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An assessment of supply-side and demand-side policies in EU-28 household electricity prices

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ABSTRACT

The increase seen in household electricity prices in the European Union over recent years was strongly influenced by the regulation component. This paper focuses on an empirical assessment of both supply-side and demand-side policies in the European Union over the period 2000-2015. More specifically, on the supply side, it analyses renewable energy support policies and the electricity industry liberalisation process and, on the demand side, energy taxes, thus contributing to the debate on the effect of these factors on household electricity prices. Using pooled Ordinary Least Square clustered at country level and regarding solar photovoltaic energy support policies, the results suggest that both the costs of quota obligation systems and the electricity sector liberalisation process have raised household electricity prices. Energy taxes, however, do not have a significant influence on such prices. Based on these results, recommendations are proposed for policy-makers.

Keywords:

Household electricity prices;
Renewable energies;
Liberalisation;
Electricity market;

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1. Introduction

The energy policy of the European Union (EU) establishes affordable household electricity prices as one of its main objectives in the framework of the Energy Union: secure, competitive and sustainable energy [1].

From a supply-side point of view, the development of renewable energies (RES-E) has been an essential concept. The EU has made great efforts to promote such clean production technologies, as shown by the 2020 Energy Strategy [1], the 2050 Energy Roadmap [2], and the 2030 Climate and Energy package [3]. Among other aims, these regulations seek to increase the share of RES-E in energy consumption over time in order to reduce the impact of climate change.

RES-E are physically integrated into the wholesale electricity market and can influence its efficiency and competitiveness. Due to the low marginal costs of these clean production technologies, RES-E can lead to a reduction in wholesale electricity prices by displacing marginal technology based on fossil fuel. However, RES-E have been developed by establishing public support policies that have mainly been financed via the electricity market, by increasing the final price paid by consumers. This has sparked a debate about the effects on household electricity prices of including RES-E in electricity markets (see Table 1).

Table 1 shows that research on RES-E and household electricity prices in the EU has been based on case studies and empirical assessments in all member states. The results of case studies are inconclusive. For example, Bode [4] and Dillig *et al.* [5] found that RES-E support policy in Germany reduced both wholesale electricity prices and final electricity costs. Similarly, Sáenz de Miera *et al.* [6] showed that wind energy in Spain led to

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Table 1: Overview of the effects of RES-E on electricity prices in the EU

CASE STUDY	RESULTS	COUNTRY
Bode (2006)	RES-E support policy probably reduced both wholesale electricity prices and final electricity costs.	Germany
Sáenz de Miera *et al.* (2006)	Wind energy development entailed wholesale electricity price reductions that were greater than the increased costs for consumers arising from the support policy	Spain
Sensfuß *et al.* (2008)	RES-E net support payments were not offset by wholesale electricity price reductions	Germany
Frondel *et al.* (2010)	RES-E did not result in lower household electricity prices	Germany
Dillig *et al.* (2016)	RES-E involved a net saving of 11.2 billion Euros in 2013	Germany
Figueiredo and Pereira da Silva (2018)	RES-E reduced electricity prices but these savings were not passed on to household consumers.	Portugal and Spain
	EMPIRICAL ASSESSMENT	
Ragwitz *et al.* (2005)	Consumer burden due to greater RES-E support policies might be only partly offset by reductions in wholesale electricity prices	EU-15
ACER (2015)	General upward trend in EU household electricity prices as a consequence of RES-E	EU-15
Moreno *et al.* (2012)	Electricity prices rose with the deployment of RES-E	EU-27
Pereira da Silva and Cerqueira (2017)	Positive correlation between RES-E deployment and household electricity prices	EU-28
Trujillo-Baute *et al.* (2018)	Positive and statistically significant impact of RES-E promotion costs on household electricity prices	EU-28 (23 member states)

wholesale electricity price reductions that were greater than the increase in costs for consumers arising from the support policy. However, Sensfuß *et al*. [7] and Frondel *et al*. [8] found that RES-E net support payments were not offset by wholesale electricity price reductions in Germany. Similar results were obtained by Figueiredo and Pereira da Silva [9] for wind energy in Spain and Portugal.

The results of other research at EU level seem to show a positive correlation between RES-E deployment and household electricity prices (Ragwitz *et al*. [10] and ACER [11], using models developed in EU projects; Moreno *et al*. [12] and Pereira da Silva and Cerqueira [13] using panel data).

On the other hand, with regard to liberalisation in the energy industry, the aim of the EU has been to ensure that consumers receive the full benefits of market deregulation in terms of lower domestic electricity and gas bills. Verbruggen *et al.* [14] establish that liberalisation involves unbundling of the main functions, access for third parties and privatisation which should allow for more exchange and 'foreign shopping' by the incumbent energy companies. Recently, however, the possible benefits of greater competition have been questioned as this has not always been established effectively [15, 16].

Table 2 shows research on liberalisation in the electricity industry and household electricity prices in the EU, which is also inconclusive.

By means of regression analysis, Ernst and Young [17] found for the EU-15 that the liberalisation process resulted in lower electricity prices and lower price-cost margins. But Thomas [18] found, using a qualitative analysis, that the liberalisation process was not related to lower electricity prices. Cruciani [19] showed that the EU liberalisation process resulted in increases in both household and industrial electricity prices. Fiorio *et al.* [20] found that unbundling resulted in lower household electricity prices in the EU-15. By analysing electricity prices and consumer satisfaction survey data, Fiorio and Florio [21] showed that there is greater consumer satisfaction when a country has both public ownership and liberalisation. More recently, Florio [22] studied the impact of the liberalisation process in the EU-15 over the period 1990-2007 using panel data models and found lower household electricity prices in member states with state-owned companies. However, also using

Table 2: Overview of the effects of liberalisation of the electricity industry on electricity prices in the EU

STUDY	TYPE OF ANALYSIS	RESULTS	COUNTRIES
Ernst and Young (2006)	Regression analysis	Lower electricity prices, reliable and secure supply, and effective interaction with other policies (such as climate change and sustainable development)	EU-15
Thomas (2006)	Qualitative method	Liberalisation process was not related to lower electricity prices as from 2000	EU-15
Fiorio *et al.* (2008)	Regression analysis	Unbundling resulted in lower household electricity prices.	EU-15
Cruciani (2010)	Panel data	Increases in both household and industrial electricity prices (without the expected development of a more efficient system)	EU-15
Florio (2014)	Panel data	Lower household electricity prices in member states with state-owned companies.	EU-15
Pereira da Silva and Cerqueira (2017)	Panel data	Reduction in household electricity prices	EU-28 (23 member states)

Table 3: Overview of the effects of energy taxes on energy consumption in European countries

STUDY	TYPE OF ANALYSIS	RESULTS	COUNTRIES
Balaras *et al.* (2005)	Simulation	Energy taxes reduced energy consumption for heating in some member states in northern Europe.	Denmark, France, Greece, Poland and Switzerland
De Almeida *et al.* (2011)	Qualitative method	Energy taxes, among other energy efficiency policies, seemed insufficient to reduce energy consumption	Belgium, Bulgaria, Czech Republic, Denmark, France, Germany, Greece, Hungary, Italy, Norway, Portugal and Romania.
Meyer *et al.* (2014)	Case study	Energy taxes reduced demand but the effect was rather slow in the last ten years of the study.	Denmark
Broin *et al.* (2015)	Panel data	Energy efficiency policies (including energy taxes) reduced energy consumption.	EU-15
Sorrell (2015)	Qualitative method	Need to combine energy efficiency policies (including energy taxes) with behavioural interventions to reduce energy consumption.	EU-15 and other countries

panel data methods, Pereira da Silva and Cerqueira [13] showed that liberalisation resulted in a reduction in household electricity prices in the EU-28, over the period 2000-2014.

The implementation of demand-side policies should also be considered as these might also have an impact on household electricity prices. Maxwell *et al.* [23] found that increases in electricity consumption result in an increase in household consumers' electricity costs as fossil fuel might be required to meet demand.

The Energy Efficiency Directive proposes various instruments to reduce energy consumption, with the focus on energy taxes to facilitate a shift towards more sustainable consumption patterns [24] by reducing demand [25] and thus mitigating the increase in electricity prices. In this context, research has mainly focused on the effects of energy efficiency policies on energy consumption. Table 3 shows that the results obtained are not unanimous.

Balaras *et al.* [26] found that the use of instruments such as energy taxes to reduce energy consumption in buildings successfully reduced energy consumption for heating in some EU member states in northern Europe. Geller *et al.* [25], however, pointed out that energy demand is relatively price-inelastic in the short term but not in the long term. Similar results were obtained by

Broin *et al.* [24], who showed that financial policies required at least seven years to have an effect on energy consumption. However, Meyer *et al.* [27], Sorrell [28] and De Almeida *et al.* [29] indicated that the introduction of energy efficiency measures, such as energy taxes, seemed insufficient to reduce energy consumption in the EU.

In this context, the objective of this paper is to contribute to the debate on the effects of the above supply-side and demand-side policies on household electricity prices. The main novelty of our paper is the following:

(i) Previous research on the impact of RES-E on household electricity prices mainly used variables related to the share of RES-E in electricity generation capacity and/or the contribution of RES-E to electricity supply. Little consideration was given to the effects of the specific type of RES-E support policies or their incentive amounts for household electricity prices. This analysis is essential in order to better understand the impact of these clean production technologies on household electricity prices. An exception was Trujillo-Baute *et al*. [30] who used the Generalised Method of Moments (GMM) to analyse the impact of renewable promotion costs on industrial and household electricity prices in the EU, although this study only covered the period 2007-2013. Our paper analyses a longer period of time (2000-2016), which might allow policy-makers to gain more information on specific effects on household electricity prices.
This paper also considers the effects of the two main solar photovoltaic (PV) support policies in the EU (both the feed-in tariff and tradable green certificates) as well as their incentive amounts. Solar PV is considered because of its great potential for electricity generation in the EU. Over the period 2005-2015, the contribution of solar PV to total electricity generated from renewable sources increased from 0.1% to 12.0% (Eurostat), allowing this technology to position itself as one of the most important renewable technologies.

(ii) Previous research does not include demand-side policies in the analysis, which were mostly studied from the point of view of their effects on energy consumption. Nevertheless, consumers' behaviour may also have effects on electricity prices. This paper analyses the effect of a specific demand-side policy, energy taxes, on household electricity prices.

(iii) This paper also contributes to the debate on the effects of electricity industry liberalisation on household electricity prices as greater competition in this industry might not be effective.

The remainder of this paper is structured as follows. Section 2 presents the problem. Section 3 describes the sample and variables and proposes the methodology. Section 4 shows the main results and discusses them. Finally, Section 5 presents the main conclusions.

2. Problem formulation

Renewable production technologies have been developed thanks to public support policies mainly financed via the electricity market [23, 31]. There are two main RES-E support policies in the EU: the feed-in tariff (FIT), and the quota obligation based on tradable green certificates [32]. Development of these policies is a long-term, evolving process that needs enduring support [14]. FIT, in either the premium-price or the fixed-price options, is the RES-E energy support policy that has been most widely used in the EU. Premium-price FIT adds a bonus to the wholesale electricity price, whilst fixed-price FIT establishes guaranteed prices for fixed periods of time. The quota obligation, on the other hand, allows RES-E producers to sell certificates in addition to electricity.

In this context, the type of RES-E support policy and their incentive amounts seem to be key for ascertaining the impact of these clean production technologies on household electricity prices. Nevertheless, the literature on RES-E and household electricity prices has mainly centred on the analysis of variables related to the share of RES-E in electricity generation capacity and their contribution to electricity supply [4, 7, 11, 12, 10, 13]. An exception is Trujillo-Baute *et al.* [30] who used the Generalised Method of Moments (GMM) to analyse the impact of renewable energy promotion costs (both price-based and quantity-based instruments) on industrial and household electricity prices in the EU over the period 2007-2013. Their results showed that the impact of RES-E promotion costs is positive and statistically significant, although relatively small. However, this study only covers the period 2007-2013, although most RES-E energy support policies were adopted in the EU in the early years of the previous decade (from year 2000).

In our paper, the analysis is applied to solar PV energy because its fast growth in recent years. Thus, this clean production technology is characterised by being "*the most promising alternative energy based on environmental, economic and safety criteria in the EU*" [33] (p. 54).

Taking into account previous literature, and that RES-E support policies have mainly been financed via the electricity market, the following hypotheses are presented to differentiate the specific impact of each RES-E support policy:

H1a FIT, as a solar PV support policy, positively influences household electricity prices.

H1b Tradable green certificates, as a solar PV support policy, positively influence household electricity prices.

H1c The higher the tariff price in FIT, the higher household electricity prices are.

H1d The higher the prices of tradable green certificates, the higher household electricity prices are.

The liberalisation process, on the other hand, can have a positive or a negative impact on household electricity prices. Taking into account both the aims of the European Commission to enable consumers to receive the full benefits of market liberalisation, and the majority of the previous empirical research, the following hypothesis is proposed:

H2 The EU electricity industry liberalisation process reduces household electricity prices.

Regarding energy efficiency policies, it is not clear if these lower consumption (with a consequent reduction in electricity prices). Taking into account the previous empirical research as well as the aims of the Energy Efficiency Directive, combined with the expected results in energy prices, the final hypothesis is proposed:

H3 Energy taxes on electricity consumption might, by reducing demand, mitigate the increase in electricity prices.

3. Empirical design

This section discusses the sample, the variables and the methodology used in the empirical assessment.

3.1. Sample

To test the above hypotheses, the Eurostat Database was used to obtain data over the period 2000-2016 as it contains the most precise information, which is constant over time, standardised among member states and belongs to the European Commission. The ACER Market Monitoring Reports [11] and the Member State RES-E Progress Reports [34] were also used for data collection. The analysis starts in 2000 as most RES-E energy support policies were implemented in the EU in the early years of that decade. Similarly, most liberalisation processes were implemented in the member states at the end of the nineties. The study period ends in 2016 because the most recent Member State RES-E Progress Report was published by the European Commission in 2017 (the last data of that report is for 2016).

Cases for which there was no information on any of the variables were not considered in the study in order to avoid missing values in the estimates and to have the same sample size in all models. As a result, we ended up with an unbalanced panel of 23 countries[1] and 303 observations.

3.2. Measuring variables

3.2.1. Dependent variable

In this study, the dependent variable is the logarithm of household electricity prices, following Ito [35] and Pereira da Silva and Cerqueira [13]. Household electricity prices are measured as the average national price applicable for medium-size household consumers (Consumption Band Dc with annual consumption between 2500 kWh and 5000 kWh) (in Euro per KWh) (ELECTR_PRICES).

3.2.2. Explanatory variables

This paper analysis the effects on household electricity prices of the two main solar PV energy support policies in the EU (FIT and the quota obligation system based on tradable green certificates). Three dummy variables were created to measure these effects: (i) RES-E energy promotion policy1, which refers to the

1 The countries included were Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungry, Italy, Ireland, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovenia, Slovakia, Spain, Sweden and the United Kingdom.

non-existence of a specific promotion policy in solar PV energy (PV_POL1), (ii) RES-E energy promotion policy2, which refers to the existence of a quota obligation in solar PV energy (PV_POL2), and (iii) RES-E energy promotion policy3, which indicates the existence of FIT in solar PV energy (PV_POL3).

The analysis also studies the impact of the incentive amount. More specifically, in FIT, the tariff refers to the price obtained by a solar PV energy producer for electricity sold to the grid (in Euros/MWh) in FIT observations and 0 otherwise (TARIFF_PRICE). In the case of premium tariffs, it is the electricity market price plus the bonus. For fixed-price tariffs, it is the amount of the tariff. There are different schemes for solar PV energy in the EU as the tariff amount varies with the size of the facility. Following Jenner *et al*. [36], the tariff price variable is the mean value of each solar PV tariff across both size and location. Regarding quota obligations, the certificate price variable considers the prices generally obtained through a market mechanism (in Euros/MWh) together with electricity market prices (in Euros/MWh) in solar PV energy producers with the quota system and 0 otherwise (QUOTA_PRICE) [37]. As certificate prices also vary with the size of the solar PV facility, this variable refers to the mean value of each solar PV certificate price across both size and location.

Liberalisation policy is introduced in the model as a dummy variable taking the value 0 before the year of the electricity sector liberalisation and 1 afterwards (LIBERALISATION_POL) [13].

Finally, in order to consider the effect of energy taxes, since the Eurostat Database does not break down taxation on different energy products, this variable considers the implicit tax rate on energy for household consumers. The European Commission points out the importance of electricity taxes, which amount to a large share of total energy taxes, for sustainable development in the EU [38]. In this context, the analysis measures the implicit tax rate on energy for household consumers as the ratio between energy taxes paid by households and final household energy consumption (in Euros per tonne of oil equivalent) (FISCAL_POL).

Finally, it is necessary to consider that electricity prices respond to demand changes in the short term. Trujillo-Baute *et al.* [30] and Romero-Jordan *et al*. [39] establish that there might be a delay in the response of consumers' demand to changes in electricity prices due to a "long-term habit inertia" or a "memory effect". Therefore, household electricity prices of the previous year (ELECTR_PRICES-1) have been introduced in the model to determine whether this effect is significant.

3.2.3. Control variables

Following previous empirical papers [40, 6, 42, 41], three relevant variables were controlled to analyse household electricity prices:

a) The contribution of RES-E to electricity supply, measured as the ratio between RES-E electricity generation and total electricity supply (% of the total gross electricity supply) (RES-E_CONTRIBUTION). The results reported in the literature are not conclusive. Some studies found a negative relation between this variable and household electricity prices. Their explanation is that RES-E resulted in lower wholesale electricity prices that offset the increase in costs of the support policies [5, 6]. However, other research found a positive relation between both variables as the reduction in wholesale electricity prices was insufficient to offset the cost of RES-E support policies [13, 23].
b) The market share of the largest generator in the electricity market, measured as the ratio between the net electricity production of the largest generator and total net electricity production in the electricity market (% of total generation) (SHARE_LGENERATOR). If the liberalisation process does not reduce the market share of incumbent companies, it might be ineffective for lowering household electricity prices [40, 41].
c) The economic situation, in which gross domestic product (GDP) is used as a proxy variable. A positive relationship is expected between this variable and the development of clean production technologies as countries with a better economic situation might have more resources to invest in RES-E [42]. The final effect of this variable on household electricity prices will again depend on whether the possible wholesale electricity price reduction arising from RES-E is, or is not, offset by the cost of the RES-E support policy.

3.3. Model

A pooled OLS (Ordinary Least Square) regressions clustered at country level was performed with the STATA12 program[2]. In addition, endogenous explanatory and control variables were lagged by one year to control for endogeneity problems in the model

2 The cluster option also implies the estimation of standard robust errors.

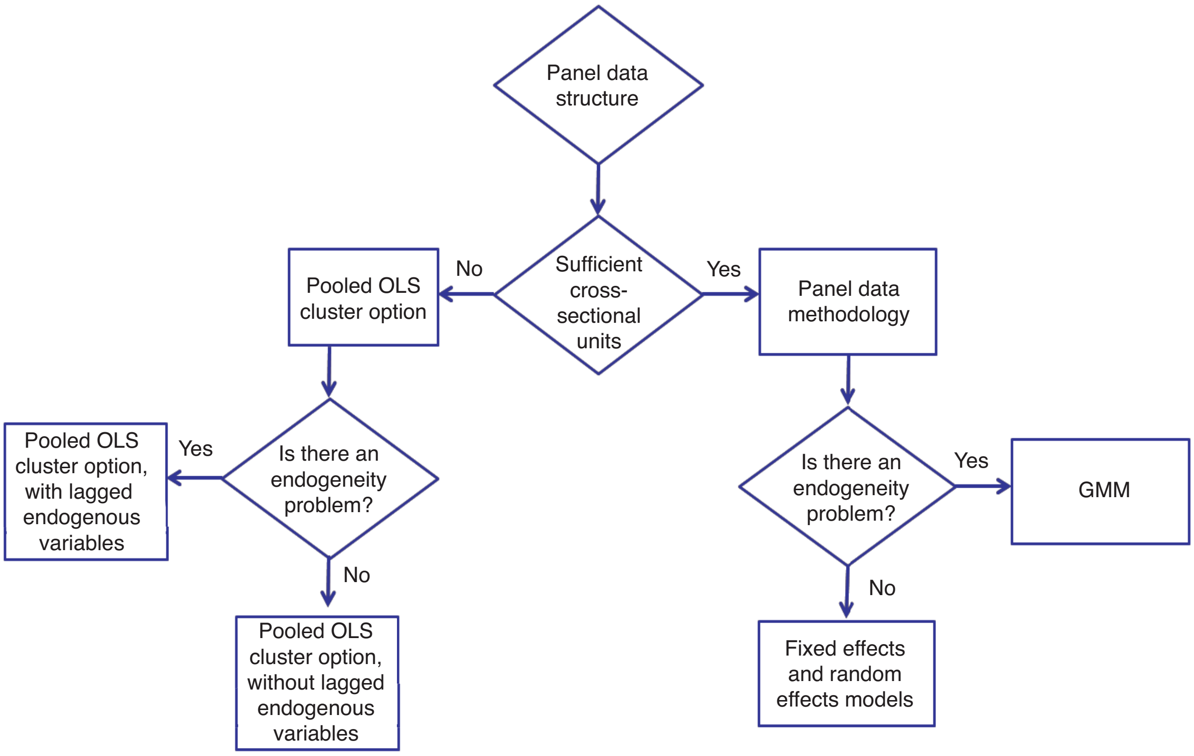

Figure 1: Problem-solving methodology

proposed. Initially, the possibility of employing a panel data methodology, such as the two-step difference GMM model drawn up for dynamic panel data models by Arellano and Bond [43], was considered. However, this methodology was not applied because the results would not be reliable as the number of instruments would be larger than the number of countries (see Figure 1 for a better understanding of the methodology employed).

The pooled OLS we run is as follows:

$$\begin{aligned}\text{ELECTR\_PRICES}_i &= a_0 + \beta_1\ \text{ELECTR\_PRICES}_{\text{it-1}} + \\ &\beta_2\ \text{PV\_POL}_\text{i} + \beta_3\ \text{TARIFF\_PRICE}_\text{i} + \beta 4\ \text{QUOTA\_PRICE}_\text{i} + \\ &\beta_5\ \text{LIBERALISATION\_POL}_\text{i} + \beta 6\ \text{FISCAL\_POL}_\text{i} + \\ &\beta 7\ \text{RES-E\_CONTRIBUTION}_{\text{it-1}} + \beta 8\ \text{SHARE\_LGENERATOR}_\text{i} + \\ &\beta 9\ \text{GDP}_\text{i} + \sum_{t=2000}^{2016} \text{D}_t + \varepsilon_i\end{aligned}$$

Where:

$\sum_{t=2000}^{2016} D_t$ is a set of time dummy variables and ε_i is the error term.

4. Results and discussion

The descriptive statistics are shown in Table 4 while the correlation coefficients of the variables used in the regression analysis are listed in Table 5. Once the non-normality of the explanatory and continuous control variables was confirmed, and considering that Pearson's correlation coefficient did not work well for discrete variables as it was very sensitive to violations of normality assumptions, Spearman's rank correlations were calculated. Although some of the variables were significantly correlated, analysis of the variance inflation factors (VIF) revealed no evidence of multicollinearity, as all of them remained under 10 [44].

Table 6 summarises the results of the regression analysis. As explained in the section on the variables, PV_POL is a qualitative variable that places PV support policies in three categories (non-existence of a specific PV support policy, FIT, and quota obligation). To make this variable operative, three dummy variables were defined, but it was only possible to add k-1 dummies to the regression models in our case 2 because in the other case the parameters cannot be estimated. The results are therefore presented by pairing the dummies

Table 4: Descriptive statistics[a]

Variables	Mean	Maximum	Minimum	Std. Dev.
ELECTR_PRICES	0.110	0.238	0.055	0.033
TARIFF_PRICE	14.069	55	0	17.767
QUOTA_PRICE	1.512	40.8	0	5.313
FISCAL_POL	179.744	441.56	72.01	76.999
RES-E_CONTRIBUTION	15.506	100	0.036	12.585
SHARE_LGENERATOR	56.677	100	15.3	26.971
GDP	537,566.9	3,134,100	5,424.4	750,717.03
Other explanatory variables			**% (number of observations = 1)**	
LIBERALISATION_POL			67.33 (204)	
PV_POL1			21.45 (65)	
PV_POL2			16.50 (50)	
PV_POL3			62.05 (188)	

[a] n = 303

to clarify what their coefficients really mean. It is sufficient to state the results of the combination of dummies PV_POL2 (quota obligation in solar PV energy) and PV_POL3 (FIT in solar PV energy), as the results of the remaining combinations may be inferred from the previous one.

Regarding solar PV energy support policies, the results do not support either Hypotheses 1a or 1b as both the FIT (PV_POL3) and tradable green certificate (PV_POL2) variables are not statistically significant. The analysis goes further by adding the effect of the incentive amount of both policies. The results do not support Hypothesis 1c as the tariff price (TARIFF_PRICE) in FIT policies is not statistically significant. This finding therefore seems to indicate that the incentive amount set in FIT policies is not passed on to final consumers or offset by wholesale electricity price reductions. Related to this finding, although their analyses are at country level, Bode [4] and Dillig *et al.* [5] showed that FIT did not involve an increase in household electricity prices in Germany. Similarly, Sáenz de Miera *et al.* [6] indicated that FIT in Spanish wind energy did not result in an increase of costs for consumers arising from the support policy.

On the other hand, the results support Hypothesis 1d as certificate prices (QUOTA_PRICE) are statistically significant (β=0.001 p=0.017) and have statistically significant impacts on household electricity prices. Therefore, solar PV net support payments cannot be offset by wholesale electricity price reductions. This finding is in line with Trujillo-Baute *et al.* [30], who indicated that quantity-based support policies (which include a quota obligation system based on tradable green certificates) had a positive and statistically significant impact on household electricity prices in the EU over the period 2007-2013.

Hypothesis 2 must be rejected because the electricity sector liberalisation process (LIBERALISATION_POL) had a positive and significant influence on household electricity prices (β= 0.016 p=0.097). This finding is in line with those obtained by Thomas [18] and Cruciani [19]. These studies, which use quantitative and qualitative methods respectively, showed that liberalisation has not achieved its aim in the EU related to the development of a more efficient system with lower household and industrial electricity prices. Our result shows that the reforms outlined in the electricity sector liberalisation process in the EU seem to have been insufficient to achieve more competitive household electricity prices. The explanation may lie in the persistence of entry barriers related to long administrative procedures to create new electricity generation facilities, or the possible market power of incumbent companies [16, 45].

Hypothesis 3 must be rejected as energy taxes (FISCAL_POL) are not statistically significant. The

Table 5: Correlation matrix[a]

Variables	1	2	3	4	5	6	7	8	9	10	11
1. LELECTR_PRICES	1										
2. PV_POL1	–0.328**	1									
3. PV_POL2	0.060	–0.232**	1								
4. PV_POL3	0.231**	–0.668**	–0.568**	1							
5. TARIFF_PRICE	0.117*	–0.521**	–0.443**	0.779**	1						
6. QUOTA_PRICE	0.080	–0.231**	0.995**	–0.565**	–0.440**	1					
7. LIBERALISATION_ POL	0.249**	–0.116*	0.177**	–0.037	0.007	0.168**	1				
8. FISCAL_POL	0.4337**	–0.383**	–0.098†	0.399**	0.302**	–0.118*	0.108†	1			
9. RES–E_ CONTRIBUTION	0.082	0.125*	0.245**	–0.081	0.049	0.246**	0.207**	–0.025	1		
10. SHARE_ LGENERATOR	–0.115*	–0.096†	–0.259**	0.279**	0.171**	–0.236**	–0.423**	–0.098†	–0.273**	1	
11. GDP	0.278**	–0.235**	0.284**	–0.019	0.141	0.283**	0.264**	0.445**	0.281**	–0.491**	1

[a] n = 303 † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

Table 6: Linear regression analysis[a]

Variables	Model
ELECTR_PRICES-1	0.916** (60.46)
PV_POL2	–0.006 (–0.41)
PV_POL3	0.015 (0.74)
TARIFF_PRICE	–3.54-04 (–1.02)
QUOTA_PRICE	0.001* (2.57)
LIBERALISATION_POL	0.016† (1.73)
FISCAL_POL	–3.00-05 (–0.42)
RES-E_CONTRIBUTION	–4.93-04* (–2.07)
SHARE_LGENERATOR	4.84-05 (0.32)
GDP	2.66-09 (0.37)
R^2	0.920
F	4367.39**
Number of countries	23
Number of observations	303

[a] Standardised coefficient with t-value in brackets
† $p< 0.10$; * $p < 0.05$; ** $p < 0.01$

results suggest that energy taxes do not lead to lower energy prices, motivated by a reduction in energy consumption. De Almeida *et al.* [29] and Sorrell [28] stress that energy taxes alone cannot promote more sustainable energy consumption. Reinforcing actions might therefore be necessary to achieve energy efficiency goals in the EU.

Finally, the results of the model analysed suggest that household electricity prices are influenced by those of the previous year (ELECTR_PRICES-1) (β= 0.916 p = 0.000). Our findings point to a delay in the response of consumers' demand to changes in electricity prices due to "long habit inertia" or "memory effect". These results are in line with those obtained by Agnolucci [46], Gam and Rejeb [47] and Romero-Jordan *et al*. [39]).

Regarding control variables, the market share of the largest generator in the electricity market (SHARE_LGENERATOR) and the country's economic situation (GDP) do not seem to significantly influence household electricity prices. The initial model was repeated by substituting the country's economic situation (GDP) with the logarithm of GDP. The results remain the same.

However, the results support a negative and significant influence of the contribution of RES-E to electricity supply (RES-E_CONTRIBUTION) on the dependent variable (β= -4.93-04 p = 0.050), in line with other studies [7,13]. This finding seems to indicate that the expected reduction in wholesale electricity prices stemming from RES-E might not offset the cost increase of RES-E support policies. The initial model was repeated substituting the contribution of RES-E to electricity supply (RES-E_CONTRIBUTION) with the generation capacity of RES-E to total electricity generation capacity as a percentage of total electricity generation capacity (RES-E_CAPACITY). The results regarding the main explanatory variables remain the same.

This paper improves and expands on the existing literature in some key areas. Most prior studies do not consider the effect of demand-side policies on household electricity prices. These should be analysed to find the specific effect that consumer's behavior can have on electricity prices. Regarding the effect of supply-side policies (both RES-E development and the liberalisation process) on household electricity prices, the results in the literature on RES-E development are inconclusive as they report, using both qualitative and quantitative methods, both reductions (for example, Bode [5]; Sáenz de Miera *et al.* [23]; Dillig *et al.* [6]) and increases (for example, Sensfuß *et al*. [20]; Frondel [24]; Moreno *et al.* [21]; Pereira da Silva and Cerqueria [7]; Figueiredo and da Silva Pereira [50]). Moreover, most studies do not consider the effects of the different types of RES-E support policies as well as their incentive amount on household electricity prices. One exception is Trujillo-Baute *et al.* [30], who analysed the effects of both RES-E price-based and quantity-based instruments on industrial and household electricity prices in the EU. However, this study only covers the period 2007-2013, although most RES-E energy support policies were adopted in the EU in the early years of the first decade. Therefore, the study of RES-E support policies from the year 2000 might allow policy-makers to gain more information about their specific effects on household electricity prices. With regard to the electricity sector liberalisation process, there is also a debate about its effects on household electricity prices as greater competition in this industry might not be effective, as shown in Streimikiene *et al.* [48] and Thomas [18]. The study of these issues might provide relevant insights to achieve more competitive household electricity prices.

Our results suggest the importance of reviewing both supply-side and demand-side policies to define measures to hold back an increase in household electricity prices. Tradable green certificates have led to high levels of remuneration for mature technologies, which may impact household electricity prices. The certificate prices set by this support policy should be reviewed to obtain more competitive household electricity prices. Policy-makers should also review the liberalisation model to identify the most appropriate types of reform for achieving the goals of energy policy. Finally, energy taxes do not seem to be a suitable measure for lowering household electricity prices. Policy-makers might consider the possibility of complementing these actions with public campaigns to promote citizens' environmental awareness. Such actions would induce more sustainable consumption, with the consequent reduction in household electricity prices.

5. Conclusions

Achieving affordable household electricity prices is one of the mail goals of the EU energy policy in the framework of the EU 2020, 2030 and 2050 Strategies. Nevertheless, household electricity prices have risen in recent years.

This paper provides an empirical evaluation of both supply-side and demand-side policies in the European Union over the period 2000-2016. The results indicate that both the supply-side policies analysed here had an impact on household electricity prices. Regarding RES-E (more specifically, solar PV) support policies, the cost of quota obligations based on tradable green certificates, but without FIT, seems to have resulted in higher household electricity prices. The liberalisation process also seems to have raised household electricity prices. However, energy taxes did not have a significant influence on these prices.

Policy-makers should consider the possibility of reviewing both the certificate prices of RES-E technologies and the specific reforms set in motion by the liberalisation process in order to reduce household electricity prices. Moreover, the adoption of public policies to promote environmental awareness might be an effective complementary measure for energy taxes.

Further research might study the effects of alternative RES-E (biomass, minihydraulic, solar thermoelectric, etc.), alternative energy efficiency measures (energy labels and ecodesign) and specific reforms introduced via liberalisation (unbundling, ownership type, etc.) on household electricity prices.

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References

[1] European Commission, editor. 2020 Climate and Energy Package. Brussels; 2009.

[2] European Commission, editor. Energy Roadmap 2050. Brussels; 2011.

[3] European Commission, editor. A policy framework for climate and energy in the period from 2020 to 2030. Brussels; 2014.

[4] Bode S. On the Impact of Renewable Energy Support Schemes on Power Prices. Institute of International Economics (HWWI). Hamburg; 2006.

[5] Dillig M, Jung M, Karl J, The impact of renewables on electricity prices in Germany - An estimation based on historic spot prices in the years 2011–2013, Renewable and Sustainable Energy Reviews 57 (2016) pages 7–15. https://doi.org/10.1016/j.rser.2015.12.003

[6] Sáenz de Miera G, del Río González P, Vizcaíno I, Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain, Energy Policy 36 (9) (2008) pages 3345–3359. https://doi.org/10.1016/j.enpol.2008.04.022

[7] Sensfuß F, Ragwitz M, Genoese M, The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany, Energy Policy 36 (8) (2008) pages 3086–3094. https://doi.org/10.1016/j.enpol.2008.03.035

[8] Frondel M, Ritter N, Schmidt CM, Vance C, Economic impacts from the promotion of renewable energy technologies: The German experience, Energy Policy 38 (8) (2010) pages 4048–4056. https://doi.org/10.1016/j.enpol.2010.03.029

[9] Figueiredo NC, da Silva Pereira, P. The price of wind power generation in Iberia and the merit-order effect, International Journal of Sustainable Energy Planning and Management 15 (2018). https://doi.org/10.5278/ijsepm.2018.15.4

[10] Ragwitz M, Held A, Resch G, Faber T, Huber C, Haas R. Monitoring and evaluation of policy instruments to support

renewable electricity in EU Member States. Fraunhofer Institute Systems and Innovation Research, Energy Economics Group (EEG); 2005.

[11] ACER, editor. Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2015; 2015. https://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/ACER_Market_Monitoring_Report_2015.pdf

[12] Moreno B, López AJ, García-Álvarez MT, The electricity prices in the European Union. The role of renewable energies and regulatory electric market reforms, Energy 48 (1) (2012) pages 307–313. https://doi.org/10.1016/j.energy.2012.06.059

[13] Pereira da Silva P, Cerqueira PA, Assessing the determinants of household electricity prices in the EU: A system-GMM panel data approach, Renewable and Sustainable Energy Reviews 73 (2017) pages 1131–1137. https://doi.org/10.1016/j.rser.2017.02.016

[14] Verbruggen A., Di Nucci R., Fischedick M, Haas R, Hvelplund F, Lauber V, ... & Schleich J, Europe's electricity regime: restoration or thorough transition. International Journal of Sustainable Energy Planning and Management 5 (2015) pages 57–68. https://doi.org/10.5278/ijsepm.2015.5.6

[15] Lagarto J, Sousa JA, Martins Á, Ferrão P, Market power analysis in the Iberian electricity market using a conjectural variations model, Energy 76 (2014) pages 292–305. https://doi.org/10.1016/j.energy.2014.08.014

[16] Tsybina E, Moreno-Cruz J, Tereshin A, Liberalisation lowers primary energy efficiency: Evidence from twin power systems, Energy 173 (2019) pages 423–435. https://doi.org/10.1016/j.energy.2019.02.004

[17] Ernst & Young LLP, editor. Final Report Research Project: The Case for Liberalization. 2006. https://webarchive.nationalarchives.gov.uk/20070507022928/http://www.dti.gov.uk/files/file28401.pdf

[18] Thomas S. Recent evidence on the impact of electricity liberalisation on consumer prices, Public Services International Research Unit (PSIRU); 2006.

[19] Cruciani M, Keppler JH, Kerebel C, The 23 January 2008 'Energy and Climate Package': a turning point for the Europe of energy (INIS-FR--11–0451) (2008). France.

[20] Fiorio CV, Florio M, Doronzo R. The Electricity Industry Reform Paradigm in the European Union: Testing the Impact on Consumers. In: Arestis P, Sawyer M, editors. Critical Essays on the Privatisation Experience, Basingstoke: Palgrave Macmillan; 2008.

[21] Fiorio CV, Florio M, Would you say that the price you pay for electricity is fair? Consumers' satisfaction and utility reforms in the EU15, Energy Economics, 33 (2) (2011) pages 178–187. https://doi.org/10.1016/j.eneco.2010.05.006

[22] Florio M, Energy Reforms and Consumer Prices in the EU over twenty Years, Economics of Energy & Environmental Policy, 3 (1) (2014) pages 37–52. https://www.jstor.org/stable/26189263

[23] Maxwell V, Sperling K, Hvelplund, Electricity cost effects of expanding wind power and integrating energy sectors. International Journal of Sustainable Energy Planning and Management, 6 (2015), pages 31–48. https://doi.org/10.5278/ijsepm.2015.6.4

[24] Broin EÓ, Nässén J, Johnsson F, Energy efficiency policies for space heating in EU countries: A panel data analysis for the period 1990–2010, Applied Energy 150 (2015) pages 211–223. https://doi.org/10.1016/j.apenergy.2015.03.063

[25] Geller H, Harrington P, Rosenfeld AH, Tanishima S, Unander F, Policies for increasing energy efficiency: Thirty years of experience in OECD countries, Energy Policy 34 (5) (2006) pages 556–573. https://doi.org/10.1016/j.enpol.2005.11.010

[26] Balaras CA, Droutsa K, Dascalaki E, Kontoyiannidis S, Heating energy consumption and resulting environmental impact of European apartment buildings, Energy and Buildings 37 (5) (2005) pages 429–442. https://doi.org/10.1016/j.enbuild.2004.08.003

[27] Meyer NI, Mathiesen BV, Hvelplund F, Barriers and potential solutions for energy renovation of buildings in Denmark. International Journal of Sustainable Energy Planning and Management 1 (2014) pages 59–66. https://doi.org/10.5278/ijsepm.2014.1.5

[28] Sorrell S, Reducing energy demand: A review of issues, challenges and approaches, Renewable and Sustainable Energy Reviews, 47 (2015) pages 74–82. https://doi.org/10.1016/j.rser.2015.03.002

[29] De Almeida A, Fonseca P, Schlomann B, Feilberg N, Characterization of the household electricity consumption in the EU, potential energy savings and specific policy recommendations, Energy and Buildings 43 (8) (2011) pages 1884–1894. https://doi.org/10.1016/j.enbuild.2011.03.027

[30] Trujillo-Baute E, del Río P, Mir-Artigues P, Analysing the impact of renewable energy regulation on retail electricity prices, Energy Policy 114 (2018) pages 153–164. https://doi.org/10.1016/j.enpol.2017.11.042

[31] Ugulu AI, Barriers and motivations for solar photovoltaic (PV) adoption in urban Nigeria. International Journal of Sustainable Energy Planning and Management,21 (2019). https://doi.org/10.5278/ijsepm.2019.21.3

[32] Nicolini M, Tavoni M, Are renewable energy subsidies effective? Evidence from Europe, Renewable and Sustainable Energy Reviews 74 (2017) pages 412-423. https://doi.org/10.1016/j.rser.2016.12.032

[33] Bórawski P, Yashchenko T, Sviderskyi A, Dunn JW, Development of renewable energy market in the EU with particular regard to solar energy, Conference Proceedings Determinants of Regional Development 1 (2019) pages 43–55.

[34] European Commission, editor. Commission Renewable Energy Progress Report from Member States. Brussels; 2017.

[35] Ito K, Do consumers respond to marginal or average price? Evidence from nonlinear electricity pricing, American Economic Review, 104 (2) (2014) pages 537–563. http://home.uchicago.edu/ito/pdf/Ito_Marginal_Average_AER.pdf

[36] Jenner S, Groba F, Indvik J, Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries, Energy Policy 52 (2013) pages 385–401. https://doi.org/10.1016/j.enpol.2012.09.046

[37] Pacesila M, Burcea SG, Colesca SE, Analysis of renewable energies in European Union, Renewable and Sustainable Energy Review 56 (2016) pages 156–170. https://doi.org/10.1016/j.rser.2015.10.152

[38] Hasselknippe H, Christiansen AC. Energy taxation in Europe: current status–drivers and barriers–future prospects, Fridtjof Nansen Institute, FNI Report, 14; 2003.

[39] Romero-Jordan, D, del Rio P, Penasco C. Household electricity demand in Spanish regions. Public policy implications. Document de Treball de l´IEB, 24; 2014.

[40] Jamasb T, Pollitt M, Electricity market reform in the European Union: review of progress toward liberalization & integration, The Energy Journal 3 (2005) pages 11–41. http://hdl.handle.net/1721.1/45033

[41] Schleicher-Tappeser R, How renewables will change electricity markets in the next five years, Energy Policy 48 (2012) pages 64–75. https://doi.org/10.1016/j.enpol.2012.04.042

[42] Chang TH, Huang C M, Lee M C, Threshold effect of the economic growth rate on the renewable energy development from a change in energy price: Evidence from OECD countries. Energy Policy, 37(12) (2009), pages 5796–5802. https://doi.org/10.1016/j.enpol.2009.08.049

[43] Arellano M, Bond S, (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations, The Review of Economic Studies 58 (2) (1991) pages 277–297. https://doi.org/10.2307/2297968

[44] Kleinbaum DG, Kupper LL, Muller KE. Applied regression analysis and other multivariable methods. Boston: PWS-KENT Publishing Company; 1998.

[45] Simhauser P, From First Place to Last: The National Electricity Market's Policy-Induced 'Energy Market Death Spiral, Australian Economic Review, 47 (4) (2014) pages 540–562. https://doi.org/10.1111/1467–8462.12091

[46] Agnolucci P, Stochastic trends and technical change: the case of energy consumption in the British industrial and domestic sectors, The Energy Journal 31 (2010) pages 111–135. https://www.jstor.org/stable/41323381

[47] Gam I, Rejeb JB, Electricity demand in Tunisia, Energy Policy 45 (2012) pages 714–720. https://doi.org/10.1016/j.enpol.2012.03.025

[48] Streimikiene D, Bruneckiene J, Cibinskiene A, The Review of Electricity Market Liberalization Impacts on Electricity Prices, Transformations in Business & Economics 12 (3) (2013) pages 40–60. http://www.transformations.knf.vu.lt/30/se30.pdf

[49] Ferreira P, Soares I, Johannsen RM, Østergaard PA. Policies for new energy challenges. International Journal of Sustainable Energy Planning Management 2019; 26. https://doi.org/10.5278/ijsepm.3552.