spot market is a day-ahead market and the spot price is an hourly contract with physical delivery on the next day. Our dataset is based on hourly information on RES electricity generation (wind and photovoltaic), demand (load). The sample data covers the period going from the 1st January 2012 to the 31st December 2016, summing up to 1827 daily 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 34.97 and a standard deviation of 11.74.

Table 1 Descriptive statistics of German electricity spot prices.

Observations	1827
Mean	34.97
Std.Dev.	11.74
Skewness	-0.33
Kurtosis	6.86
Jarque-Bera	1171.37
Prob.	0.0000

The sample kurtosis (6.86) 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 RES generation, we use daily forecasts of wind power and photovoltaic generation for the full period as illustrated in Figure 4 and 5.

Figure 4 .Wind power feed-in (2012-2016)

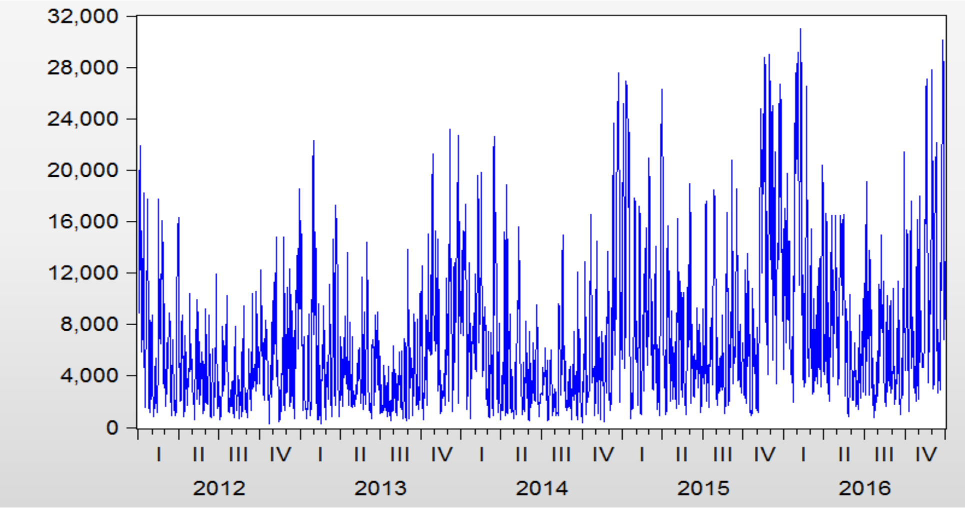
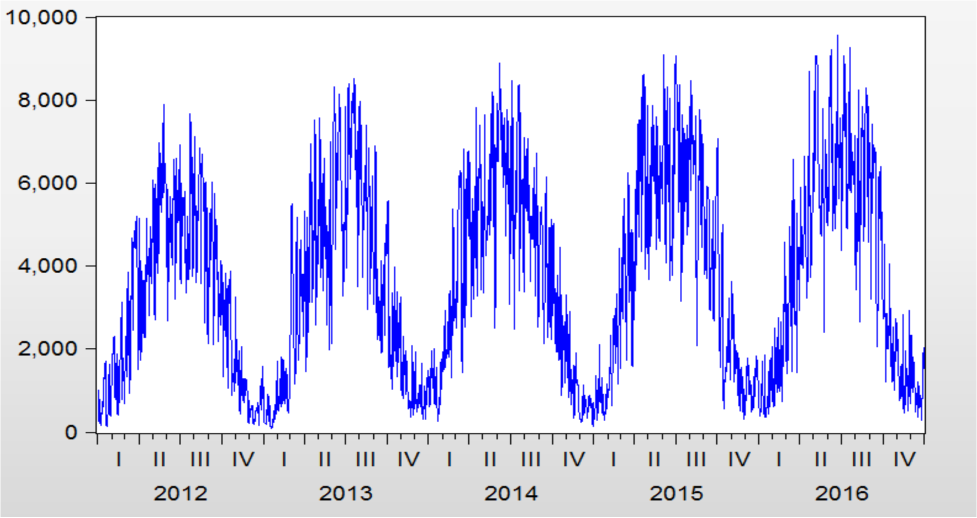


Figure 5.Photovoltaic power generation (2012-2016)



These forecasts are made by the four German transmission system operators (TSO).[1]

The descriptive statistics (Table 2) show that the wind power and photovoltaic forecasts fed into the grid has a respectively a daily mean of 6817 and 3651 MWh per day but a high variability.

Table 2. Descriptive statistics of wind feed-in and photovoltaic

	Wind	PV
Observations	1827	1827
Mean	6817.63	3651
Std.Dev.	5652.75	2380
Skewness	1.54	0.28
Kurtosis	5.32	1.91
Jarque-Bera	1135.58	113.14
Prob.	0.0000	0.0000

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

For the load representing power demand, we use daily forecasts for the full period as illustrated in Figure 6. Due to data publication at a 15 minutes frequency, 15-minute MW data are averaged for each hour and again averaged to MW per day.

Figure 6. Electricity Load (2012-2016)

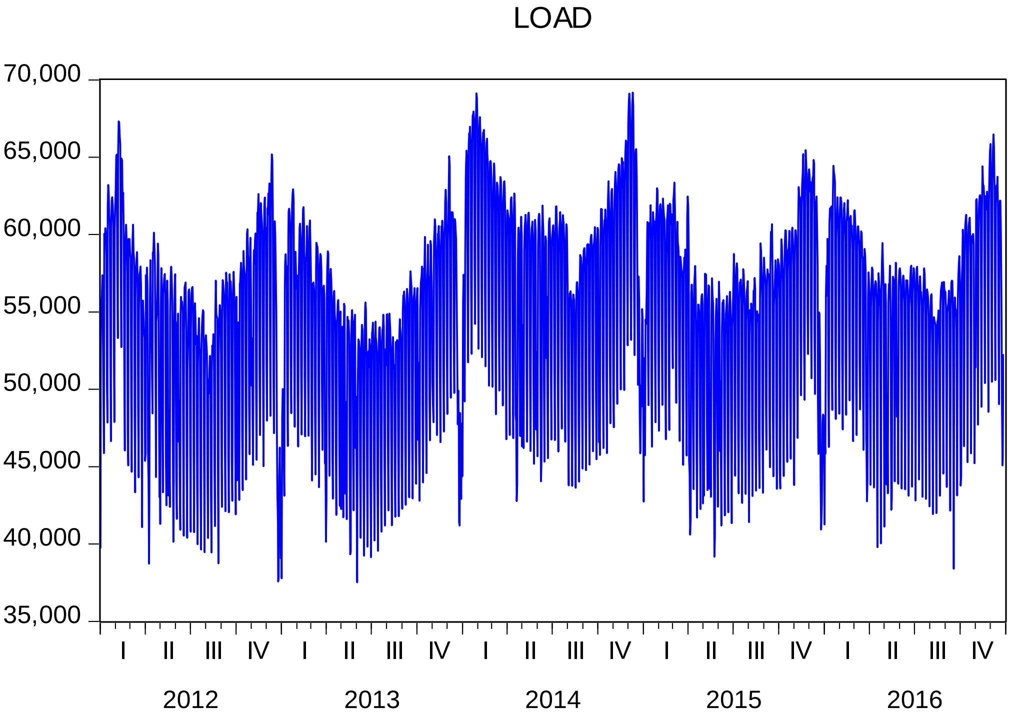


Table 3. Descriptive statistics of power load

Observations	1827
Mean	54693.85
Std.Dev.	6601.35
Skewness	-0.42
Kurtosis	2.39
Jarque-Bera	83.79
Prob.	0.0000

The descriptive statistics (Table 3) show that power demand, i.e load forecasts has a respectively a mean of 54.7 GW per hour but a high stability as the standard deviation is low.

3.2 Empirical methodology: SUR model

The seemingly unrelated regression (SUR) method is a multivariate regression introduced by Zellner (1962). It is used in estimating the parameters of a system of equations, taking into account for heteroskedasticity and contemporaneous correlation in the errors across equations. Estimating a system of equations can be done by estimating separately each equation in the system, using univariate methods (OLS for example).

An alternative approach consists on estimating, simultaneously, the complete set of parameters of the equations in the system. SUR methodology is a simultaneous approach allowing to take into account possible correlation in the residuals across equations. Therefore, it is an appropriate approach for studying hourly electricity prices due their high correlation. Indeed, the spot market is a day-ahead market and the spot price is an hourly contract with physical delivery on the next day.

Thus, in order to explore the link between daily electricity spot price and RES (Photovoltaic and wind power in-feed-in), we follow Hardle and Truck (2010) and Huisman (2007), and estimate a system of seemingly unrelated (SURE) regressions, one for each hour of the day:

$$S_{\{h,d\}} = \alpha_{\{h\}} + \beta_h \, L_{\{h,d\}} + \gamma_{\{h\}} W_{\{h,d\}} + \varphi_{\{h\}} \, P_{\{h,d\}} \quad + \sum_j \mu^s \, D^s_{\{h\}} + \varepsilon_{\{h,d\}}$$

The spot price $S_{\{h,d\}}$ in hour *h* of day *d* depends on: the load $L_{\{h,d\}}$ in hour *h* of day *d*, the wind feed-in *W* in hour *h* of day *d*; the photovoltaic generation P in hour *h* of day *d*; and finally a set of seasonal dummies *D* to account for the weekend and the months. There are N=24 equations in the system, one for every hour of the day.

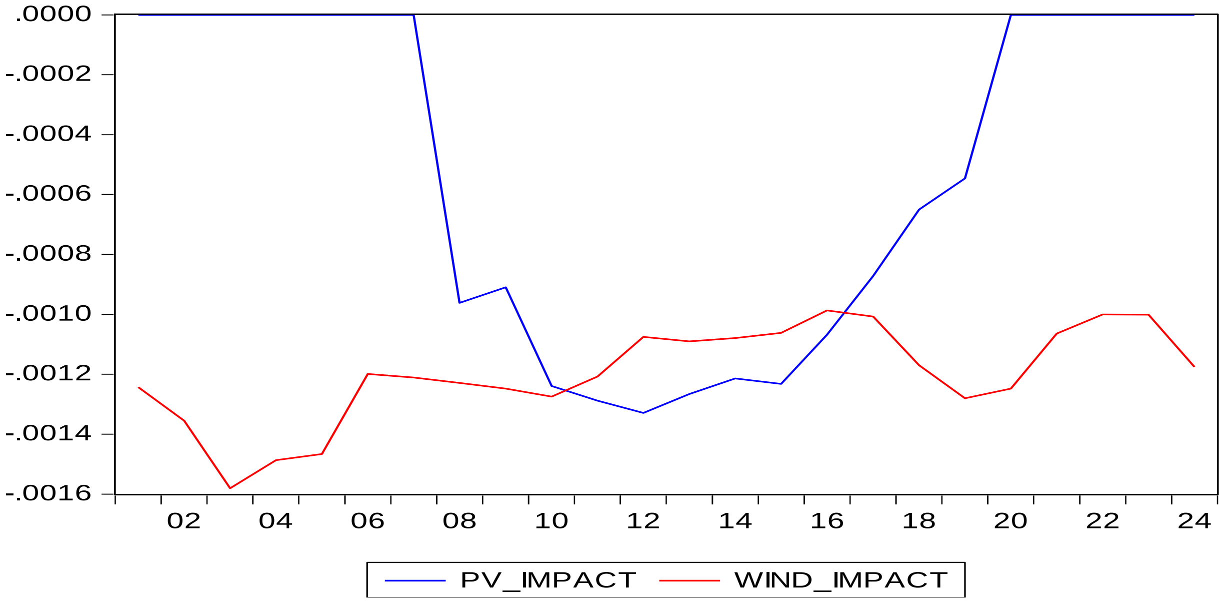
Indeed, the analysis of electricity spot prices correlogram shows a multiscale seasonality due to electricity demand which has a typical seasonal pattern as it varies throughout the day and during the week, as well as across the year. Therefore, our SUR model should incorporate seasonality by using seasonal dummy D. It is well known that 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.

We tested for unit roots in the electricity spot price hourly time-series using the augmented Dickey-Fuller (ADF) test (Dickey and Fuller 1979). The null hypothesis of a unit root could be rejected . Indeed, stationarity of electricity spot prices can be explained by the fact that electricity is a not storable commodity , then 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, photovoltaic and load power, where the seasonal dynamics are accounted for by using the same seasonal dummies *D* for the weekend and the months, their deseasonnalized time series show also a stationary behavior

As the number of coefficients resulting from a SUR model estimates is very high (about 138 coefficients), we have make the choice of reporting the results of merit order effect from hour 1 a.m. to hour 12 p.m at the following figure 7.

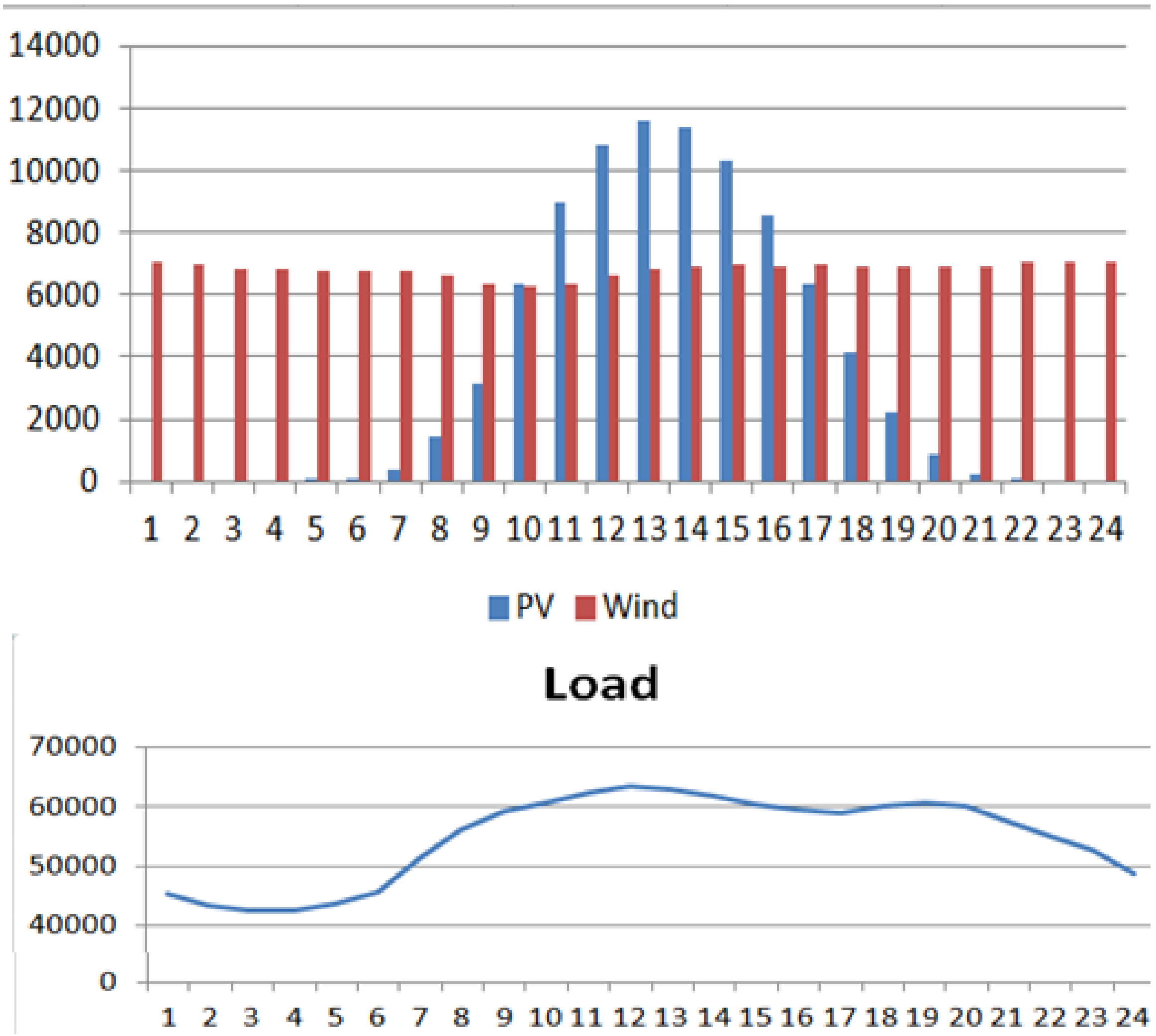
Figure 7. Merit order effect of Wind and PV feed-in



Our results on hourly data confirm that there is a statistically significant negative effect of wind and photovoltaic feed-in on the electricity spot price: the so called merit order effect.

The results reported in figure7 reveal a negative impact of wind and photovoltaic generation on electricity spot price in Germany. However, the two impacts dynamics are quite different as the wind impact, although more pronounced at the early hours of the day due to weak demand, has approximatively the same mean level during the days, whereas the PV impact reaches its maximum level between 12 AM and 1 PM with a shape of a bell curve with no sunshine at early mornings, during evenings and nights. The generation of solar power over the day exactly follows the daily course of demand for electricity as shown by the following figure 8.

Figure 8. PV and Wind electricity generation and load dynamics from 0 a.m to 12 p.m



The PV typical daily shape of merit order effect is due to the fact that PV electricity is predominantly generated during the middle of the day when power consumption is at its midday peak. During middle of the day, the demand is so high, that the electricity price should be at its most expensive. However, as the solar PV power will mainly displaces electricity from expensive power plants (especially gas-fired power plants and pumped-storage), it will thus lower the equilibrium electricity price.

The growing of installed PV capacity had allowed the coverage of the midday peak load even on less sunny days, while on sunny days the electricity production during the middle of the day will cover even part of the base load, especially during the weekend and holidays.

When our empirical results are weighted by the loads of the corresponding to each of the 24 hours, we can conclude that for each additional GWh of wind feed-in, the electricity price decreases by 1.28 €/MWh at the spot market, and for each additional GWh of photovoltaic feed-in, it decreases by 1.93 €/MWh.

This price decreasing effect of wind electricity generation in Germany is more pronounced than in Ketterer (2014) and in Cludius et al.(2014), as we have used a more recent sample data with an hourly resolution. Therefore, and given the average wind electricity generation during 2012-2016, the merit-order effect roughly corresponds to an average price decrease, in absolute terms, of approximately 15€/MWh.

4. Policy implications:

Due to merit order effect, especially during middle of the day, the solar PV power will mainly displaces electricity from expensive power plants (especially gas-fired power plants).

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.

Therefore, 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.

Moreover, 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. Furthermore, the fact that back-up is mainly done by coal plants, when there is no sunshine nor wind blowing, creates a big challenge for Germany in its progress towards decarbonizing its energy mix.

Furthermore, 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. Therefore, the Internal Electricity Market in Europe (IEM) consists in integrating all European electricity markets into one unique market making them interconnected systems. Then, commercial exchanges can be established taking advantage of power price difference, allowing energy to be transported from where it is cheaper (Germany) to where it is more expensive (Neighbors especially France). Many power plants in neighboring countries could also suffer for an insufficient dispatching (flexible gas-fired plants, but also nuclear plants) that could induce a crowding out effect from their domestic power market by jeopardising their profitability.

Furthermore, the rising bills for households due EEG Umlage showed that the affordability of electricity is the issue which most concerns the public especially low-income households in Germany which are at risk to suffer from a fuel poverty. Moreover, the stability of more decentralized electricity system asks for huge investments in storage and in grid reinforcements.

Such approach suggests that several cross-subsidies can be observed when renewable are subsidized: the producers of conventional electricity as the end-users are the losers, the producers because of the crowding-out effect due to the priority of renewables on the spot market, and the consumers because of taxes levied to finance the overcost. The providers of electricity are the winners because they sell at regulated prices the electricity bought at lower prices on the spot. Producers of conventional electricity (excluding wind and solar power) incur two kinds of losses: a value loss owing to the decrease in the wholesale price; they sell their electricity at a lower price; a volume loss because the electricity generated by renewables is no longer produced by traditional means. Electricity consumers incur an additional charge levied via the tax, which is paid directly to the RE producers (wind and solar energies).Producers of renewable (wind and solar) benefit from two kinds of transfers: a transfer in revenues from the wholesale market (i.e., the sale of their electricity at the market price) and a transfer from the tax (guaranteed price). Wholesalers and providers benefit from a revenue transfer corresponding to the conventional electricity producers' loss of income. With the drop in wholesale prices, these operators (wholesalers and providers) pay less for the electricity they sell to their customers. Part of this rent can be kept by the intermediaries if the decrease in wholesale prices is not passed on to the customer (e.g. residential customers with government-regulated electricity contracts) and part can be recovered by customers with market-supply contracts in which the sales price is indexed to the wholesale price. In the latter case, customers recover 'with one hand' a share of the tax paid 'with the other'. But this rent can also be kept by the intermediary. All in all, these two categories of agents (RE producers and intermediaries) are the 'winners', and this of course corresponds to the transfer borne by the 'losers'.

Although a power system with high share of renewable is in need of considerable backup capacity on a regular basis, the low power prices may hurt the conventional power firms making backup capacity unprofitable. Therefore, a capacity market could be created in order to avoid missing money problem of these back-up power plants.

5.Conclusion:

In this paper, we have studied how wind and photovoltaic electricity generation influences the electricity price in Germany Electricity Market and showed that, during 2012-2015, the merit-order effect corresponds to an average price decrease of approximately 15€/MWh.

These findings could be quite interesting for the future of the German electricity market design, especially for the reform of RES support scheme, feed-in tariff (FIT) provided by German Renewable Energy Act, ”Erneuerbare-Energien-Gesetz” (EEG) allowing the burden on non-privileged consumers (EEG Umlage) to be reduced. They are also of great interest in order adress the merit-order effect of RES power feed-in, inducing an insufficient dispatching of the flexible gas-fired plants and then jeopardising their profitability; the so called missing-money problem.

Finally, EU-ETS price weaknesses creates a big challenge for Germany in its road to decarbonizing its energy mix as back-up for RES intermittency is mainly done by coal plants.

If we assume that a sustainable energy system -comprised largely of renewable energy sources- is the only long-term solution to Germany and European energy mix future, the RES growing expansion may incur high challenges that should be adressed.

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