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Spotpreisvarianz an europäischen Strombörsen – Einflussfaktoren und die Rolle der Erneuerbaren Energien

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Kurzfassung: Dieses Paper untersucht den Einfluss von fluktuierenden erneuerbaren Energien (RES) auf die Varianz des Spotpreises an europäischen Strombörsen. Ein theoretisches und ein empirisches Modell für 23 Länder in Europa bilden die Grundlage der Analyse für das Jahr 2015. Die Ergebnisse zeigen, dass es zwei Einflussfaktoren gibt, die sich für die Mehrheit der untersuchten Länder mit signifikantem Anteil an RES bestätigen lassen: Die Varianz der fluktuierenden erneuerbaren Erzeugung selbst erhöht die Preisvarianz in 67% der Länder, wohingegen die zeitliche Korrelation der erneuerbaren Erzeugung mit der Nachfrage die Preisvarianz in 77% der Länder senkt. Es zeigt sich eine quadratische Abhängigkeit der Strompreisvarianz von der durchschnittlichen RES Erzeugung. Das heißt, dass sowohl hohe als auch sehr niedrige Mengen an RES die Preisvarianz statistisch signifikant erhöhen können, während moderate Mengen RES dagegen zu niedrigerer Preisvarianz in der Mehrheit dieser Länder sorgen. Das bedeutet, dass es in vielen Ländern eine Phase im Verlaufe des Ausbaupfades von RES gibt, in denen die Varianz des Spotpreises geringer ist als am Anfang oder Ende des Ausbaupfades. Dies macht deutlich, dass marktbasierte Anreize der Preisvarianz für Investitionen in Flexibilisierungpotentiale nicht zu jedem Zeitpunkt des Ausbaupfades eines Landes ausreichen. Gleichzeitig kann aufgezeigt werden, dass große Mengen RES sehr wohl die Preisvarianz erhöhen und somit genau diese Maßnahmen für eine nachhaltige Realisierung der Ausbauziele für erneuerbare Energien nötig machen.

Keywords: Europäischer Strommarkt, Erneuerbare Energien, Strompreisvarianz, Merit Order

1 Introduction

There has been a significant growth of electricity generation by renewable energies throughout Europe over the past decade. This paper analyzes how the generation behavior of intermittent renewable energy sources (RES) influences spot price variance in Europe. With the share of RES in the grid growing, the establishment of technologies ensuring network stability is gaining more importance. A high price variance in the current market setting is a major precondition for investments in reserve power plants, storage plants, and infrastructures which increase the flexibility of the demand side of the market. This paper identifies the factors that influence price variance and particularly examines the role of renewable energies. It adds new evidence to this controversy by analyzing the question for a broad range of countries in Europe.

The theoretical basis for this work is a literature review and the development of a theoretical model to explain price variance. Then, this theoretical model is tested with empirical data for 23 countries and the year 2015 in a regression analysis. Different factors like demand levels, the variance of demand and RES production, and others that are influencing price variance

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are analyzed in an econometric multi-country analysis. Thus, the results provide a good basis for conclusions about general influences on the spot price variance in Europe.

2 Theoretical background

While the literature is quite homogenous concerning the reducing effect of RES on spot price levels, the question of price variance triggers different opinions. While most studies expect rising price volatility levels with increasing shares of RES (see e.g. Green & Vasilakos, 2010; Ketterer, 2014; Klinge Jacobsen & Zvingilaite, 2010; Milstein & Tishler, 2011; Woo, Horowitz, Moore, & Pacheco, 2011), some researchers argue that price variance is dependent on type and amount of RES and that RES can even reduce price variance (see e.g. Jónsson, Pinson, & Madsen, 2010; Tveten, Bolkesjø, Martinsen, & Hvarnes, 2013; Wozabal, Graf, & Hirschmann, 2016). Most of the studies which have been done so far focus on single countries or single technologies. That means that the choice of method, dependent variable, and explanatory variables varies much among different authors. Models which try to explain the price variance often consider RES generation (wind and PV), variance of this production, demand, prices of primary energy sources, temperature, competitiveness of the market, weather data like wind or radiation data, or daylight hours.

In this section, a theoretical model is presented which is designed to explain the influential factors of electricity price variance. The model was developed by Wozabal et al. (2016) and forms the basis of my empirical analysis. It identifies two pivotal factors impacting the electricity price in Germany: the shape of the supply function and the distribution of the residual demand in an electricity market. Green & Vasilakos (2010) as well argue that significant price volatility is dependent on those two factors: they state in a similar way that volatility depends on sufficient changes of RES feed-in, i.e. the distribution of residual demand, and the relationship between net demand and price.

Figure 1 shows the theoretical model which is based on a standard static market model with a given, inelastic load of electricity.

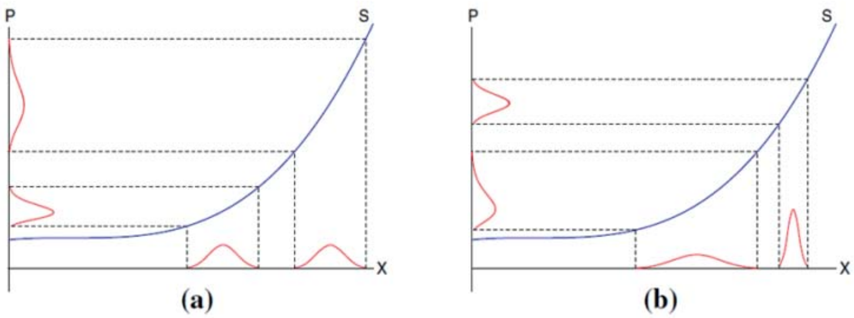

Figure 1: The two pivotal influencing factors on electricity price variance - shape of the supply curve and distribution of the residual load

Source: Wozabal et al., 2016

The intersection of the residual demand X (demand minus RES) and the blue, static supply curve S (aggregate industry cost function without RES) determines the electricity price P. The distributions drawn over the x-axis represent the stochastically varying residual demands, whereas the densities of the stochastic prices are drawn over the y-axis. The distribution of the

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residual demand creates the price distributions according to the slope of the static supply curve in a given time frame. In flat areas of the curve, alternating RES infeed causes smaller price changes as in parts with steeper slope.

In Figure 1, two time frames in two different market situations with different levels of RES infeed are compared to each other. We can observe two effects of increased RES feed-in besides the decreasing price level here. Firstly, the shift from a steep to a flat area of the supply curve causes a decrease of price variance. Secondly, in case of a change from a narrow to a broader residual demand distribution the price distribution broadens and increases the price variance. Depending on the relative size of those two effects, increased share of RES production can either increase or decrease price variance.

One of the assumptions of the model described is that the competitive market curve follows a convex shape. For the case of the German-Austrian market zone, several studies found out that a concave-convex market curve fits the real supply curve better than a purely convex market curve as shown in Figure 2 (see e.g. Fanone, Gamba, & Prokopczuk, 2013; He, Hildmann, Herzog, & Andersson, 2013; Wozabal et al., 2016).

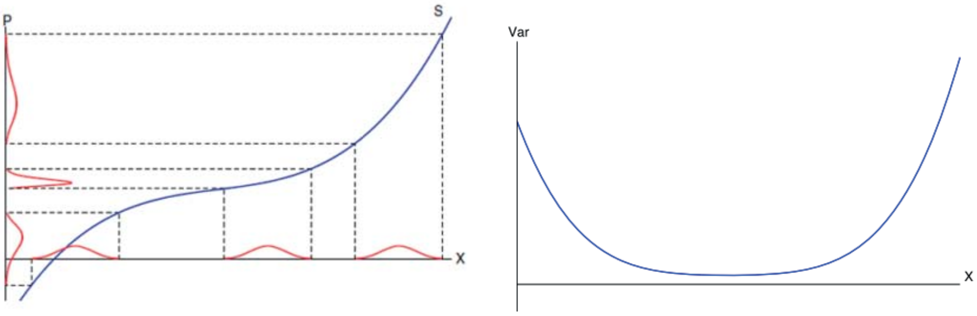

Figure 2: Price variance changes with a concave-convex supply function and price variance in dependence of mean residual demand assuming a concave-convex supply function

Source: Wozabal et al., 2016

In literature, this is explained as a consequence of the dispatch decision of conventional power plants which rather accept very low prices than switch off their plants due to high ramping costs. Assuming a concave-convex supply function, a high variance can be observed for a low and high residual demand, whereas for a medium residual demand low price variances occur due to the theoretical model (see also Figure 2).

3 Empirical model

The two influencing factors - the shape of supply and the distribution of residual demand - considered in the theoretical model are captured by different variables in an empirical analysis. An ordinary least square (OLS) regression model is developed in order to explain electricity price variance in dependency of RES infeed.

For this analysis, only the two intermittent renewable energies wind and PV are considered. Wozabal et al. (2016) analyzed the German-Austrian market zone for the years 2007 to 2013. My analysis is focusing on the year 2015 and extended to 23 countries in Europe. I apply a slightly modified empirical analysis of the described theoretical model of Wozabal et al. (2016)

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and extend the analysis to several European countries following the approach of Welisch, Ortner, & Resch (2016).

The dependent variable of the OLS regression $Price\ var$ is defined as the daily variance of the day-ahead spot price. This time frame is adequate because it is long enough so that varying RES feed-in can have an effect on the spot price, whereas a lower time resolution would lead to a loss of information since RES production would become too aggregated. Wozabal et al. (2016) include in their model daylight hours, temperature, oil price, and a three months lagged oil price. The oil price and the lagged oil price are included in my analysis as well. In order to capture the seasonality and cyclical patterns, though, I slightly adapt the empirical model and include dummies instead of daylight hours and temperature (see e.g. Paraschiv et al., 2014; Welisch et al., 2016). The daily average residual load enters the regression in form of a linear term and in form of a quadratic term. The quadratic residual load term is included in the analysis in order to include the possibility of a concave-convex supply curve as it was described for the theoretical model. Additionally, for taking into account the volatility of the residual load itself, the daily variance of the residual load is included.

$$Price\ var = \beta_0 + \beta_1 Residual\ Load + \beta_2 Var(Residual\ Load) + \beta_3 Residual\ Load^2 + \beta_4 Oil\ Price + \beta_5 Lagged\ Oil\ Price + \sum_{i=2}^{12} \beta_{4+i}\ dummies_{month} + \sum_{i=2}^{7} \beta_{15+i}\ dummies_{day} + \varepsilon \quad (1)$$

4 Data

The used primary data are time series from ENTSO-E (2016) and - in the case of the oil price - EIA (2017). As primary data for the independent variables, I use the day-ahead spot price [€/MWh], the day-ahead load [GW], the day-ahead generation forecast for wind and PV [GW], and the Europe Brent spot price FOB [€/barrel]. All variables are day-ahead market data and enter the models in daily resolution. Only in cases where there is no day-ahead data available, actual infeed resp. demand data is used.

Table 1 gives an overview of the developments in the German-Austrian market zone from 2007 to 2013 (the period analyzed by Wozabal et al. (2016)) and in 2015. The numbers are annual figures based on the hourly primary data, i.e. the table shows annual means and yearly empirical variances. The mean day-ahead price ranged between 31.82 €/MWh in 2015 to 64.83 €/MWh in 2008. After the maximum in 2008, the economic crisis hit and the spot price fell to 38.93 €/MWh. It recovered a little bit in the following years but after 2011, the spot price has continuously been decreasing to its minimum in 2015. Price variance was also the highest in 2008 and the lowest in 2015.

Table 1: Descriptive statistics of the German-Austrian market zone

Source: 2007 - 2013 by Wozabal et al. (2016) and 2015 own calculations based on ENTSO-E (2016)

Annual mean/variance	2007	2008	2009	2010	2011	2012	2013	2015
Price [€/MWh]	35.86	64.83	38.93	44.51	51.50	42.51	37.60	31.82
Price var [(€/MWh)²]	430.04	672.55	252.16	174.68	158.01	202.90	235.11	155.76
Wind [GW]	4.25	4.48	4.16	4.53	5.29	5.69	5.86	9.50
Wind var [GW²]	13.06	13.79	11.60	13.00	18.65	18.89	22.72	55.62

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PV [GW]				1.11	2.27	3.18	3.40	4.73
PV var [GW²]				3.25	11.08	22.86	27.93	44.84
RES [GW]	4.25	4.48	4.16	5.64	7.56	8.87	9.27	13.76
RES var [GW²]	13.06	13.79	11.60	14.88	25.98	36.57	43.26	85.43
Load [GW]	63.15	63.03	58.92	62.44	62.78	60.12	60.75	61.44
Load var [GW²]	117.50	109.15	122.93	109.44	125.34	132.11	121.96	122.02
Residual load [GW]	58.90	58.55	54.75	56.80	55.22	51.26	51.49	47.10
Residual load var [GW²]	113.14	103.24	119.03	103.88	112.98	127.36	120.87	134.64
Observations	8729	8753	8730	8760	8759	8784	8760	8016

The average load stayed more or less at the same level around 60 GW over the years with being on a slightly lower level in 2015 than in 2007. Average wind production more than doubled between 2007 and 2015 and reached 9.5 GW in 2015. PV production grew more than four times in just five years between 2010 and 2015. Accordingly to the increase in RES production, the average residual load decreased from 58.9 to 47.1 GW. The variance of RES production nearly doubled from 43.26 in 2013 to 85.43 in 2015 but load variance stayed almost at the same level. Residual load variance increased slightly from 120.87 to 134.64 at the same time. For the first time, variance of the residual load is higher than that of the load in 2015 due to the sharp increase in RES variance.

Table 2 presents the descriptive statistics of all countries analyzed for the year 2015 (annual averages calculated from the hourly primary data).

Table 2: Descriptive statistics of all countries examined for 2015

Source: ENTSO-E (2016)

Annual average values	Price [€/MWh]	Load [MW]	RES sum [MW]	PV [MW]	Wind off-shore [MW]	Wind on-shore [MW]
Austria	31.82	6898	630	94	[]	537
Austria/Germany	31.82	61442	13765	4728	1100	8376
Belgium	44.73	9943	888	347	284	299
Czech Republic	32.33	7656	317	249	[]	68
Denmark	22.90	3717	1609	76	494	1040
Estonia	31.09	785	74	[]	[]	75
Finland	29.66	9224	238	[]	[]	238
France	38.45	53733	3025	816	[]	2212
Germany	31.82	54562	13152	4622	1100	7871
Greece	51.93	5886	830	410	[]	420
Hungary	40.61	4576	81	[]	[]	81
Latvia	41.85	823	14	[]	[]	14
Lithuania	41.92	1235	86	7	[]	78

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Netherlands	40.06	17331	908	116	94	698
Poland	39.66	18675	1110	[]	[]	1110
Portugal	50.48	5590	1292	83	[]	1210
Romania	35.68	6564	1353	204	[]	1149
Slovakia	33.58	3232	62	60	[]	1
Slovenia	41.45	1402	42	42	[]	[]
Spain	50.33	28406	6928	1452	[]	5476
Sweden	21.16	14874	1794	[]	[]	1794
Switzerland	40.29	7006	39	31	[]	8
UK	43.53	37328	4520	874	1610	2032

Note: [] means no data available.

Annual average prices range between 21.16 €/MWh in Sweden and 51.93 €/MWh in Greece. The German-Austrian market zone is the biggest one with an average load of 61.4 GW. The highest relative share of RES is found in Denmark with an average share of 43% of the load produced by RES. In terms of absolute numbers, Germany is producing the highest amount of RES with an average RES generation of 13.2 GW in 2015. Overall, the countries Denmark, Germany, Greece, Portugal, Romania, Spain, Sweden, and the UK have an RES share higher than 10%.

Since a Durbin-Watson test indicates significant autocorrelation in the residuals, heteroscedasticity and autocorrelation robust (HAC) standard errors are used in the performance of the regressions which is a common approach in literature (see e.g. Andrews, 1991; Welisch et al., 2016; Wozabal et al., 2016; Zeileis, 2006). Furthermore, an augmented Dickey-Fuller test on the hourly data provides strong evidence against a unit root of the data (exception: in the case of the load variable the hypothesis of a unit root cannot be rejected for six countries). All modeling is conducted in Matlab R2015b.

5 Results

Firstly, the results for the German-Austrian market zone in the year 2015 are presented and compared to the results from literature by Wozabal et al. (2016) for the years 2007 to 2013. Secondly, the results for the other European countries are assessed.

5.1 German-Austrian market zone

5.1.1 Model 1

The results of Model 1 are displayed in Table 3. Model 1 is the basic model which only includes the terms of the residual load.

The comparison of the results shows that the absolute values of the coefficients are smaller for 2015, that their algebraic sign is the same for all significant coefficients, and that the same coefficients are statistically significant. This means the results of Wozabal et al. (2016) can be reproduced very well for Model 1.

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Table 3: Comparison of OLS results from Wozabal et al. (2016) and own results, Model 1

Model 1	Own results	Wozabal et al. (2016)
	Coefficients	
Intercept	404.29 (0.000)	981.73 (0.001)
Residual Load	-18.75 (0.003)	-40.06 (0.000)
Residual Load var	1.10 (0.000)	1.70 (0.000)
Residual Load2	0.19 (0.004)	0.43 (0.000)
Oil Price	0.23 (0.465)	-2.66 (0.136)
Lagged Oil Price	0.35 (0.566)	2.71 (0.126)
	(Weekly and monthly dummies)	(Daylight hours and temperature)
Adjusted R^2	0.36	0.25

Note: p-values in brackets; [green] statistically significant at a 0.05-level

Both, the coefficients of the $Residual\ Load$ and of the quadratic term $Residual\ Load^2$, are statistically significant. The variance of the residual load increases the price variance significantly. The results show that the residual demand has a convex quadratic influence on the price variance as anticipated in the theoretical model (see Figure 2). That means that low and high average residual demand leads to higher price variance. The results of the empirical analysis, therefore, support the hypotheses of the theoretical model. Both, the shift to steep parts of the supply curve due to low or high residual demand and the distribution of the residual demand itself, have a significant influence on the price variance.
The absolute values of the coefficients are lower in my analysis in all cases. One reason could be that the average price variance in the years 2007 – 2013 was higher than that in 2015 and, therefore, the estimated effect is more pronounced.

5.1.2 Model 2

Model 1 is further refined and the residual load is split up into its two components: $Load$ and RES. Accordingly, the quadratic terms $Load^2$ and RES^2 are included and the interaction terms $cov(RES, Load)$ and $Load * RES$ complement the equation.

Table 4: Comparison of OLS results from Wozabal et al. (2016) and own results, Model 2

Model 2	Own results	Wozabal et al. (2016)
	Coefficients	
Intercept	-396.817 (0.236)	152.550 (0.729)
Load	7.726 (0.558)	-15.590 (0.256)
Load var	0.620 (0.035)	1.150 (0.000)
RES	20,852 (0.109)	18.640 (0.096)
RES var	1.236 (0.000)	1.880 (0.000)

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RES, load covariance	-2.250 (0.000)	-5.920 (0.000)
Load * RES	-0.405 (0.017)	-0.690 (0.002)
$Load^2$	-0.010 (0.936)	0.230 (0.007)
RES^2	0.182 (0.035)	1.070 (0.000)
Oil Price	-0.329 (0.454)	-2.34 (0.122)
Lagged Oil Price	0.157 (0.805)	4.05 (0.012)
	(Weekly and monthly dummies)	(Daylight hours and temperature)
Adjusted R^2	0.36	0.29

Note: p-values in brackets; [green shading] statistically significant at a 0.05-level

My own results support the majority of results of Wozabal et al. (2016), except for the regressors *Load*^{2} and *Lagged Oil Price* which are not statistically significant in my analysis. Again, all coefficients are lower in their absolute value for 2015 than the ones for 2007-2013. The variances of the load and RES have a statistically significant positive effect on the price variance. Therefore, the results confirm the theoretical hypothesis that the distribution of the residual load, i.e. the distribution of the load and RES production, influences the price variance. The covariance and the interaction of RES and load, in contrast, have a negative effect on the price variance. While higher load would increase the price, higher RES infeed would decrease it. This opposite effect explains why the interaction terms have a negative influence on the price variance. However, the variances of RES and load themselves still increase the price variance.

5.1.3 Main findings for the German-Austrian market zone

For Model 1, all coefficients which were significant for Wozabal et al. (2016) could be confirmed for 2015 and support the hypothesis of a convex quadratic influence of the residual demand on the price variance. The theoretical model predicts higher price variances for low and high residual demand (see again Figure 2). This hypothesis about the relationship of residual demand and price variance in the theoretical model can also be supported when looking at the polynomic trend of the empiric price variance in the German-Austrian market zone (2007-2015) which is shown in Figure 3.

The annual average residual demand has decreased from 58.90 GW in 2013 to 47.10 GW in 2015 in the German-Austrian market zone. Price variance was higher towards both ends of this time frame than in the middle part. One drawback of this argumentation is that the sharp increase in price variance in 2008 because of the economic crisis could distort the polynomic trend. However, Wozabal et al. (2016) calculated in their analysis that a daily mean of 12 GW RES infeed produces the lowest daily price variance in the German-Austrian market zone. RES infeed was 9.27 GW in 2013 and 13.76 GW in 2015, so their mentioned tipping point was reached somewhere in between those two years. The minimum of the empirical price variance lies also somewhere between those two years (see Figure 3). My empirical findings, therefore, support the hypothesis of a convex quadratic influence of the residual demand on price

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variance in the German-Austrian market zone and show that price variance increases with high and low residual demand.

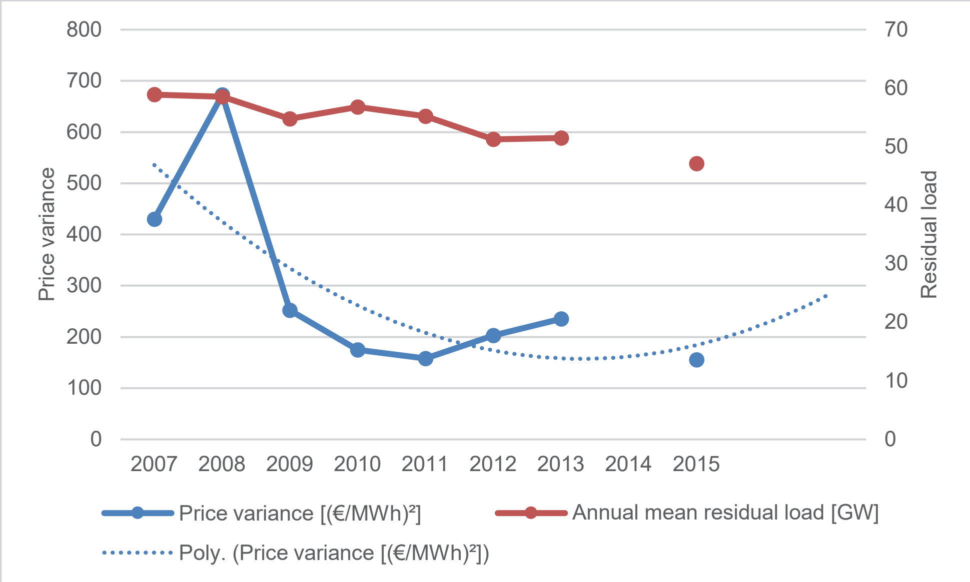

Figure 3: Empirical price variance in the German-Austrian market zone

Source: Author’s own illustration with data for 2007 - 2013 from Wozabal et al. (2016), 2015 own analysis

The main findings from Model 2 are that the variances of RES and load increase the price variance, while their covariance decreases price variance. That means that at a higher level of covariance the effects of the single variances are less distinct. Also, the variance of RES has a bigger impact on the price variance than the variance of the load. RES production, therefore, seems to be the more important part of the residual load for price variance.

5.2 Model results for other countries

In addition to the German-Austrian market zone, the models are applied to 22 other countries in Europe. The detailed results are available on request. The results for all countries with an RES share of the total load of more than 10% in 2015 are presented here. Those countries account for 68% of the installed RES capacity in the EU[1].

5.2.1 Model 1

The results of Wozabal et al. (2016) which can be reproduced well for the German-Austrian market zone are similar in most countries for Model 1. All coefficients which were statistically significant in the study of Wozabal et al. (2016) – $Residual\ Load$, $Residual\ Load\ var$, and $Residual\ Load^2$ - are also significant for the majority of the countries with a RES share higher than 10%.

In all countries where the residual load has a significant impact on price variance, this impact is negative. The quadratic term $Residual\ Load^2$ has a positive impact (except for Portugal). That means, for the majority of the analyzed countries with a RES share of more than 10% in Europe, the hypothesis of the convex quadratic influence of the residual load can be confirmed.

[1] Based on the installed capacity of photovoltaics and wind power in 2013 and 2014 (EPIA, 2014; EWEA, 2015)

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Furthermore, the variance of the residual load has a positive impact; increasing variance of the residual load increases the price variance in all countries with statistically significant results.

Table 5: Model 1 results for countries with an RES share of total load larger than 10%

Model 1	Austria/ Germany	Denmark	Germany	Greece	Portugal	Romania	Spain	Sweden	UK	Austria/ Germany (Wozabal et al., 2016)
Intercept	404.29	-15.88	325.94	1156.92	109.09	214.84	107.91	-26.58	742.30	981.73
Residual Load	-18.75	-0.04	-18.00	-377.85	24.32	-13.06	-3.98	1.02	-43.36	-40.06
Residual Load var	1.10	0.00	1.24	55.94	27.70	102.69	5.73	3.11	-0.19	1.70
Residual Load²	0.19	0.00	0.21	33.58	-4.83	-1.68	-0.08	0.08	0.69	0.43
Oil Price	0.23	0.09	0.20	-0.35	0.43	1.22	0.28	-0.41	0.81	-2.66
Lagged Oil Price	0.35	-0.43	0.29	-0.28	-0.25	0.00	0.29	0.11	0.94	2.71

Note: [green] statistically significant at a 0.05-level

5.2.2 Model 2

In Model 2, the coefficients of $RES\ var$, $RES\ Load\ cov$, and the interaction term $Load * RES$ are statistically significant for the majority of the countries. The covariance of RES and load is a very important factor which reduces price variance in Europe. Seven out of nine countries show a significant negative influence (except for 0.00 in the case of Denmark) of this covariance on the price variance. The interaction term $RES * load$ shows also a significant negative impact on price variance for six out of nine countries. Model 2 shows the importance of the interaction between load and RES: the higher the correlation, the lower price variance gets. Exceptionally though, in the case of Portugal, the interaction of RES and $load$ increases the price variance.

The impact of the variance of the load is only significant in the German-Austrian market zone and in Spain. The variance of RES production, though, is significant for six out of nine countries. Within the residual load, the RES production seems to be more important for the price variance than the load variance which can also be seen in the absolute values of both of the coefficients.

Greece and Portugal – both countries with high average price levels – show high absolute values for the coefficients for the load. Those countries are also the only ones to show significant coefficients for the quadratic term $Load^2$. Thus, the price variance in those two countries is very much impacted by the load.

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Table 6: Model 2 results for countries with an RES share of total load larger than 10%

Model 2	Austria/ Germany	Denmark	Germany	Greece	Portugal	Romania	Spain	Sweden	UK	Austria/ Germany (Wozabal et al., 2016)
Intercept	-396.82	-1076.57	-409.55	1005.76	915.57	54.24	213.30	-147.27	102.11	152.55
Load	7.73	0.49	9.43	-337.03	-292.32	49.63	-14.62	18.11	-4.72	-15.59
Load var	0.62	0.00	0.64	68.23	-53.01	112.76	2.61	5.64	0.12	1.15
RES	20.85	0.01	20.57	358.48	-47.72	-27.08	-3.24	10.73	45.29	18.64
RES var	1.24	0.00	1.28	67.78	17.91	115.78	7.31	2.18	7.66	1.88
RES Load cov	-2.25	0.00	-2.50	-63.27	-66.44	-220.36	-12.58	-6.79	-3.90	-5.92
Load*RES	-0.40	0.00	-0.45	-65.51	12.69	5.98	0.27	-2.74	-2.17	-0.69
Load²	-0.01	0.00	-0.02	30.15	26.68	-7.08	0.25	-0.36	0.19	0.23
RES²	0.18	0.00	0.19	45.11	-2.84	5.15	0.21	6.00	3.49	1.07
Oil Price	-0.33	-0.31	-0.39	-0.32	0.79	1.16	0.06	-0.35	1.04	-2.34
Lagged Oil Price	0.16	-0.43	0.15	-0.29	-0.03	-0.12	0.38	-0.04	0.72	4.05

Note: statistically significant at a 0.05-level

5.2.3 Main findings for Europe

This paper is able to reproduce the results of Wozabal et al. (2016) for the German-Austrian market zone in a more current time period quite well. The results for the German-Austrian market zone can only partly be observed in other European countries but there is also no major contradiction. Different electricity mixes, various degrees of competitiveness, different technical preconditions and geographic dissimilarities might be reasons for that. However, three factors – the variance of RES generation, the covariance of RES and load, and the interaction of RES and load – can be shown to be the most important ones driving price variance in Europe.

In both of the models, Denmark shows statistically significant but very low coefficients. One reason is that Denmark has a very low average price (see Table 2) and, therefore, the variance is also lower. However, the small absolute values of the coefficients could also mean that Denmark has effective measures like DSM in place which are able to react to the analyzed influences. Greece shows very high absolute values of the coefficients which could also be because of the high average price (see also Table 2). Almost no regressor is statistically significant for Sweden which is an exceptional case. Reasons could be that Sweden is well interconnected, has large controllable hydro power capacities available and has – like Denmark – more DSM measurements in place than other countries. The Nordic countries were also amongst the first ones to implement full liberalization of the electricity markets and, therefore, might have effective flexibility mechanisms implemented.

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The chosen macro scope of the EU provides a certain level of similarities of the countries' markets, but still, there are differences which cannot be adequately covered. For example, detailed market insights like the exact consideration of interconnections, cross-border flows, market size, the level of competitiveness of the market, or country-specific regulations were not possible. As an outlook, it might be beneficial to establish a cross-country model including those factors in order to identify the role of differences between countries.

6 Conclusion and policy implications

This paper deals with the question how intermittent renewable energies (RES) influence the electricity spot price variance in Europe. Three factors can be determined that show significant influence on a broad range of countries throughout Europe: the variance of RES generation, the covariance of load and RES generation and the interaction of RES and load.

Furthermore, countries with an average RES share higher than 10% were analyzed. The variance of the RES generation itself increases the price variance in more than two-thirds of those countries. Thus, the grade of fluctuation of RES does have a significant influence on price variance. The empirical analysis is furthermore able to confirm the hypothesis of a convex quadratic influence of the residual load for the majority of those countries. This means that in those countries, low and high residual load levels increase the price variance. However, moderate levels of RES lead to a lower price variance. That means that an increased share of RES does not necessarily increase price variance but can even lower it.

Extreme prices are often understood as signals to market participants and are indicators and incentives for investments in greater flexibility. The result that increasing RES can even lower price variance has, therefore, important market implications. The empirical analysis shows that there are times in the growth process of RES in a market when price variance is even lowered by RES. That means that during such a phase the market alone cannot provide incentives for sufficient investments in flexibility facilities. Politicians and investors alike have to be aware of those developments and cannot expect price variance alone to be the driver for such investments.

Another major conclusion of this study is the fact that the covariance and interplay of RES and demand play crucial roles for price variance and are able to reduce it significantly. More than 77% of the countries show a significant negative impact of the time-wise correlation of load and RES generation. This implies that RES technologies whose production tends to coincident with times of peak load rather decrease price variance than other RES technologies. Similarly, the results support the importance of demand-side management (DSM) since it also aims at increasing demand-side flexibility and the time-wise synchronization of RES production and demand.

This study identifies the main factors which are driving price variance significantly in a broad range of countries in Europe and provides a profound basis for understanding the mechanisms behind current issues about the integration of renewable energies into the existing energy system.

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