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The impact of renewable energy sources on the Portuguese electricity prices:
The merit-order Effect

VERSÃO FINAL APÓS DEFESA

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Resumo

As Fontes de Energia Renováveis (FER) têm sido tratadas como um instrumento essencial para assegurar os objetivos internacionais de energia sem comprometer o desenvolvimento sustentável de cada país bem como o bem-estar da população. No entanto, os efeitos que a penetração das FER tem nos preços da eletricidade têm de ser levados em conta. O Efeito de Ordem de Mérito (EOM) é a redução esperada no preço grossista da eletricidade causada pela penetração das FER. Este trabalho quantifica o EOM em Portugal, desde 2009 até 2018. Os dados usados foram mensais e o modelo aplicado foi um GARCH (2,1). Adicionalmente, as poupanças esperadas no preço grossista da eletricidade são comparadas com os custos esperados nos preços no consumidor, de modo a verificar se a penetração das FER se traduz num benefício ou num custo para o consumidor. Os resultados sugerem um EOM de 21,24€/MWh o que se traduz numa poupança para os consumidores de 1,93 bilhões de euros.

Palavras-chave

Efeito de Ordem de Mérito; Fontes de Energia Renováveis; Portugal; GARCH; Preço da Eletricidade

Resumo Alargado

A dependência energética para alcançar níveis mais altos de crescimento económico entra em conflito com os objetivos internacionais de reduzir as emissões de Gases de Efeito de Estufa (GEE). Assim, as fontes de energia renovável (FER) foram tratadas como um instrumento essencial para atingir as metas internacionais de energia sem comprometer o desenvolvimento sustentável de cada país e o bem-estar da humanidade.

Uma das questões que surgem da incorporação do FER no sistema elétrico é o seu impacto nos preços grossistas da eletricidade. Nos países europeus, os mercados grossistas de eletricidade são baseados em custos marginais e os seus agentes são classificados de acordo com a ordem de mérito das ofertas de fornecimento para cada período de negociação. Isso significa que a geração de eletricidade a partir das FER é a primeira na ordem de despacho, devido aos seus custos marginais mais baixos, substituindo os custos mais altos de geração de fontes de energia não renováveis (FENR). Espera-se que o aumento da energia gerada pelo FER e a consequente diminuição da energia gerada pelo NRES reduzam os preços da eletricidade nos mercados grossistas de eletricidade. A esse fenómeno dá-se o nome de Efeito de Ordem de Mérito (EOM). Este estudo contribui para a literatura existente, não apenas quantificando o EOM em Portugal, usando um modelo econométrico inovador, mas também estimando se a redução esperada nos preços grossistas da eletricidade se traduz em um benefício financeiro para o consumidor final ou se, por outro lado , essa redução não é suficiente para compensar os impostos crescentes usados para apoiar o investimento nas FER.

Dados da ERSE (Entidade Reguladora dos Serviços Energéticos) informam que, de 2009 a 2018, a sobretaxa resultante da introdução das FER representou, em média, 15,20% da fatura total de energia elétrica, sem impostos adicionais pagos pelo consumidor final. Dados do Eurostat também nos dizem que, de 2009 a 2018, o preço que o consumidor final pagou sem impostos e taxas foi, em média, 17,36 €/MWh.

Para poder quantificar o EOM em Portugal foi usado um modelo GARCH (2,1), uma vez que estavam presentes efeitos ARCH. Foram também adicionados termos AR, MA, SAR e SMA para resolver problemas de auto-correlação e auto-correlação parcial. A variável dependente foi o preço da eletricidade e como variáveis explicativas foram usadas a geração de eletricidade por FER, a geração de eletricidade por FENR, o saldo importador e a procura.

Os resultados mostram que existiu um EOM em Portugal, entre os anos de 2009 e 2018, de 21,24€/MWh o que se traduz em poupanças para o consumidor no valor de 10,58 bilhões de euros. Para além disso, estimou-se que os custos adicionais que o consumidor suportou pela introdução das FER no sistema elétrico português foram de 8,65 bilhões de euros. Assim, calcula-se que, entre os anos de 2009 e 2018, a introdução das FER no sistema elétrico português traduziu-se numa poupança para os consumidores a rondar os 1,93 bilhões de euros.

Abstract

The Renewable Energy Sources (RES) have been treated as a key instrument to accomplish the international energy goals without compromising the sustainable development of each country and the humankind wellbeing. However, the effects that the penetration of RES have on electricity prices must be considered. The Merit order Effect (MOE) is the expected reduction of the wholesale electricity prices caused by the penetration of the RES. This study quantifies the MOE in Portugal, for the years of 2009 to 2018. The data frequency is monthly, and the applied methodology was a GARCH (2,1). Additionally, the expected savings in the wholesale prices are compared to the expected costs in the retail prices, in order to see if the RES penetration translates into a benefit or a cost to the end consumer. The findings suggest a MOE of 21,24€/MWh which translates into a €1,93 billion savings for the consumer during the years of 2009 to 2018.

Keywords

Merit Order Effect; Renewable Energy Sources; GARCH; Portugal; Electricity Prices

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Acronyms List

ADF	Augmented Dickey-Fuller
ARCH	Autoregressive Conditional Heteroskedasticity
AVC	Audio-visual Contribution Tax
ERSE	*Entidade Reguladora dos Serviços Energéticos*
EU	European Union
GHG	Green House Gases
IB	Import Balance
IQR	Inter Quartile Range
MOE	Merit Order Effect
NRES	Non-renewable Energy Sources
OECD	Economic Co-operation Development
ORG	Ordinary Regime Generation
PP	Phillips-Perron
Q1	First Quartile
Q3	Third Quartile
RES	Renewable Energy Sources
SEC	Special Electricity Consumption Tax
SRG	Special Regime Generation
URT	Unit Root Tests
VAT	Value Added Tax

1. Introduction

Under the growth hypothesis, it can be assumed that energy consumption plays an important role in the economic growth. Energy consumption is, therefore, a central good for countries to achieve a sustainable development and assure the wellbeing of its economic agents.

The economic growth has been a central concern for countries for many centuries. However, in the last decades, policymakers also started to raise their concerns about environmental issues. In 1997, the Kyoto Protocol was signed, under the supervision of the United Nations, which commits its parties by setting internationally binding emission reduction targets ("KYOTO PROTOCOL TO THE UNITED NATIONS FRAMEWORK" 1998). More recently, the European Union (EU) has adopted a combination of targets and policies regarding climate and energy areas for the years of 2020 and 2030. The 2020 package contains measures to achieve a 20% reduction in the greenhouse gas emissions (GHG), a 20% share of renewable energy in the EU's total energy consumption and a 20% improvement in the energy efficiency (Council & Framework, 2020). Respecting the 2030 package the targets raise to a 40% reduction in the GHG emissions, a 27% share of renewable energy in the EU's total energy consumption and a 27% energy savings compared to a business-as-usual scenario (Council & Framework, 2020).

Hence, this energy dependence to achieve higher levels of economic growth greatly conflicts with the international goals of reducing the GHG emissions. Thus, the Renewable Energy Sources (RES) have been treated as a key instrument to accomplish the international energy goals without compromising the sustainable development of each country and the humankind wellbeing. In fact, the share of RES consumption has been rapidly increasing in the last years. In the Organisation for Economic Co-operation and Development countries (OECD) the share of RES consumption has increased from 7.75% in 2000 to 12% in 2015 as in the EU the share has increased from 7.92% in 2000 to 16.56% in 2015. In Portugal, the share of RES consumption raised from 20.11% in 2000 to 27.16% in 2015 (World Bank)[1].

This increase in the RES share on the electric system has raised some concerns between some electricity system stakeholders, with some studies in the literature showing that RES integration comes with many challenges and requires further investigation (Auer & Haas, 2016; Henriot & Glachant, 2013; V. Maxwell, 2015). One of the questions that arise from the incorporation of the RES in the electric system it is its impact on the wholesale

[1] https://data.worldbank.org/

electricity prices. In European countries, the wholesale electricity markets are based in marginal costs and its agents are classified according to the merit order of the of supply offers for each trading period (Carvalho & Pereira, 2019). This means that the electricity generation from RES is the first in dispatching order, due to its lower marginal costs, replacing the higher costs of the non-renewable energy sources (NRES) generation. The increasing energy generated by RES and the consequent decrease in the energy generated by the NRES, is expected to reduce the spot electricity prices in wholesale electricity markets. To this phenomenon is known as The Merit Order Effect (MOE).

The reduction in the wholesale electricity prices that it is expected by the increasing installed capacity of the RES represents an obvious benefit. Notwithstanding, in order to support the investment in the installation of RES technologies, the consumers must bear with additional taxes or direct increases in their electricity bills. Therefore, the MOE that is expected to be verified raises a different question of whether this will also cascade into a financial benefit to the end consumer.

This study contributes to the existent literature not only by quantifying the MOE in Portugal, using an innovative econometric model, but also by estimating whether the expected reduction in the wholesale electricity prices translates into a financial benefit to the end consumer or if, on another hand, that reduction is not enough to compensate the increasing taxes used to support the investment in the RES.

The rest of this study is organized as follows: in section 2 it is portrayed a literature review; section 3 presents a brief description of the Portuguese electrical power system; section 4 sets out the data the methodology used; section 5 gives the results and the discussion; finally, in section 6 it is given the conclusion.

2. Literature Review

There is already an abundant literature on the merit order effect phenomenon. Also, there seems to be a wide consensus on the effect that the penetration of RES has on the wholesale electricity prices. In fact, the majority of the studies state that the introduction of RES on the electrical system leads to a decrease in the wholesale electricity prices.

The first known work in what is stated that the RES penetration should decrease the wholesale electricity prices due to its lower marginal costs, was brought by Jensen & Skytte, (2002), who performed a theoretical study of the green certificates system. Although they findings suggest a decrease on the wholesale prices with the introduction of the RES, they also state that more research in the area of green certificates is needed before the actual implementation takes place, since it can cause a significant increase on the consumer prices.

The existence literature presents a considerable volume of studies regarding Germany, due to its leading position in the public promotion of photovoltaic and wind electricity. As reported by Rathmann, (2007), the increase of the RES generation can influence the price in two different ways, namely: (i) the usual MOE caused by the lower marginal costs of the RES; (ii) the fact that the RES decreases CO2 emissions which makes the CO2 price to be lower and, consequently, reduces the electricity prices. Rathman concluded with his study that the penetration of RES reduced the wholesale electricity prices in Germany by 6,4€/MWh from 2005 to 2007, but an increase on the RES related taxes translated into a 2,6€/MWh increase on the electricity retail prices. Würzburg, Labandeira, & Linares, (2013) conducted a study using multivariate regression models, in order to quantify the MOE for the Austrian–German region, a market that clearly qualifies for a merit-order effect analysis given its characteristics. They used data from 2005 to 2010 and concluded that an increase of 1 GWh in RES reduces price by 1 €. Other findings were that the MOE varies depending on the region and the assessment method chosen, and that there is a wealth transfer from producers to consumers.

For Italy, the second biggest photovoltaics market, Clò, Cataldi, & Zoppoli, (2015) used a Generalized least-squares method with Prais–Winsten estimator, in order to study the MOE in the Italian market. They found that the introduction of RES in the electrical market results on a decrease of 2.3 €/MWh for 1 GWh solar and 4.2 €/MWh for 1 GWh wind, generation increase, from Jan 2005 to Oct 2013. Besides that, they compared the costs of the RES introduction with its benefits and concluded that the solar power costs greatly exceed the savings and the wind savings slightly exceed the costs.

There isn't many known literature regarding the study of the MOE in Portugal. However, the literature knows a great amount of studies regarding Spain, a country neighbouring Portugal and with similar characteristics. Gelabert, Labandeira, & Linares, (2011) performed an ex-post analysis of renewable energy and cogeneration on Spanish electricity prices between 2005 and 2010. The main finding was that an increase of 1 GWh of RES results in a decrease of 1,9€/MWh on the electricity wholesale prices, which translates on a 4% reduction of the average price for the analysed period. It was also stated in this study that large amounts of RES with the current electricity market design is incompatible with the remuneration of investment in NRES capacity. Costa-campi & Trujillo-baute, (2015)studied the MOE for Spain, from April 2010 to June 2012, using an AR(1) ARCH model. The main findings were that by every additional 1 GWh of solar energy, there is a decrease of 2,51€/MWh and for each 1 GWh of wind energy, there is a decrease of 1,11€/MWh on the electricity wholesale prices. Other findings were that 1 additional GWh of RES increases the retail price by 0.031%.

3. Portuguese Electric Power System

The Portuguese electric power system has been through several changes in the last years, mainly to the introduction of the new renewable energies in the electricity market. The electricity is, therefore, generated using different technologies and different primary sources of energy, namely coal, natural gas, fuel, diesel, water, wind, sun, biomass and waste. Also, the number of producers has been significantly increasing since many new power plants have been emerging, whether under the cogeneration or the renewable energy generation. These modifications in the Portuguese electrical system can be verified in the installed capacity. In fact, in Figure 1 it can be seen that the installed capacity has raised 3507 MW from 2009 until 2018, settling at 21616 MW in 2018. The mix between RES and NRES can also be easily seen in Figure 2, since the share of RES installed capacity was 50,3% in 2009 increasing to 63,7% in 2018. This means that the amount of RES was 9104 MW in 2009 and 13763 MW in 2018, translating on a 4659 MW increase. Contrary, the amount of NRES was 9104 MW in 2008, and 7853 in 2018, translating on a 1251 MW decrease.

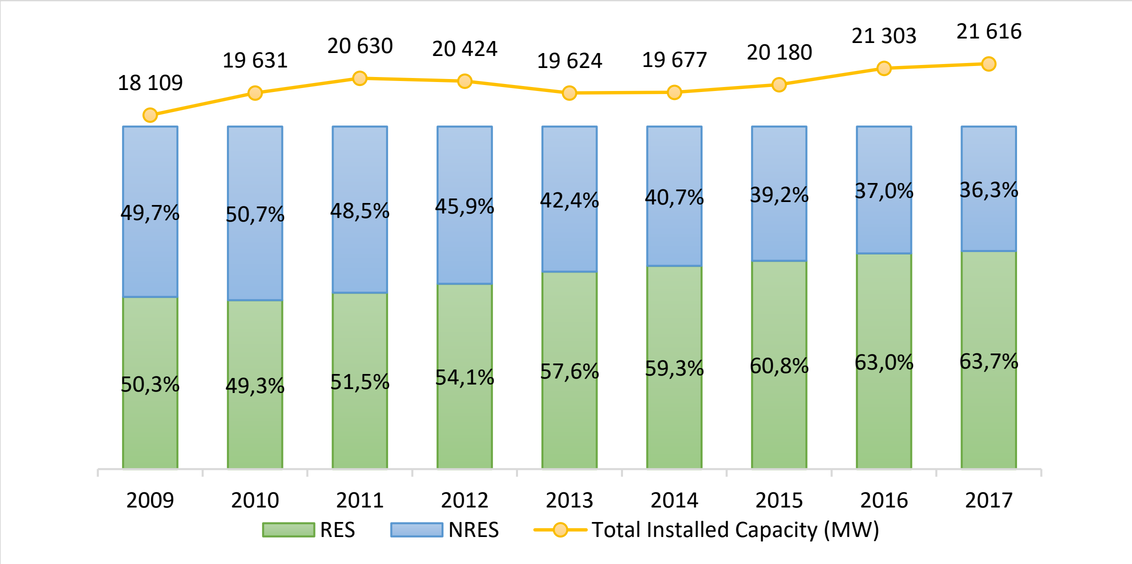


Figure 1. Evolution of the installed capacity in Portugal

The electricity generation in Portugal is divided into two legal regimes, namely: (i) ordinary regime generation (ORG), which contains the generation of electricity from traditional NRES and large hydroelectric plants and (ii) special regime generation (SRG), relative to the cogeneration and electrical production from RES. Portugal is one of the countries with highest share of renewables in the electricity generation. However, the intermittency of the RES and its high dependency on the weather conditions makes the share of RES and NRES on the electricity generation to vary greatly over the years, as it can be seen in Figure 2.

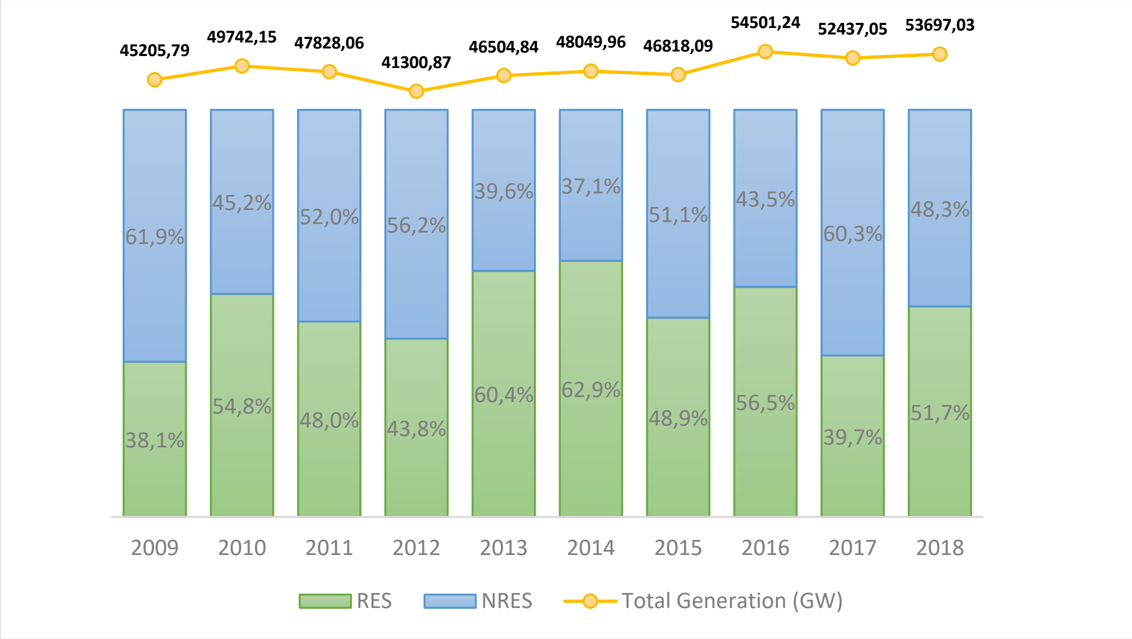


Figure 2. Evolution of the electricity generation in Portugal

In 2009 the RES share was 38% as in 2018 that share was 52%, which represents an increase of 14%. However, in 2012 the RES reached a share of 63%, representing the highest value between the years of 2009 and 2018. A very demonstrative factor of the intermittency in the share of RES on the electricity generation is that, in the ten years between 2009 and 2018, there were 5 where the share of RES was higher and five where that share was lower.

As for the electricity price on the consumer, it can be divided in three parts, namely networks, energy and fees and taxes. Figure 3 illustrates the different charges on the electricity consumer.

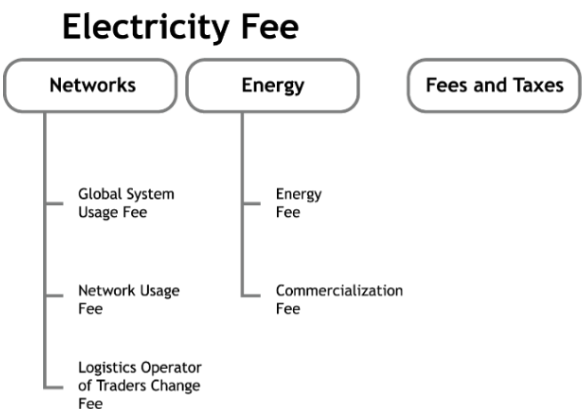


Figure 3. Charges with electricity in Portugal.
Source: APREN

Networks stands for the amount related to the infrastructures that transport electricity from its generation to the point of consumption. The energy value is related to the cost of electricity generated ant its commercialization. Finally, fees and taxes designate the various types of taxation, such as VAT (Value Added Tax) SEC (Special Electricity Consumption Tax) and AVC (Audio-visual Contribution Tax).

The majority of the taxes paid by the electricity consumers are included in a parcel named CIEG, that's stands for Energy Policy, Sustainability and General Economic Interest Costs. This fee contains an explicit tax (SRG overcharge) in order to promote the RES generation, which means that the use of the RES translates on a direct cost to the end consumer. Data from ERSE (*Entidade Reguladora dos Serviços Energéticos*[2]) tells us that, from 2009 till 2018, the SRG overcharge was, on average, 15,20% of the total electricity bid without additional taxes paid by the end-consumer. Data from Eurostat also tells us that, from 2009 till 2018, the price that the end-consumer paid without taxes and levies was, on average, 17,36€/MWh.

[2] https://www.erse.pt/inicio/

4. Data and methodology

In order to quantify the effect on the wholesale electricity price of the introduction of RES on the Portuguese electric system, the electricity price was used as the dependent variable. Although the data is available on an hourly basis, it was transformed into daily averages in order to reduce unwanted noise. The main explanatory variables are the RES generation, that include the Hydric, Wind, Solar and Biomass generation, and the NRES generation, that include Coal, Gas and Other non-renewable sources generation. The rest of the independent variables are the Import Balance (IB), which represents the difference between the imports and exports, and the Demand, which, in the case of the electricity market, stands for all the consumption. All data was collected from REN (SIMEE[3]), for the years of 2009 until 2018, i.e. 3652 observations. The descriptive statistics are shown in Table 1.

Table 1. Summary statistics

	Descriptive statistics					
Variables	Units	Obs.	Mean	Std.Dev.	Min	Max
Price	€/Mwh	3652	45.8760	13.1643	0.0000	93.1117
RES	Gw/h	3652	2.8080	1.3113	0.6409	8.1089
NRES	Gw/h	3652	2.7379	0.9604	0.3315	5.0884
IB	Gw/h	3652	0.1544	0.8080	-2.1568	2.2595
Demand	Gw/h	3652	5.6845	0.5942	4.2529	7.1099

Before proceeding to the estimation of the model, some tests on the data were performed in order to check for the existence of outliers, i.e., observations points that are distant from the other observations, and to study the stationarity of the series.

The electricity price is expected to be highly dependent on the type of electricity generation source and, in its turn, the source of electricity generated is expected to be highly sensitive on the climatic and meteorological conditions. Hence, these premises make the existence of outliers on the data to be very likely. From here, there are three distinctive ways to deal with the presence of outliers: (i) we can opt to maintain the original data with the outliers; (ii) the outliers can be removed, creating gaps on the data; (iii) the outliers can be transformed into different values.

The existence of outliers implies a distorted analysis that leads to unreliable results and incorrect policy decisions (Palmegiani, 2016). Thus, it was opted to transform the outliers so

[3] http://www.mercado.ren.pt/PT/Electr/InfoMercado/

that they assume values closer to the other observations. For this matter, the normal observations values interval (i.e., non-outliers values) was identified, meaning that all values that are outside of the referred interval are considered to be outliers. Hence, the first and third quartiles were calculated for each variable and, then, the Inter Quartile Range (IQR) was calculated by subtracting the first quartile (Q1) from the third quartile (Q3) ($IQR = Q3 - Q1$). Secondly, the lower and upper bounds of the non-outliers interval were calculated with the following equations: (i) $Lower\ Bound = Q1 - (IQR * 1.5)$ and (ii) $Upper\ Bound = Q3 + (IQR * 1.5)$. Lastly, all values that were above the interval assumed the upper bound value and the values under the interval assumed the lower bound value.

As for the properties of stationary, Unit Root Tests (URT) were performed, namely the Augmented Dickey-Fuller test (ADF) and Phillips-Perron test (PP). Both tests have as null hypothesis that the series has a unit root, meaning that the rejection of the null hypothesis implies the stationarity of the series. Thus, if a series is considered to be stationary in level its order of integration is I(0) while if the series is only stationary in the first difference, its order of integration is I(1). It is important to analyse the integration order of the different variables, since most of the econometric models implies the variables to be at the same order.

In order to choose the correct econometric model to be applied, a simple OLS regression was conducted, with the constant term as the only regressor. The model can be seen in Equation 1.

$$Price = c + \varepsilon_t \tag{1}$$

where c is a constant and ε_t the random error term, for each market period t. From here, the presence of ARCH effects (Autoregressive Conditional Heteroskedasticity) is tested by applying the ARCH test, that is based on the information that the lagged estimated residues have relative to contemporary estimated residues. The null hypothesis of the ARCH test is no heteroskedasticity in the residuals. The null hypothesis is rejected, which leads to the conclusion that we are in the presence of ARCH effects. This means that, in order to model the electricity price, the ARCH type models should be applied.

Bollerslev, (1986) generalized the ARCH model, producing the GARCH (p,q) specification as follows in Equation 2:

$$\sigma_t^2 = \omega + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 \tag{2}$$

where w is a constant, $\sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2$ is the GARCH component of order p and $\sum_{j=1}^{q} \beta_j \sigma_{t-j}^2$ is the ARCH component of order q. The most common GARCH specification in applied research is GARCH (1,1), where the effect of a shock in volatility declines geometrically over time.

5. Results and discussion

As stated before, it is important to check the existence of outliers on the dataset. For this matter, the boxplot graphics were plotted for each variable and the results can be seen in Annex 1. The graphics suggest the existence of outliers for the variables Price, RES, IB and Demand. This phenomenon was concerned by transforming those values into the upper or lower bounds values. The process to do that was explained in the previous chapter, and the results can be seen in the table below.

Table 2. Outliers removal process

	Price	RES	IB	Demand
First Quartile	38,4122	1,8036	-0,3935	5,3243
Third Quartile	54,0377	3,5693	0,7821	6,0385
Inter Quartile Range	15,6255	1,7657	1,1756	0,7142
Lower Bound	14,9739	-0,8450	-2,1568	4,2529
Upper Bound	77,4760	6,2179	2,5455	7,1099

By analysing Table 2 we can see that, in the case of the Price variable, the interval in which the observation points must be in order to not be considered an outlier is [14,9739;77,4760]. This means that every observation point that is under 14,9739 will assume the value 14,9739. On the other hand, every value that is above 77,4760 will assume the value 77,4760.

It is important to verify that, by analysing the RES boxplot graphic, it seems that the outliers are only presence on the upper side of the graph. This should mean that the minimum RES value is not lower than -0,8450 and, in fact, by analysing table 1 it can be seen that the minimum RES value is 0.9604. The new descriptive statistics can be seen in table 3.

Table 3. Summary statistics without outliers

	Descriptive statistics					
Variables	Units	Obs,	Mean	Std,Dev,	Min	Max
Price	€/Mwh	3652	46,0461	12,4212	14,9739	77,4760
RES	Gw/h	3652	2,7986	1,2833	0,6409	6,2179
NRES	Gw/h	3652	2,7378	0,9605	0,3315	5,0884
IB	Gw/h	3652	0,1544	0,8080	-2,1568	2,2595
Demand	Gw/h	3652	5,6845	0,5942	4,2529	7,1099

As also stated before, the ADF and PP unit root tests were performed in order to study the stationarity of the series. By analysing Table 4 it can be seen that the ADF test tells us that all variables are I(0) except when the trend is removed, where most variables appear to be I(1). PP test tells us that all variables are I(0), even if the trend is removed, except for the Demand variable.

Table 4. Unit Root Tests

Variables		ADF			PP		
		CT	C	None	CT	C	None
Price	Level	-4,690535***	-4,064045***	-0,739775	-22,97396***	-20,84089***	-1,941898**
	First Difference	-15,76654***	-15,76415***	-15,76568***	-104,8507***	-104,8552***	-104,8767***
RES	Level	-6,178653***	-6,137663***	-2,257037**	-16,75112***	-16,56098***	-3,774375***
	First Difference	-38,21428***	-38,21946***	-38,22448***	-124,7350***	-124,7667***	-124,7833***
NRES	Level	-4,719397***	-4,670968***	-1,257988	-32,01279***	-31,82823***	-4,879186***
	First Difference	-15,24021***	-15,24486***	-15,24692***	-147,5446***	-147,5684***	-147,5906***
IB	Level	-9,248447***	-8,165129***	-7,965732***	-38,37493***	-35,83199***	-35,11185***
	First Difference	-25,42879***	-25,43222***	-25,43522***	-170,4520***	-170,4883***	-170,5159***
Demand	Level	-6,180783***	-6,184911***	-0,635235	-44,50299***	-44,45687***	-0,975639
	First Difference	-13,18291***	-13,18084***	-13,18063***	-188,2156***	-188,3953***	-188,4367***

Notes, ADF represents the Augmented Dickey Fuller test, PP represents the Phillips Perro test,; CT stands for constant and trend, C stands for constant; *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively

These results can lead us to conclude that all variables are I(0). However, the different results obtained when the trend is removed tells us that we should include the trend on the estimation in order to have more credible results.

The estimation of the exogenous variables determinants was made for each day, from January 1, 2009 through December 31, 2018, using the software EViews 10. At first, a GARCH (1,1) specification was performed with the price as the dependent variable and the RES, NRES, IB and Demand as the exogenous variables. The constant term and trend were also added as regressors. Subsequently, the ARCH test was performed to test for heteroskedasticity in the residuals. The null hypothesis of homoscedasticity was rejected. Also, the Correlogram of Standardized Residuals and the Correlogram of Standardized Residuals Squared were deployed in order to check for the existence of autocorrelation and partial autocorrelation. The results can be seen in Figures 4 and 5.

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	0.671	0.671	1645.2	0.000
		2	0.540	0.164	2712.2	0.000
		3	0.506	0.173	3647.6	0.000
		4	0.486	0.124	4511.0	0.000
		5	0.489	0.137	5385.9	0.000
		6	0.509	0.150	6334.9	0.000
		7	0.551	0.189	7445.7	0.000
		8	0.487	-0.022	8313.4	0.000
		9	0.447	0.018	9046.1	0.000
		10	0.438	0.033	9748.5	0.000
		11	0.430	0.029	10428.	0.000
		12	0.412	-0.006	11050.	0.000
		13	0.441	0.084	11764.	0.000
		14	0.485	0.111	12625.	0.000
		15	0.433	-0.032	13314.	0.000
		16	0.401	-0.001	13905.	0.000
		17	0.382	-0.015	14440.	0.000
		18	0.378	0.013	14963.	0.000
		19	0.388	0.040	15515.	0.000
		20	0.417	0.060	16153.	0.000
		21	0.469	0.116	16961.	0.000
		22	0.405	-0.059	17565.	0.000
		23	0.373	-0.003	18078.	0.000
		24	0.370	0.011	18580.	0.000
		25	0.359	-0.007	19054.	0.000
		26	0.353	-0.008	19512.	0.000
		27	0.387	0.051	20062.	0.000
		28	0.428	0.067	20737.	0.000
		29	0.367	-0.061	21233.	0.000
		30	0.355	0.027	21698.	0.000
		31	0.356	0.016	22165.	0.000
		32	0.359	0.030	22640.	0.000
		33	0.353	0.004	23099.	0.000
		34	0.368	0.012	23598.	0.000
		35	0.417	0.077	24239.	0.000
		36	0.361	-0.045	24719.	0.000

Figure 4. Correlogram of Standardized Residuals

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	0.068	0.068	16.654	0.000
		2	-0.070	-0.075	34.738	0.000
		3	-0.062	-0.052	48.779	0.000
		4	-0.036	-0.034	53.494	0.000
		5	-0.032	-0.036	57.164	0.000
		6	0.001	-0.002	57.170	0.000
		7	0.033	0.025	61.112	0.000
		8	0.005	-0.004	61.216	0.000
		9	-0.004	-0.002	61.273	0.000
		10	0.015	0.018	62.058	0.000
		11	-0.008	-0.009	62.280	0.000
		12	-0.023	-0.018	64.209	0.000
		13	0.024	0.028	66.395	0.000
		14	0.037	0.030	71.310	0.000
		15	0.002	-0.000	71.324	0.000
		16	-0.016	-0.010	72.283	0.000
		17	-0.033	-0.028	76.223	0.000
		18	-0.024	-0.018	78.338	0.000
		19	0.066	0.068	94.557	0.000
		20	0.033	0.016	98.661	0.000
		21	0.071	0.072	117.24	0.000
		22	0.025	0.025	119.54	0.000
		23	-0.013	-0.001	120.17	0.000
		24	0.007	0.026	120.34	0.000
		25	-0.005	0.003	120.45	0.000
		26	-0.017	-0.012	121.47	0.000
		27	0.037	0.041	126.41	0.000
		28	0.038	0.028	131.70	0.000
		29	0.019	0.016	133.10	0.000
		30	-0.016	-0.008	134.08	0.000
		31	-0.024	-0.012	136.13	0.000
		32	-0.018	-0.013	137.34	0.000
		33	-0.004	-0.004	137.38	0.000
		34	0.020	0.010	138.90	0.000
		35	0.050	0.038	147.96	0.000
		36	0.032	0.030	151.67	0.000

Figure 5. Correlogram of Standardized Residuals Squared

Since all the probabilities are below the 5% level, it can be concluded that autocorrelation and partial autocorrelation is present. Hence, in order to solve the heteroscedasticity problem, the GARCH specification order was increased into a GARCH (2,1). As for the autocorrelation, ARMA terms and seasonal ARMA terms (SARMA) were added as regressors. Each ARMA and SARMA term was added and removed one by one, until the problem of autocorrelation was solved. The ARMA and SARMA terms added were AR(1); AR(2); SAR(7); MA(1); and SMA(7). The results of the correlograms with the ARMA and SARMA terms can be seen in Figure 6 and 7.

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	0.026	0.026	2.4233	
		2	-0.025	-0.026	4.7872	
		3	0.007	0.009	4.9910	
		4	0.033	0.032	9.0177	
		5	-0.004	-0.006	9.0902	
		6	0.013	0.015	9.6948	0.002
		7	0.030	0.029	13.070	0.001
		8	0.002	0.000	13.084	0.004
		9	-0.025	-0.023	15.370	0.004
		10	0.011	0.011	15.776	0.008
		11	0.003	-0.000	15.818	0.015
		12	-0.016	-0.015	16.707	0.019
		13	-0.006	-0.004	16.836	0.032
		14	-0.013	-0.016	17.476	0.042
		15	-0.002	-0.000	17.486	0.064
		16	-0.012	-0.010	17.974	0.082
		17	-0.010	-0.010	18.345	0.106
		18	-0.018	-0.017	19.475	0.109
		19	-0.015	-0.013	20.280	0.122
		20	-0.007	-0.006	20.453	0.155
		21	0.021	0.022	22.099	0.140
		22	-0.026	-0.025	24.485	0.107
		23	-0.014	-0.011	25.207	0.119
		24	0.004	0.004	25.262	0.152
		25	-0.030	-0.031	28.480	0.099
		26	-0.016	-0.012	29.367	0.105
		27	0.003	0.002	29.411	0.133
		28	0.007	0.005	29.590	0.162
		29	-0.018	-0.015	30.791	0.160
		30	-0.002	0.001	30.804	0.196
		31	0.007	0.004	30.997	0.228
		32	0.022	0.023	32.785	0.204
		33	-0.012	-0.010	33.285	0.225
		34	0.016	0.015	34.275	0.229
		35	0.006	0.004	34.428	0.264
		36	0.013	0.012	35.022	0.283

Figure 6. Correlogram of Standardized Residuals with ARMA and SARMA terms

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	0.020	0.020	1.4580	0.227
		2	0.023	0.022	3.3642	0.186
		3	-0.008	-0.009	3.5952	0.309
		4	-0.007	-0.007	3.7773	0.437
		5	0.007	0.008	3.9699	0.554
		6	-0.018	-0.018	5.1440	0.525
		7	-0.017	-0.016	6.1573	0.522
		8	-0.009	-0.007	6.4388	0.598
		9	-0.031	-0.030	9.9864	0.352
		10	-0.019	-0.018	11.353	0.331
		11	-0.013	-0.011	11.985	0.365
		12	-0.014	-0.014	12.751	0.387
		13	0.023	0.023	14.657	0.329
		14	0.018	0.017	15.847	0.323
		15	0.003	0.000	15.889	0.389
		16	-0.008	-0.010	16.104	0.446
		17	-0.016	-0.016	17.015	0.453
		18	-0.023	-0.024	18.875	0.400
		19	0.002	0.002	18.888	0.464
		20	-0.007	-0.006	19.055	0.518
		21	0.039	0.038	24.593	0.265
		22	-0.005	-0.006	24.696	0.312
		23	-0.023	-0.024	26.645	0.271
		24	-0.012	-0.010	27.145	0.298
		25	-0.014	-0.013	27.875	0.314
		26	-0.012	-0.014	28.420	0.338
		27	-0.001	-0.002	28.422	0.389
		28	0.004	0.004	28.493	0.439
		29	0.006	0.005	28.648	0.483
		30	-0.024	-0.023	30.688	0.431
		31	-0.016	-0.014	31.610	0.436
		32	-0.023	-0.023	33.551	0.392
		33	-0.004	-0.005	33.621	0.437
		34	0.005	0.001	33.704	0.482
		35	0.006	0.002	33.815	0.525
		36	0.014	0.013	34.575	0.536

Figure 7. Correlogram of Standardized Residuals Squared with ARMA and SARMA terms

As it can be seen, the majority of the probabilities are above the 5% level, which leads to the conclusion that the Q-stats are not statistically significative and, therefore, the presence of autocorrelation and partial autocorrelation is rejected. The Jarque-Bera normality test was also performed, to test if the residuals follow a normal distribution. The null hypothesis of normal distribution was rejected. However, this result is expected when in presence of daily data, and it does not constitute a problem if the sample is considered to be big, i,e, more than 100 observations. Since the data in this study has 3652 observation, the non-normality of the residuals should not constitute a problem. Having performed the residual diagnostics, the results of the GARCH(2,1) can be seen in Table 5.

Table 5. Estimated GARCH (2,1)

Dependent variable: Price		
Method: ML- ARCH - Normal distribution (BFGS / Marquardt steps)		
Sample (adjusted): 10/01/2009 31/12/2018		
Included Observations: 3643 after adjustments		
Main Equation:		**Coefficient**
	RES	-3,4521***
	NRES	4,1374***
	IB	-1.0424***
	DEMAND	1.1428***
	C	23.0723***
	@TREND	0.0081***
	AR(1)	1.4127****
	AR(2)	-0,4222***
	SAR(7)	0.9752***
	MA(1)	-0,8058***
	SMA(7)	-0,9033***
Adjusted R-Squared: 0.9023	Akaike Info Criterion: 5,1753	
Log likelihood: -9411,7380	Schwarz Criterion: 5,2008	
Durbin Watson Stat: 1.8944	Hannan-Quinn Criterion: 5,1844	

Note: ***, ** and * represents significant level for 1%, 5% and 10%, respectively.

By analysing the results above, it can be seen that all variables are statistically significant at a significant level of 1%. As expected, the penetration of RES in the electric system has a negative effect on the wholesale electricity prices. In fact, an additional 1 GW of RES generation translates into a 3,4521€/MWh decrease on the electricity wholesale prices. On the other hand, an additional 1 GW of NRES generation translates into a 4,1374€/MWh increase on the electricity prices. As proposed by Stefano Clò (2014), the RES and NRES coefficients were multiplied by the daily average data of the RES and NRES, in order to estimate the total impact in the electricity prices. Thus, it can be concluded that the RES generation translates into a 9,6610€/MWh reduction in the electricity prices. Also, if the total RES generation would have to be supported by NRES, that would mean an increase of 11,58€/MWh. This translates into a total MOE of 21,24€/MWh. At the same line of reasoning, the total savings obtained by the RES penetration on the electric system were calculated by multiplying the total price reduction by the total electricity consumption. Thus, it is estimated that the total savings were, approximately, €10,58 billion over the period of 2009 till 2018.

As stated before, the introduction of RES also translates into a cost on the end-user of 17,36€/MWh. This means that, over the period of 2009 till 2018, there was a cost of €8,65 billion on the consumer. If we remove this cost on the total savings on the wholesale prices, it can be concluded that, the introduction of RES on the Portuguese electric system results on a benefit for the consumer of, approximately, €1,93 billion.

The positive impact of demand on the electricity prices was also expected. This occurs because, in order to meet the high values of energy demand, the NRES start to enter on the electricity generation and, therefore, its higher marginal costs will result in higher electricity prices. The adjusted R-squared coefficient means that these variables can explain, approximately, 90% of the wholesale electricity prices.

6. Conclusion

The relation between the penetration of the RES in the Portuguese electric system was studied for the years of 2009 to 2018. Portugal is one of the countries that is facing big transformations in its energy generation system, in order to achieve the international goals of reducing the CO2 emissions, without compromising its development and its nations wellbeing. The methodology used was innovative for this kind of study, using a model mostly used for financial series.

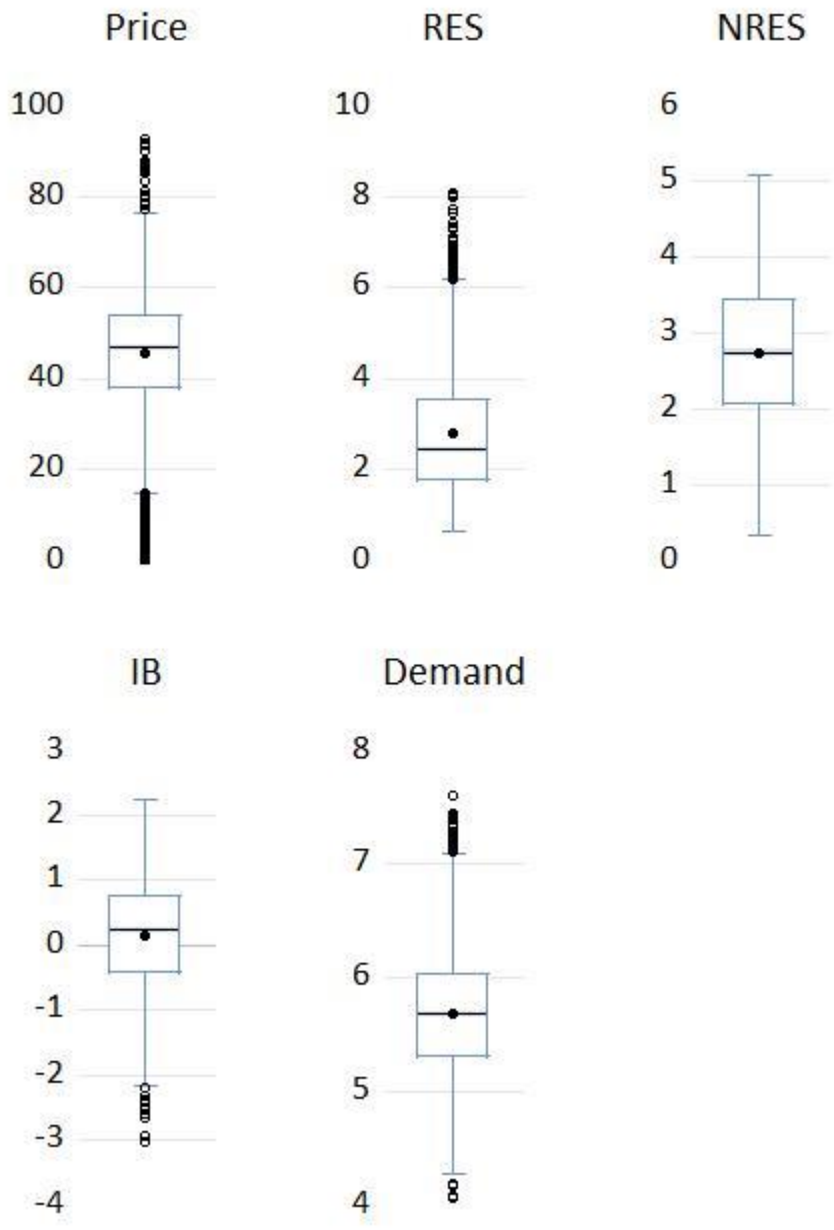
The results of the MOE in Portugal greatly converge with the existent literature, with the findings suggesting a decrease of 21,24€/MWh on the Portuguese wholesale electricity prices. This reduction translates into a €10,58 billion savings during the period of 2009 and 2018 in Portugal. In this study is also estimated that the costs on the consumer for the penetration of RES in the electric system were around 17,36€/MWh. At the end, this means that the introduction of RES in the Portuguese electrical system translated into savings for the consumer of around €1,93 billion.

The main drivers for policy makers to transfer the generation of electricity from the NRES to the RES is environmental and sustainability reasons. Several studies were already performed that proves the great impact that the RES have on the CO2 emissions reduction. Hence, a hypothetical increase on the consumers bids should not constitute a restriction to invest on cleaner sources of energy, provided that this increase does not affect the basic needs of its population. In the case of Portugal, it seems to be a double benefit, since the environmental benefits from the RES are in line with financial benefits for the consumer. However, policy makers should pay close attention to the relation between the MOE in the wholesale electricity prices, and its effect on the end-consumer prices. In fact, an extremely high value of the Feed-in-tariffs can transform the end-user financial benefits into an excessive cost and, on the other hand, a low value of those tariffs can concern the evolution of the RES investments,

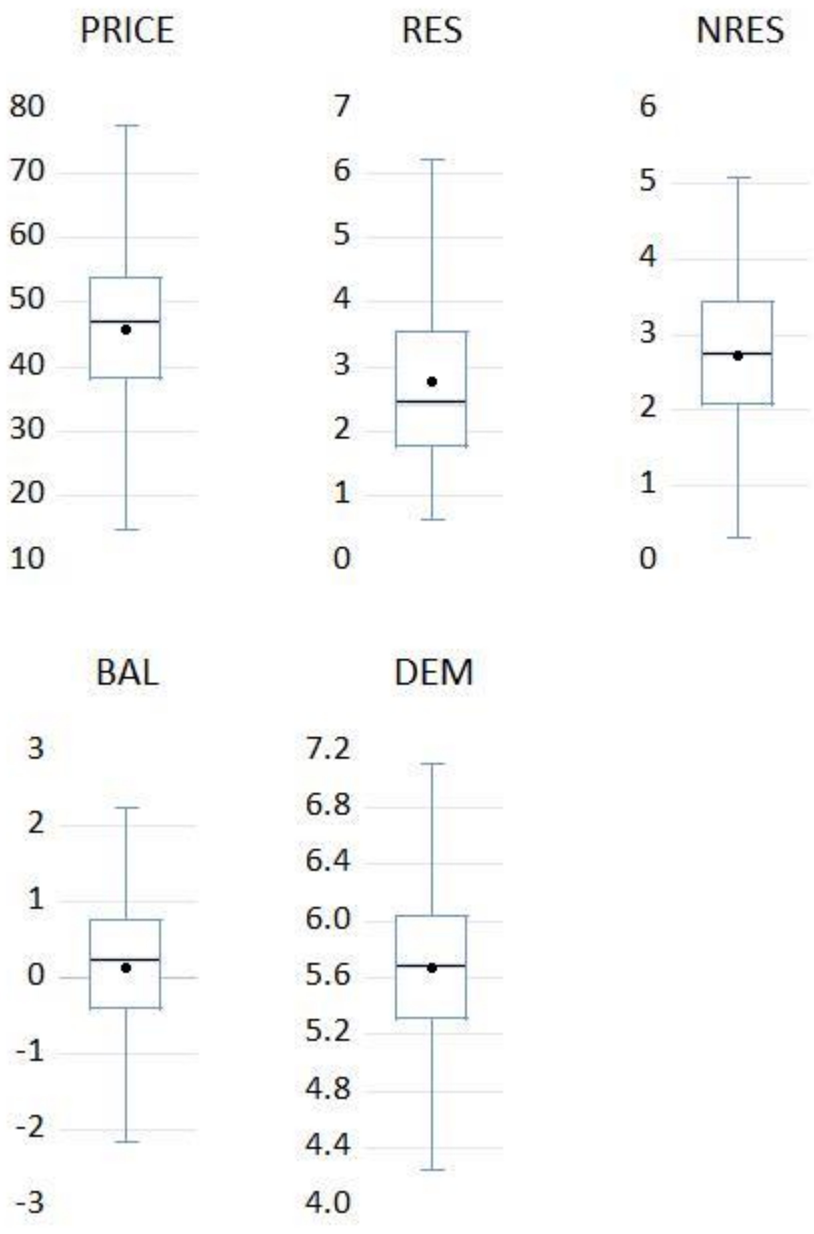
The fact that higher values of demand translates into higher electricity prices should also make policy makers to put their efforts into developing measures to reduce the electricity consumption. The investment on more efficient technologies and subsidies to help families get access to that technology can constitute a very efficient measure. Also, educational campaigns to alert people to the need of reducing the electricity consumption can prove to be a very effective measure.

Future studies can try to model the electricity prices, with an hourly frequency, and for each individual type of energy source, A lower data frequency can greatly help to improve the information collected by the analysis software and, thus, bring more accurate and real results, Some environmental variables as the temperature can prove to be very helpful in order to smooth the very high volatility of the electricity prices.

Annex



Annex 1. Boxplots graphs



Annex 2. Boxplot graphs after outliers removal

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