Heliyon 5 (2019) e02354

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.heliyon.com

Accommodating renewable energy sources in a small electricity market: An analysis considering the interactions of sources within Portugal and Spain

Tiago Lopes Afonso [a,b], António Cardoso Marques [a,b,*], José Alberto Fuinhas [b,c]

[a] University of Beira Interior, Management and Economics Department, Rua Marques d'Ávila e Bolama, 6201-001, Covilhã, Portugal
[b] NECE-UBI, Management and Economics Department, Rua Marques d'Ávila e Bolama, 6201-001, Covilhã, Portugal
[c] Faculty of Economics and CeBER, University of Coimbra, Portugal

ARTICLE INFO

Keywords:
Iberian electricity market
VAR model
Electricity price
Generation sources
STL decomposition
Economics

ABSTRACT

The Portuguese and the Spanish electricity generation systems are analysed in this paper. The Iberian market has been isolated and has an increasing proportion of renewable sources. The main objective of this study is to understand how electricity generation sources are interacting with electricity wholesale prices. The VAR approach was used because of its high robustness to cope with the endogeneity detected by Granger block Exogeneity tests. To do this, workweek data recorded since the opening of the Iberian market (July 2, 2007) was used. Despite the geographical proximity of the countries and their access to natural resources, the results provide empirical evidence of different modes of interaction in the market. This outcome could be due to the different sizes of the national systems. The Portuguese electricity generating system does not have an extensive structure to share back-up with Spain via conventional sources. Spain's substantial generation structure could be used to provide intermittent back-up generation for Portugal. Considering the similar supply and demand patterns of the Iberian generation systems, their openness to the other markets with different consumption and generation patterns could allow a more rational utilization of the renewables already deployed and, consequently, bring greater efficiency to the Iberian electricity market.

1. Introduction

The diversification of the electricity generation by the introduction of Renewable Energy Sources (RES) is well underway in domestic electricity mixes worldwide. Diversified mixes incorporating RES, require electricity power systems with internal mechanisms to accommodate these kinds of sources, such as cross-border interconnections, and pumping to create storage. To achieve this, the European Union has set both renewable power generation targets and minimum targets for interconnection between countries [1].

Different electricity sources, such as intermittent renewables, contribute to the generation mix. Intermittent renewables are characterized by: (i) low marginal costs; (ii) high initial investment costs; and (iii) discontinuous generation. The existence of a large electricity market is important to meet electricity demand during periods when the natural resources of wind and sun are unavailable. Indeed, cross-border interconnections are one of the most flexible instruments in a power system, given that they can be made available instantaneously. Flexible interconnections allow the external market to meet the demand for electricity when domestic generation is scarce, and export surplus electricity when domestic generation is high, and demand is low. The operation of wholesale electricity markets has been adapting to the variability of wind production. However, with the development of solar photovoltaic generation, peak prices may undergo changes, because the most productive period of this source coincides with peak demand.

When the electricity market is small, as in the Iberian market, which consists of Portugal and Spain, the markets of each country are likely to be strongly integrated. Indeed, as the interconnections between the Iberian electricity market (MIBEL) and the rest of Europe are scarce and fairly restricted, the two domestic electricity generation systems are very dependent on each other to satisfy their respective electricity demands and export any surplus.

Electricity market prices could make an important contribution to increasing these interactions between the two power systems, and generation sources could be important in defining the wholesale price of electricity and consequently increasing the exchange of electricity. In the literature, it is generally the impact of intermittent renewable energy on electricity prices that is analysed [2, 3]. This paper takes a fresh

* Corresponding author.
E-mail addresses: amarques@ubi.pt, acardosomarques@gmail.com (A.C. Marques).

https://doi.org/10.1016/j.heliyon.2019.e02354
Received 8 November 2018; Received in revised form 17 July 2019; Accepted 19 August 2019

approach, by analysing the causal inference between electricity prices and generation sources. The objectives of this paper are: (i) to analyse the role of electricity prices on electricity generation sources, (ii) to assess the effect of electricity generation sources (intermittent and continuous) on the electricity price, and (iii) to compare the behaviour of the two markets that constitutes the MIBEL. Bearing in mind the need to diversify electricity mixes, the electricity market can play an important role in accommodating different generation sources. It could bring economic rationality to the whole system, without requiring major investment in a new generation of backup infrastructure. In practice, this common market could play an important role in sharing back up for intermittent RES.

In this study, daily frequency data was used, more specifically, daily data for working days. The time span starts on the first day of MIBEL operation, on 2 July 2007 and continues up to 30 March 2018. An electricity system is managed in real time, so endogeneity between variables was anticipated. To handle these characteristics, a Vector Autoregressive (VAR) model was used. Generally, the Iberian market is hampered by restrictions, so it is urgent to increase market efficiency to accommodate renewables more easily.

The remainder of this paper is as follows. In Section 2 there is a brief literature review. Section 3 describes the data and method used in the study. The results are presented in Section 4 and discussed in Section 5. Section 6 presents the conclusions.

2. Background

Many countries have been increasing the share of RES in their energy mix, to reduce both carbon dioxide and meet international agreements. This relationship is well documented in the literature on emissions [4, 5]. The transition from fossil to renewable sources results from commitments to both national and international programmes, such as the Kyoto Protocol, the directives of the European Union and, most recently, the *2015 United Nations Climate Change Conference*, in Paris.

The European Union Directives [6, 7, 8] and incentive programmes established targets to deploy RES. Feed-in tariffs and renewable portfolio standards are some examples of these RES incentives, revealing the importance the European Union has given to the new renewables (namely wind and photovoltaic). Feed-in tariffs and renewable portfolio standards are really effective in encouraging the deployment of RES [9]. However the penetration of renewable sources through this type of incentive programs increases the cost of electricity to final consumers (e.g. [10]). Moreover, the well-known characteristic of RES intermittency can lead to excess installed capacity [11]. Indeed, some literature warns that greater use of RES could constrain economic activity [12]. Other authors [13] note that the use of the new renewables requires a flexible system. A flexible system is characterized by high capacity generation by fossil fuels and renewable energies, a high interconnection capacity and electricity storage. This flexibility is encountering barriers that can slow hamper the change [14]. Thus, cross-border interconnections and market integration issues worldwide, have deserved particular attention in the literature [15, 16, 17].

The high penetration of RES in the energy mix of countries has received particular attention in the literature, due to the effect that these intermittent sources can have on electricity prices. The low marginal cost of wind and solar photovoltaic power can decrease the wholesale market price, this phenomenon is known as merit order effect [18]. With respect to wind generation, the effect seems to be consensual: wind power generation reduces the wholesale electricity market price [19].

The literature has found that the impact of intermittent renewable generation is more prevalent in European Countries due to their earlier deployment of renewables. In Italy, higher generation through intermittent renewables has decreased the wholesale price, but led to higher volatility [20]. In Slovakia, evidence of the merit order effect was found with respect to photovoltaic energy [21], although its effect was small, because of the high share of nuclear power plants in Slovakia. In the preceding study the cost of supporting schemes was found to be greater than the savings obtained through solar generation. Other studies such as Luňáčková et al. [2] found that photovoltaic generation does not reduce electricity prices but, due to subsidies, could actually increase wholesale electricity prices and the cost for consumers.

The merit order effect was also found in the largest electricity market in the world. the Midcontinent Independent System Operator (United States and Canada), where the negative effects of wind power on electricity price were also found [3]. However, the merit order effect is not a feature of small electricity markets. In Australia, wind and solar photovoltaic generation decrease wholesale electricity prices, when studied using intraday and daily data (the results are similar in both frequencies) [22]. The merit order effect for Portugal and Spain has already been analysed in the literature [23]. The author found evidence for the merit order in both intermittent generation sources: wind power and solar photovoltaic.

The previously mentioned studies have quantified the decrease in electricity prices due to intermittent generation with low marginal costs, but the inverse relationship has not been analysed. This study aims to fill this gap, by discovering whether there is a bidirectional effect between electricity wholesale prices and electricity generation sources.

3. Materials and methods

In order to achieve the objectives previously defined and, in particular, to assess the interaction between electricity sources and the impact of these interactions on the price of electricity, the variables used, for each country, were: (i) electricity generation by source; (ii) the market price for each country; and (iii) net exports of electricity. As the paper intends to compare the characteristics of the two countries comprising the MIBEL, the Spanish and Portuguese electricity systems were analysed separately.

Management of the electricity system, in particular, the composition of the mix, operates in real time. As such, in order to accurately assess those dynamics, a daily[1] frequency was used, for the period covering 2 July 2007 (when the Iberian market started operating) to 30 March 2018 (according to the data available at April 2018). The analysis focused on the workweek, i.e. from Monday to Friday, and comprised of 2805 observations. The database came from the Transmission System Operators (TSO) of each country, namely REN (Redes Energéticas Nacionais), and REE (Red Eléctrica de España), for Portugal and Spain, respectively. The sources of electricity generation considered were hydropower, coal, wind power, solar photovoltaic and nuclear plants (only for Spain). All of these variables are in MWh.

As this study is focused on the interaction between electricity generation sources and the electricity market, we used information about: (i) intermittent renewable energy sources (*RES-I*) that includes solar photovoltaic and wind power; (ii) electricity generated by conventional sources (*CONV*), i.e. coal and pumped[2] storage (run of the river was not included), in the Spanish case, electricity generated by nuclear plants was also considered; (iii) net exports of electricity, i.e. electricity exports minus electricity imports (*SXM*); and (iv) daily price (*LPRICE*), which is the natural logarithm of the arithmetical average price for each country. It should be noted that the price variable was extracted directly from the database of MIBELs' electricity market operator (OMIE), and the units are EUR/MWh. The market price for both electricity systems overlapped

[1] It is worthwhile to note that the smallest available frequency is 10 minutes in Spain and 15 minutes in Portugal. In order to obtain unbiased result, because of excessive white noise, the data were converted to a daily frequency.

[2] In the Spanish case, data on the electricity generated by water reservoirs and pumping consumption is only available separately on a monthly frequency. At a higher frequency, only the balance between electricity generated and pumping consumption is available. Using a linear interpolation, the pumping consumption was estimated to subsequently calculate the absolute value of the electricity generated by hydro as daily data.

most of the time. This means that capacity was available via the interconnections most of the time, and the price only differed when the interconnections were fully occupied. This was the market-splitting phenomenon. The *SXM* components, in MWh, were extracted from the OMIE's Market Results section.

Electricity generated by *CONV* can play a double role in the management of the system, by backing-up renewables (large hydro) and providing a base load (coal). Hydropower allows the storage of water to generate electricity at a future time. Unlike fossil sources, it does not increase greenhouse gas emissions. Nuclear plants are the least flexible energy source, due to their inability to quickly increase the electricity they generate. As such, they have an absolute base-load role within the electricity system, are always in continuous generation, and have dispatch priority. When the market price is low, one of the national electricity systems can import surplus electricity from the other, preventing a network bottleneck. Thus, the energy traded in the Iberian market depends primarily on the capacity of interconnections (availability), but also on the market price and electricity demand in real time.

There are several ways to deal with seasonality in the electricity data, namely the insertion of seasonal dummy variables and the use of a seasonality functions, such as sinusoidal functions. Another way to obtain de-seasonalized series consists of decomposing the time series into seasonal and trend components. A time series analysis of seasonal trend decomposition using the Loess (STL) method was developed by Cleveland et al. [24]. In contrast to the well-known Census X11 and X-13 ARIMA-SEATS, STL decomposition can be applied to any data. STL decomposition consists of decomposing the time series into seasonal, trend and remainder components. The adjusted series was obtained by subtracting the seasonal component from the original series. The results for the STL decomposition are shown in Fig. 1 for the Spanish case and in Fig. 2 for the Portuguese case. This adjusted series was used in the next steps.

In order to avoid biased results due to the presence of potential outliers, these were controlled by observing the Interquartile Range (IQR) in the boxplot. In Fig. 3, the boxplots are presented, and data outside the range of the power and upper limit was excluded.

The descriptive statistics of the variables, after seasonal adjustment and outlier correction can be seen in Table 1.

Continuing with the data analysis, subsection 3.1 describes how the stationary properties of the variables were analysed in order to find the most suitable models for accomplishing the objective of this study. In subsection 3.2, the assumptions of the vector autoregressive model are shown, as well as the specification model.

3.1. Unit root tests

There are two different points of view regarding the data frequency for integration tests. The frequency can be important to evaluate the stationarity of the series [25], and frequency data can affect the integration order [26]. Following the most recent literature [22, 23], unit root tests based on autoregressions were applied.

To check the stationary properties of the series, traditional unit root tests were performed, namely the ADF (Augmented Dickey Fuller) test, as well as the PP (Philips Perron) test. Results can be seen in Table 2. The null hypothesis for both the ADF and PP tests on the series had a unit root, thus the variable was non-stationary. The two tests pointed in the same direction. The null hypothesis was rejected at a statistically significant level of 1% for practically all variables. The exception was rejected at a statistically significant level of 5% (see Table 2). The results thus supported the stationarity of the variables in levels, in both tests, so all series were I(0).

3.2. VAR model

Having verified that the variables were I(0), the VAR (Vector Autoregressive) model was estimated with the variables in levels. The adjustment speed of the variables within the electricity system was expected to be fast. VAR/VECM models are widely used in empirical energy economics studies [27, 28, 29]. This method is particularly suitable when the variables are simultaneously explained and explanatory. This model can be specified as follows:

$$X_t = \sum_{i=1}^{k} \Gamma_i X_{t-i} + CD_t + \varepsilon_t, \tag{1}$$

where k is the number of lags Γ_i and C are the coefficient matrices of endogenous variables; ε_t denotes the residuals, X_t = [endogenous variables] and D_t = [constant].

The path of the empirical study was as follows. The first step was to analyse the optimal lag length. After this, the residual diagnostics tests were computed. In the third step, the Granger causality/Block Exogeneity Wald test was performed to examine the endogeneity of the variables. The forecast error variance decomposition revealed how a variable responds to shocks in specific variables. In turn, the Impulse Response Functions (IRF) allowed the behaviour of the variables to be observed, assuming the existence of an impulse in one variable. Overall, this path is the guideline for the next section.

4. Results

The lag order selection procedures for both the Spanish and the Portuguese electricity systems were performed. For Portugal, the Schwartz information criterion (SIC), and the Hannan-Quinn information criterion (HQ) suggested the number of lags being 5, and the Akaike Information Criterion (AIC) suggested an optimal lag of 7. Following good econometric practice, 5 and 7 were tested, and the results remained identical. Therefore, five lags were chosen according to the most restricted criterion. For Spain, the SIC, HQ, pointed to 6 lags and AIC pointed to 7. As the data is daily, and considers the workweek (Monday-Friday), i.e. 5 days per week, the optimal lag length was chosen for both models, and was 5 lags. Whichever criterion was used, the results for the diagnostics tests remained unchanged.

Two VAR models were estimated, one for Spain and one for Portugal. Then, estimation, residual diagnostic tests were made for both models. The autocorrelation Lagrange Multiplier test had the null hypothesis of no serial correlation. The null hypothesis for the White test (no cross terms) was homoscedasticity. The Jarque-Bera normality test had the null hypothesis of error terms following a normal distribution. For all these tests the null was rejected at a statistically significant level of 1%, which means that the residuals of the estimated models had autocorrelation, heteroscedasticity and did not follow a normal distribution. The residuals diagnostic results were in line with other studies [30]. Considering the high frequency of data (daily), this outcome does not pose a significant problem (e.g. [31]). Indeed, the series did not follow a normal distribution due to the high value of kurtosis, i.e. the distribution is leptokurtic. Taking into account these preliminary results, the Granger causality was performed, and the results can be seen in Table 3.

The Granger Causality/Block Exogeneity results suggested that the variables must be considered as endogenous variables, which reinforce the appropriateness of using VAR modelling to understand the relationships between generation sources and the Iberian electricity market.

Regarding Spain, Table 3 reveals the high endogeneity between variables. In short, the causalities are: *CONV↔RES*-I; *CONV↔SXM; CONV←LPRICE; RES-I↔SXM; SXM←LPRICE;* and *LPRICE→RES-I*. Focusing on Portugal, the causalities found are: *CONV↔RES-I; CONV↔LPRICE; CONV←SXM; RES-I↔LPRICE;* and *RES-I↔SXM.*

In Spain, conventional sources had no effect on market prices. Intermittent generation was also unable to affect market prices, even with the low associated marginal costs. In Portugal, net exports only affected electricity generated by wind power and solar photovoltaic at a 10% statistically significant level. The availability of these resources cannot be controlled. Inversely, renewables could affect market prices,

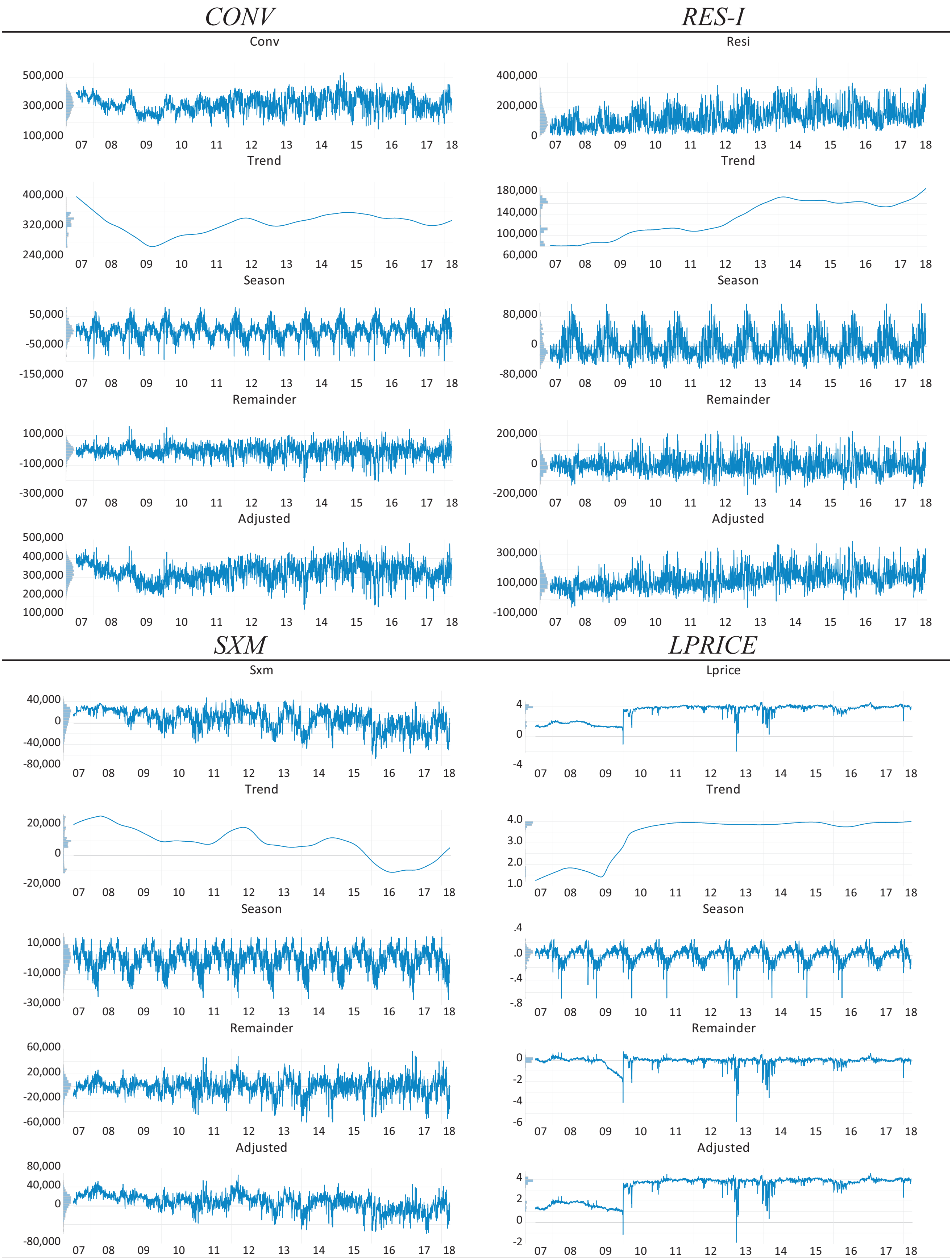

Fig. 1. STL decomposition for Spain.

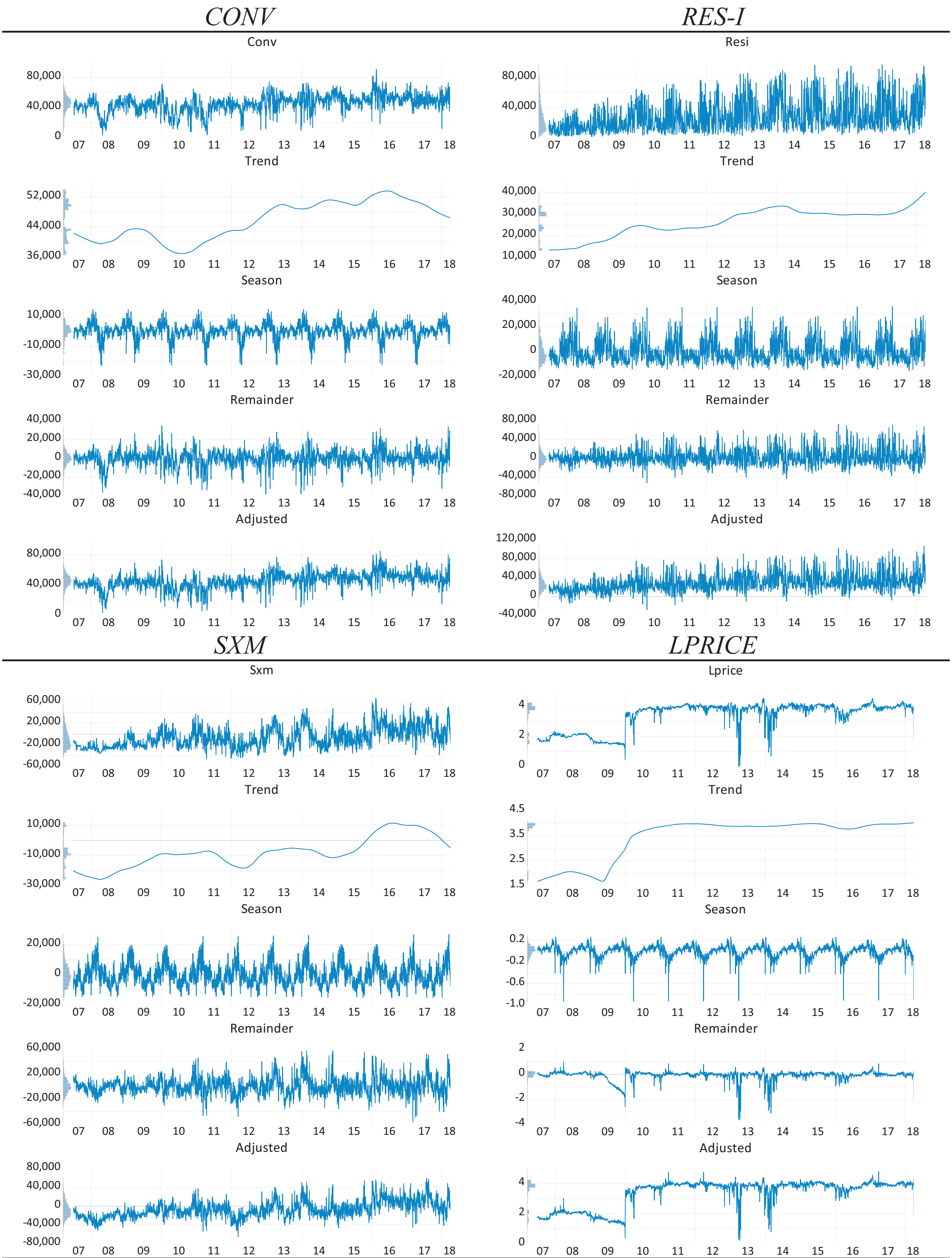

Fig. 2. STL decomposition for Portugal.

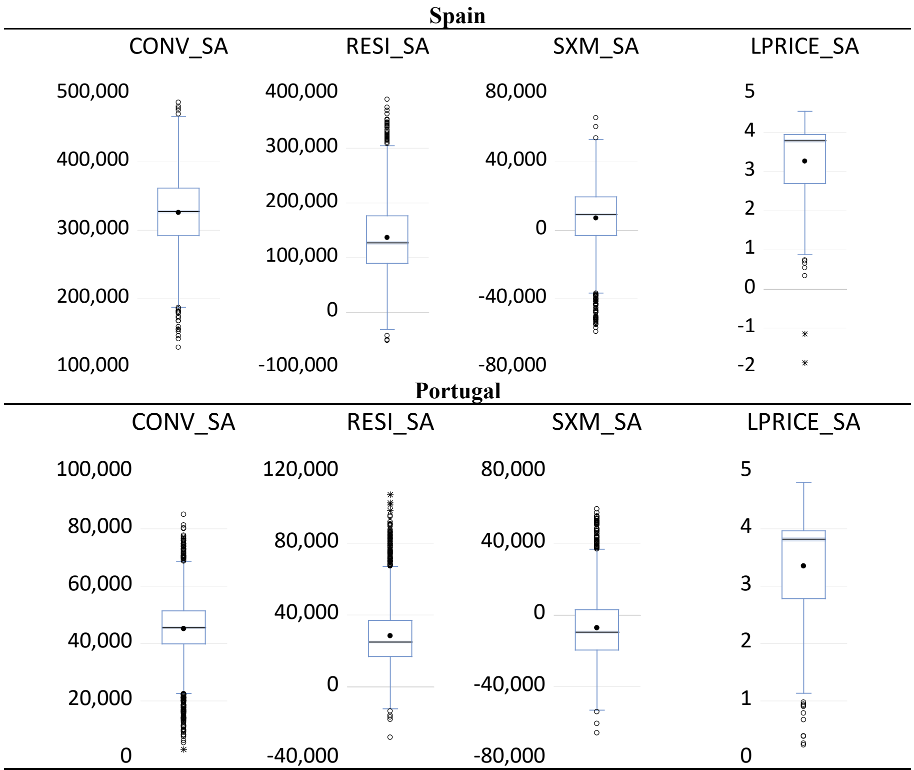

Fig. 3. Boxplots after the seasonal adjustment.

Table 1
Descriptive statistics.

	Spain				Portugal			
	CONV	*RESI*	*SXM*	*LPRICE*	*CONV*	*RESI*	*SXM*	*LPRICE*
Mean	326153.00	136385.60	7361.34	3.27	45322.49	27883.09	-7361.34	3.35
Median	327846.70	127878.60	9391.68	3.80	45689.33	25070.07	-9391.68	3.83
Maximum	466623.10	306649.80	53406.72	4.55	68725.62	67131.62	36762.06	4.81
Minimum	187658.00	-40077.56	-36762.06	0.83	22650.21	-13413.86	-53406.72	1.02
Std. Dev.	50630.09	64596.61	17395.03	1.02	9708.59	16245.13	17395.03	0.92
Skewness	-0.18	0.46	-0.43	-1.13	-0.18	0.57	0.43	-1.11
Kurtosis	2.84	2.99	2.96	2.55	3.17	3.06	2.96	2.55
Jarque-Bera	18.99	100.48	87.18	617.77	19.28	153.90	87.18	595.44
Probability	0.000075	0	0	0	0.00	0.00	0.00	0.00
Sum	9.15E+08	3.83E+08	20648544	9175.96	1.27E+08	78212080	-2.1E+07	9406.50
Sum Sq. Dev.	7.19E+12	1.17E+13	8.48E+11	2908.97	2.64E+11	7.4E+11	8.48E+11	2362.62
Obs	2805	2805	2805	2805	2805	2805	2805	2805

Table 2
Unit root tests.

Variables	ADF		PP	
	CT	C	CT	C
Spain				
CONV	-4.781588***	-4.604016***	-29.74209***	-29.57797***
RES-I	-21.79461***	-12.13546***	-30.68999***	-33.37377***
SXM	-9.910417***	-7.741062***	-33.79116***	-28.03276***
LPRICE	-3.416046***	-2.910281**	-6.821407***	-4.430039***
Portugal				
CONV	-12.79930***	-9.470920***	-36.62791***	-34.07476***
RES-I	-31.69533**	-13.54086***	-33.33834***	-37.11663***
SXM	-9.910417***	-7.741062***	-33.79116***	-28.03276***
LPRICE	-4.111598***	-3.299129**	-7.137697***	-4.470606***

Notes: CT stands for constant and trend; C stands for constant; *** and ** represents a statistical significance level of 1% and 5%, respectively.

but only at a 5% statistically significant level. The major difference between the two countries is their differing capacity to induce exports through electricity generation and market prices, which occurred in Spain, but not in Portugal.

The variance decomposition and the Impulse Response Functions (IRFs) were performed taking into account the usual Cholesky order, i.e. placing the variables in decreasing order of exogeneity. Nonetheless, whichever order was chosen, the overall results remained unchanged. The variance decomposition for both Spain and Portugal is shown in Table 4.

Regarding the variance decomposition of *CONV*, after 30 periods, it explained around 66 % of the forecast error variance by itself, with 29.52 % being due to *RES-I*. This occurred because, in Spain, *CONV* includes electricity generated by hydroelectricity and nuclear plants, i.e. uninterruptable generation. Electricity generated by water has a backup role in the system, and a baseload role in periods of abundant precipitation. Like gas turbines, hydropower is a flexible source. Intermittency is not a

Table 3
Granger causality test/Block Exogeneity Wald Tests – Spain and Portugal.

	Dependent Variable			
Spain				
	CONV	*RES-I*	*SXM*	*LPRICE*
CONV does not cause		13.31968***	14.61526**	6.537358
RES-I does not cause	227.0548***		15.84230***	6.487275
SXM does not cause	37.62211***	47.56584***		5.121093
LPRICE does not cause	45.78069***	42.05374***	10.17345*	
All	289.3082***	128.3547***	34.64295***	21.90866*
Portugal				
	CONV	*RES-I*	*SXM*	*LPRICE*
CONV does not cause		14.46798**	5.789855	16.91381***
RES-I does not cause	68.69278***		10.56912*	13.30634**
SXM does not cause	18.68197***	152.5584***		2.664926
LPRICE does not cause	29.38388***	38.56805***	5.735190	
All	155.8649***	271.4654***	28.31397**	50.52439***

Notes: the results are based on Chi squared statistics.
***, ** and * represents statistically significant level for 1%, 5% and 10%, respectively.

problem, as there is no shortage of water in the reservoirs so, even with *RES-I*, the system can maintain the renewable share, by using large amounts of hydropower.

With regard to *RES-I*, after one period, the forecast error variance is explained 99% by itself. After 30 periods, around 9% of the forecast error variance is explained by the *SXM,* due to the interaction with the Portuguese electricity generation system, and only around 2% is explained by *CONV*. Conventional sources have a back-up role due to hydroelectricity, but the backup for intermittent generation seems to be achieved by the market.

After 30 periods, shocks in *CONV* explain around 0.43% of the forecast error variance of the *SXM*. Meanwhile, *RES-I* explain about 0.67%. Spain usually exports by using electricity generated by *RES-I* and nuclear plants. Excess electricity generated by nuclear plants can provoke electricity exports. The nuclear power plants are the least flexible generation source and also have dispatch priority. Because their generation is continuous, production is independent of other sources, but the other sources must take nuclear generation into account. Net exports are stimulated by intermittent generation due to low marginal costs and the availability of resources (sun and wind).

100% of the forecast of the error variance of *LPRICE*, is explained by itself after 1 period, in contrast to the result of the variance decomposition of *CONV*. The cost of *CONV* depends on the price of fossil raw materials and not on the market price of electricity. Only after 30 periods is 1.41% of the forecast error variance explained by *SXM*. Generation sources are incapable of influencing market prices.

In the estimated model for the Portuguese electricity system, *CONV* only includes electricity generated from coal and hydropower for obvious reasons, i.e. the absence of nuclear power in Portugal. The forecast error variance for Portugal is also presented in Table 4. After one period, 68% of the forecast error variance for *CONV* is explained by itself, almost 17% by *RES-I*, and around 14% by the market price. After 10 periods, i.e. two workweeks, this result is divided, around 12% by *RES-I* and *LPRICE*. Only after 30 periods does *SXM* explain 12% of the *CONV*. The substitution effect between *CONV* and *RES-I* is noticeable after 1 period, although the effect is less representative than in the Spanish case. It should be noted that *CONV* has two different roles: providing a back-up via hydroelectricity, and a base load through coal power stations. Because of its back-up role, this outcome was expected.

Focusing on *RES-I*, after only one period, around 87% of the forecast error variance is explained by itself, and around 13% by *LPRICE*. As to net exports of electricity, even after 30 periods around 99% is explained by itself. Wind power and solar photovoltaic have a small impact on net exports of electricity. Compared with the Spanish electricity system, this result is VERY similar. After 30 periods, 99.9% of the forecast error variance of *LPRICE* is explained by itself.

Fig. 4 represents the IRFs of the endogenous variables for both Spain

Table 4
Variance decomposition.

Spain						Portugal				
Variance Decomposition of *CONV*:										
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
1	32974.55	54.4493	45.2564	0.2921	0.0022	6490.02	68.1210	16.9542	0.0790	14.8458
5	38795.66	53.2052	44.4104	0.6884	1.6960	7827.18	71.1835	12.9028	2.1575	13.7562
10	42971.71	60.0846	36.3472	1.9012	1.6671	8521.54	72.1181	11.1199	4.7870	11.9750
30	48140.22	65.8843	29.5196	3.1391	1.4571	9403.60	68.2167	9.6804	12.0124	10.0905
Variance Decomposition of *RES-I*:										
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
1	49432.55	0	99.7950	0.16210	0.0429	12779.99	0.0000	86.7797	0.3867	12.8337
5	62218.80	0.1639	96.3345	1.80556	1.6961	14818.88	0.0211	79.1798	8.6415	12.1576
10	64588.66	0.5627	93.1608	4.58670	1.6898	15099.06	0.6344	77.1495	10.3733	11.8428
30	67582.41	2.0371	86.3531	9.1723	2.4374	15544.84	1.2365	73.0383	13.2373	12.4879
Variance Decomposition of *SXM*:										
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
1	10260.93	0.0000	0.0000	99.9245	0.0755	10\272.49	0.0000	0.0000	100.0000	0.0000
5	12585.96	0.3270	0.0915	99.3480	0.2335	12523.41	0.1010	0.1521	99.6571	0.0898
10	14465.93	0.4256	0.3337	99.0259	0.2147	14382.02	0.1392	0.2444	99.5367	0.0796
30	16551.78	0.4318	0.6778	98.2926	0.5978	16486.67	0.5570	0.4043	98.6403	0.3984
Variance Decomposition of *LPRICE*:										
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*	SXM	*LPRICE*	*RES-I*	*SXM*	*LPRICE*
1	0.229219	0.0000	0.0000	0.0000	100.0000	0.209178	0.0000	0.0000	0.1257	99.8743
5	0.324253	0.0701	0.0285	0.0739	99.8275	0.290652	0.0697	0.2352	0.1458	99.5493
10	0.405048	0.0696	0.2675	0.2688	99.3941	0.355183	0.2491	1.0541	0.3017	98.3951
30	0.590744	0.1571	0.8470	2.0166	96.9793	0.510967	0.9947	2.0178	1.5310	95.4564

Note: Cholesky Ordering for Spain: *LPRICE SXM RES-I CONV*. Cholesky ordering for Portugal: *SXM LPRICE RES-I CONV*.

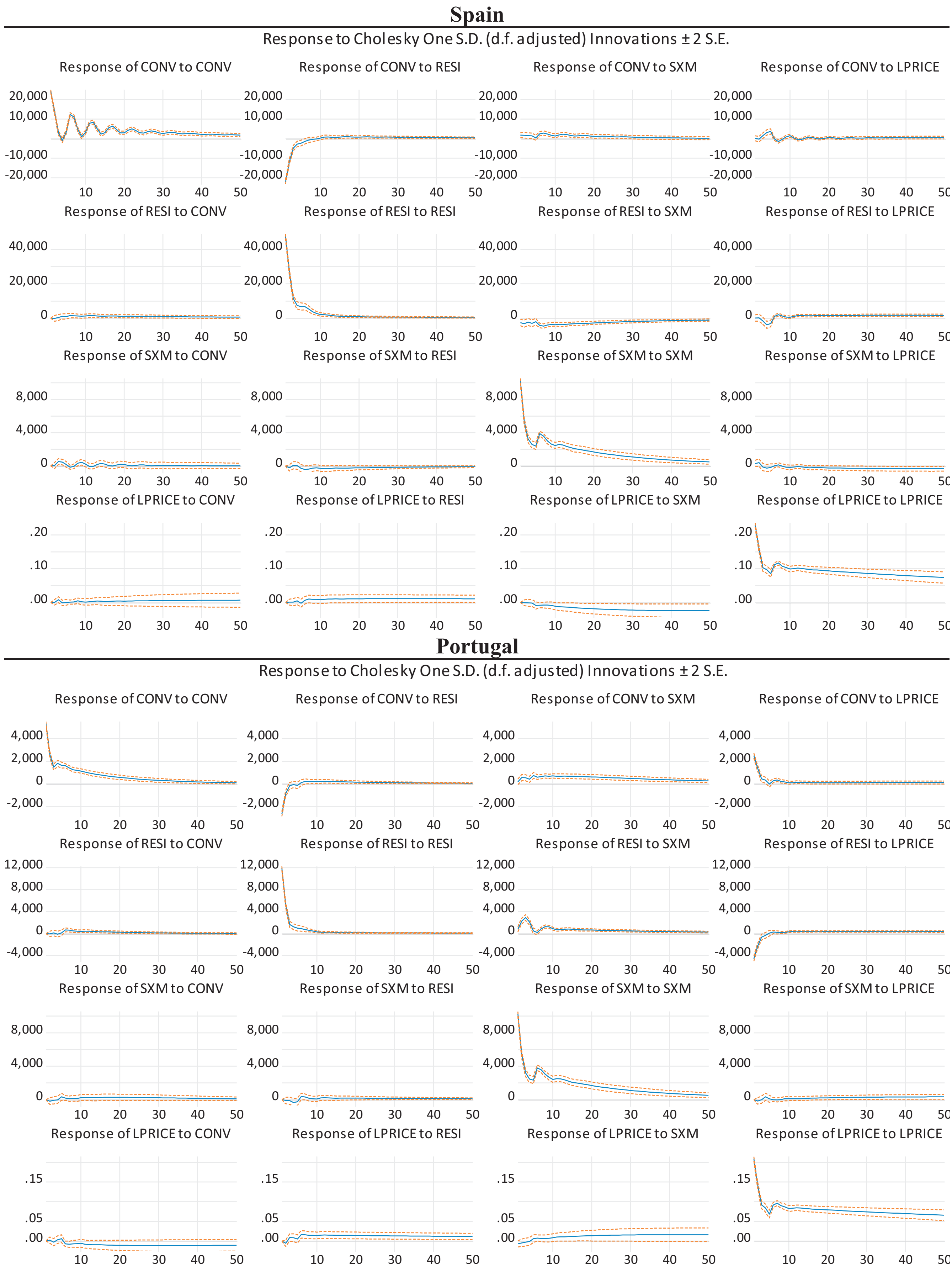

Fig. 4. Impulse responses functions. Note: The vertical axes of some graphs were rescaled in order to enhance observations of the results.

and Portugal. Looking at Spain, in general, all variables converge to the equilibrium within one month and, as such, there is no long memory and the adjustment is fast. From the Figure, one can observe that *RES-I* has a positive response to shocks in *CONV*. *SXM* also has a positive impact, but of less intensity. The response of *LPRICE* to shocks in *CONV, RES-I* and *SXM* is very low. This result is in line with the variance decomposition outcomes. A one standard deviation shock in *LPRICE* decreases *RES-I*, but not *CONV*.

The response of *CONV* seemed to have a kind of sinusoidal effect in Spain. In order to assess the potential cause of this phenomenon, the models were re-estimated without considering the large nuclear baseload source. As suspected, this type of pattern was then removed but, more importantly, the results remain the same. All of this suggests that there is a weekend effect, that can be explained by the low flexibility of nuclear power plants, which are unable to quickly increase or decrease the amount of electricity generated. The response of *RES-I* to shocks in *SXM* is negative and similar to shocks on *CONV*. Electricity generated by *RES-I* is not constant, and depends on the availability of natural resources.

Looking at Portugal, in the second half of Fig. 4, the IRFs of the VAR model of the Portuguese system are presented. In general, all variables converge to equilibrium within 50 periods at most, although with different adjustment speeds. A one standard deviation shock to *CONV* causes a positive response in *RES-I*, even with low intensity. *RES-I* has a negative response when a deviation shock is introduced in *LPRICE*. When *SXM* suffers a shock, intermittent sources have a positive response, similar to *CONV*, but with greater intensity. Electricity exports occur when there is surplus electricity generation by renewable sources. The impulse response of *CONV* to *RES-I* shows that a one standard deviation shock to *RES-I* tends to increase *CONV*. A substitution effect between *CONV* and *RES-I* can be observed, despite being weak. *RES-I* has dispatch priority, but intermittent generation, while *CONV* is always available.

5. Discussion

This paper is focused on the analysis of the interactions between electricity generation sources, in two separate domestic electricity generation systems which must cooperate with each other. Both the Spanish and the Portuguese electricity systems were analysed and compared. The systems are managed in real time and, accordingly, high frequency data was used to ensure robustness in the estimations. The five weekdays (Monday to Friday) were chosen for two reasons: (i) most people consume electricity in their homes at the weekend, while industries operate during the week, so the consumption patterns are different in these two periods; and (ii) the need to reduce white noise from the series. Indeed, the procedure of only studying data from workdays, rather than the entire week, thus reducing it from 7 to 5 days per week, allowed the entire period to be examined, capturing economic cycles, while using a lower number of observations.

In general, the results for both Spain and Portugal are similar in terms of the interaction between electricity generation sources. Nonetheless, the difference between Spain and Portugal, in terms of system size is noticeable. Regarding the results of the interaction between electricity generation sources and the market (electricity exports and price), the findings appear to be dissimilar for the two generation systems. This result is in line with the findings of Ciarreta et al. [32]. Total electricity consumption in Spain is almost 6 times larger than in Portugal, and the size of the generation structure is quite different. The Spanish system is able to share back-up with the Portuguese system, while the inverse is less likely. The Portuguese power system faces a problem, of scale. To address this, the results of this study suggest that one possibility for the Iberian market would be auctions of shared back-up, using flexible fossil generation sources, such as gas turbines and cogeneration. The Iberian market has the potential for greater adjustment, due to the difference between installed capacity in Portugal and Spain. This could be crucial not only to accommodate the renewables already installed, but also to enlarge the use of these generation sources.

When focusing on the markets, a comparison with the largest European electricity market (Nord Pool) is inevitable. The differences between the Iberian Market and Nord Pool Spot (NPS) are understandable. The Iberian Market is composed by two countries with similar electricity standards, while NPS is composed of more countries with different characteristics regarding electricity supply and demand, and a higher share of electricity consumption is transacted. The NPS consists of a larger number of countries than the Iberian Market. The NPS has access to other electricity markets, e.g. Netherlands and Germany. The members of NPS have distinct electricity mixes. For instance, Estonia's main electricity generation source is oil shale, Denmark has a high share of offshore wind farms, while Sweden intensively uses hydroelectricity and nuclear plants.

Ideally, countries forming an electricity market should have different supply and demand patterns to allow flexibility in the management of both a scarcity and surplus of electricity. Pricing policy measures can also shape electricity demand to introduce flexibility into the market. These incentives should lead consumers to increase or even reduce their electricity consumption according to the availability of RES. In the case of the Iberian market, the interconnections to other electricity markets are limited and restricted to the region. Access to other electricity markets could bring greater efficiency to the market through increased heterogeneity in the net load (total electricity demand minus the supply from renewables). With a more balanced electricity market, it would be possible to fully satisfy demand without increasing the installed capacity of generation sources, and surplus electricity could be exported.

6. Conclusion

This paper examines the interaction of two power systems of different sizes, interacting in a small electricity market. The interactions between electricity generation sources and electricity wholesale price within the Portuguese and Spanish electricity generation systems were analysed separately to allow comparison, for a time span from 2 July 2007 to 30 March 2018. Daily frequency data was used and the VAR approach was chosen, as it is highly robust in the presence of endogeneity among variables. Two VAR models were estimated, one each for the Portuguese and Spanish electricity systems in the Iberian Market. After this, variance decomposition and impulse response functions were carried out.

Despite the results being similar for the two systems with respect to the interaction between electricity sources, the interaction within the Iberian market as a whole was found to be quite different. The scale of the national electricity systems of the two countries is quite dissimilar. The two systems should play different roles in the Iberian market. The Spanish system is more able to accommodate shared backup capacity, due to its large generation structure. This measure could bring additional economic efficiency to the whole market.

The accommodation of renewables is more challenging and economically inefficient in small markets, such as the Iberian market. Ignoring their difference in scale, there are evident similarities between Portugal and Spain, such as geographical proximity, meteorological conditions and the availability of resources to generate electricity, excluding the nuclear plants in Spain. Consequently, the patterns of consumption are similar in these two countries. However, this study confirms that electricity markets benefit when the characteristics of their members are heterogeneous. Pricing policy measures could shape demand patterns to take greater advantage of the installed capacity of renewable energy. These differing patterns of supply and demand could then allow the electricity systems to better accommodate different kinds of generation sources. This implies that the Iberian market needs to be more open to interact with different countries. This openness could also be extremely useful for dealing with the new challenges facing power systems, such the accommodation of small-scale generation for self-consumption.

Declarations

Author contribution statement

Tiago Lopes Afonso: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

António Cardoso Marques: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

José Alberto Fuinhas: Analyzed and interpreted the data.

Funding statement

This work was supported by NECE-UBI, Research Unit in Business Science and Economics, sponsored by the Portuguese Foundation for the Development of Science and Technology, project UID/GES/04630/2019.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The very useful suggestions provided by two anonymous revisors are recognized.

References

[1] European Commission, Achieving the 10% Electricity Interconnection Target, 2015.
[2] P. Luňáčková, J. Průša, K. Janda, The merit order effect of Czech photovoltaic plants, Energy Policy 106 (2017) 138–147.
[3] D. Quint, S. Dahlke, The impact of wind generation on wholesale electricity market prices in the midcontinent independent system operator energy market: an empirical investigation, Energy 169 (2019) 456–466.
[4] K. Dong, G. Hochman, Y. Zhang, R. Sun, H. Li, H. Liao, CO 2 emissions , economic and population growth , and renewable energy : empirical evidence across regions, Energy Econ. 75 (2018) 180–192.
[5] Y. Chen, Z. Wang, Z. Zhong, CO 2 emissions , economic growth , renewable and non-renewable energy production and foreign trade in China, Renew. Energy 131 (2019) 208–216.
[6] European Commission, DIRECTIVE 2001/77/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market, Off. J. Eur. Commun. 6 (2001).
[7] European Commission, DIRECTIVE 2003/30/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport, Off. J. Eur. Commun. 4 (2003) 42–46.
[8] European Commission, DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Off. J. Eur. Commun. (2009) 16–62.
[9] K. Alizada, Rethinking the diffusion of renewable energy policies: a global assessment of feed-in tariffs and renewable portfolio standards, Energy Res. Soc. Sci. 44 (2018) 346–361.
[10] C. Gallego-Castillo, M. Victoria, Cost-free feed-in tariffs for renewable energy deployment in Spain, Renew. Energy 81 (2015) 411–420.
[11] R. Flora, A.C. Marques, J.A. Fuinhas, Wind power idle capacity in a panel of European countries, Energy 66 (2014) 823–830.
[12] M. Bhattacharya, S.R. Paramati, I. Ozturk, S. Bhattacharya, The effect of renewable energy consumption on economic growth: evidence from top 38 countries, Appl. Energy 162 (2016) 733–741.
[13] A.S. Brouwer, M. Van Den Broek, A. Seebregts, A. Faaij, Impacts of large-scale Intermittent Renewable Energy Sources on electricity systems, and how these can be modeled, Renew. Sustain. Energy Rev. 33 (2014) 443–466.
[14] J. Hu, R. Harmsen, W. Crijns-graus, E. Worrell, M. Van Den Broek, Identifying barriers to large-scale integration of variable renewable electricity into the electricity market : a literature review of market design, Renew. Sustain. Energy Rev. 81 (2018) 2181–2195.
[15] K. Van den Bergh, K. Bruninx, E. Delarue, Cross-border reserve markets: network constraints in cross-border reserve procurement, Energy Policy 113 (2018) 193–205.
[16] M. Cepeda, Assessing cross-border integration of capacity mechanisms in coupled electricity markets, Energy Policy 119 (2018) 28–40.
[17] M. V Loureiro, J. Claro, P. Fischbeck, Electrical Power and Energy Systems Coordinating cross-border electricity interconnection investments and trade in market coupled regions, Electr, Power Energy Syst. 104 (2019) 194–204.
[18] F. Sensfuß, M. Ragwitz, M. Genoese, The merit-order effect: a detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany, Energy Policy 36 (2008) 3086–3094.
[19] J. Cludius, H. Hermann, F. Chr, V. Graichen, The merit order effect of wind and photovoltaic electricity generation in Germany 2008 – 2016 : estimation and distributional implications, Energy Econ. 44 (2016) 302–313.
[20] S. Clò, A. Cataldi, P. Zoppoli, The merit-order effect in the Italian power market: the impact of solar and wind generation on national wholesale electricity prices, Energy Policy 77 (2015) 79–88.
[21] K. Janda, Slovak electricity market and the price merit order effect of photovoltaics, Energy Policy 122 (2018) 551–562.
[22] Z. Csereklyei, S. Qu, T. Ancev, The effect of wind and solar power generation on wholesale electricity prices in Australia, Energy Policy 131 (2019) 358–369.
[23] N.C. Figueiredo, P.P. da Silva, The "Merit-order effect" of wind and solar power: volatility and determinants, Renew. Sustain. Energy Rev. 102 (2019) 54–62.
[24] Robert B. Cleveland, William S. Cleveland, Jean E. McRae, Terpenning Irma, STL: a seasonal-trend decomposition procedure based on loess, J. Off. Stat. 6 (1990) 3–73. http://www.nniiem.ru/file/news/2016/stl-statistical-model.pdf.
[25] J. Otero, J. Smith, Testing for cointegration: power versus frequency of observation — further Monte Carlo results, Econ. Lett. 67 (2000) 5–9.
[26] S. Zhou, The power of cointegration tests versus data frequency and time spans, South. Econ. J. 67 (2001) 906–921.
[27] H. Kim, H. Thompson, Wages in a factor proportions model with energy input, Econ. Model. 36 (2014) 495–501.
[28] M. Shahbaz, M. Zeshan, T. Afza, Is energy consumption effective to spur economic growth in Pakistan? New evidence from bounds test to level relationships and Granger causality tests, Econ. Model. 29 (2012) 2310–2319.
[29] H. Bloch, S. Rafiq, R. Salim, Economic growth with coal, oil and renewable energy consumption in China: prospects for fuel substitution, Econ. Model. 44 (2015) 104–115.
[30] L.M. de Menezes, M.A. Houllier, Germany's nuclear power plant closures and the integration of electricity markets in Europe, Energy Policy 85 (2015) 357–368.
[31] T. Lumley, P. Diehr, S. Emerson, L. Chen, The importance of the normality assumption in large public health data sets, Annu. Rev. Public Health 23 (2002) 151–169.
[32] A. Ciarreta, S. Nasirov, C. Silva, The development of market power in the Spanish power generation sector : perspectives after market liberalization, Energy Policy 96 (2016) 700–710.