The relationship between renewable energy and retail electricity prices: Panel evidence from OECD countries[1]

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Abstract

The centrality of electricity to everyday life is indisputable, and the price thereof can have significant implications. Literature is inconclusive over the effect of the renewable energy share in the energy mix on retail electricity prices as a country-specific regulatory policy has a significant impact on retail electricity prices. The purpose of this paper is to determine the effect of the increasing renewable electricity share on retail electricity prices for 34-OECD countries, considering the change in market structure for 23 EU countries. The results show that the influence of the renewable energy share in the energy mix on retail electricity prices is positive and statistically significant. Increasing renewable sources is inescapable in reaching SDG7, while increased awareness of true price signals should prompt private investment while phasing out support schemes in the long run. A sound regulatory framework is required to account for renewable intermittency as well as effective supply and demand matching. The positive impact on electricity prices should not deter policymakers from promoting renewable energy as the effect is marginal and is expected to decline in forthcoming years, improving energy security. The benefits of employing renewables far outweigh the environmental cost.

Keywords: renewable energy; electricity prices; OECD; energy dependence

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[1]The authors would like to acknowledge the financial support received from Economic Research Southern Africa (ERSA) for publishing working paper 797 and the insightful comments received from the anonymous referees that improved the paper.

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1. Introduction

The centrality of electricity to everyday life is indisputable, and the price thereof can have significant implications. The European Commission [1] states that while low electricity prices "raise purchasing power," and increases both living standards and industry competition, high electricity prices act as a signal to move to cleaner energy and improve energy efficiency. Studying the effect of increasing renewables on electricity prices is crucial in understanding market signals.

The International Energy Agency (IEA) works along with 26 Organization for Economic Co-operation and Development (OECD) member countries in co-operation with the European Commission (EC) to reform energy supply and demand by introducing alternative energy sources while aligning environmental and energy policies as well as assisting with the integration thereof [2]. Many IEA member countries embarked on the process of electricity market liberalization in the 1990s motivated by sector inefficiencies, the increasing trend of privatizing state-owned companies, and the declining transitional cost towards a different system. Electricity market liberalization contributed to significant economic benefits, as competition increased efficiency within the sector, producing long-term consumer benefits. However, the system requires government involvement in upholding checks and balances. [2]

The European Union (EU) fully liberalized the majority of their electricity markets in 2014, all member countries except Bulgaria and Malta are compliant. Market liberalization for numerous countries has been in effect for 5 to 10 years, excluding Cyprus, which was the last to liberalize. Industry electricity prices decreased in Australia, Denmark, Finland, Norway, Sweden, the United Kingdom, and the United States after market liberalization [3]. However, retail electricity prices have seen an increase, mainly due to increasing fuel cost and cost associated with CO_2 emissions within Europe [2]. Trujillo-Baute et al. [4] attribute the sharp increase in retail elasticity prices over the years to the increase in renewable energy sources, while [1] states that wholesale electricity prices have decreased significantly. However, retail electricity prices tend to increase due to network charges, taxes, and levies [1]. Transmission and distribution networks, along with fuel cost, are essential cost components of electricity that is not fully reflected in consumer electricity prices [2]. Cost reductions in these components are a result of developments in economic regulation and not necessarily from increased competition in the electricity market [2]. Fuel efficiency and ultimately, energy efficiency have shown significant improvements with productive investment under market liberalization, improving the overall economic efficiency of a power plant [2]. The International Renewable Energy Agency (IRENA) [5] recently projected that within the next two years, all renewable energy sources would be price competitive with fossils fuels. This new development is likely to increase the renewable energy share even further. Additional expected reductions in the cost of Renewable energy technologies over the years could potentially lower electricity prices in the future [5].

Full market liberalization reduces electricity prices by increasing competition; moreover, the European Union has committed to reducing emissions under the Kyoto protocol and therefore employed renewable energy support schemes to encourage the implementation of renewable technologies [6] [7]. The Paris Agreement reached at the United Nations Framework Convention on Climate Change (UNFCCC), Conference of the Parties (COP 21) in 2015 strengthens policies on climate change and incentives the transition towards a low-carbon energy system. The average CO_2 intensity of electricity needs to decrease by 96% from 2015 to 2050 to prevent global temperatures from increasing by 2°C [7].

Pressures on CO_2 emissions motivated carbon-tax in several OECD member countries, including the European Union implemented in 2003, individual states of the United States, Canada in 2008, South Korea in 2015, and most recently China in 2016 [8]. The IEA [8] states that high carbon prices and increasing shares of Renewable Energy Sources (RES) can generate sufficient revenue to recover the fixed cost of low-carbon power sources, potentially increasing renewable investments. Wholesale electricity prices are decreasing due to the merit-order effect; once the fixed cost of renewable technologies is covered, the marginal cost associated is very low and consequently places first in the merit order. The aftermath results in decreased revenue for all operators as well as overcapacity. For an effective investment to happen, these issues have to be addressed for the transitional period towards low-carbon technologies. Support policies include fixed-price instruments, shared risk instruments, and subsidies.

Consumer decisions are made based on retail electricity prices, which have not seen the same decreases as wholesale electricity prices. The retail electricity prices can be affected by a variety of factors such as the variation of fossil fuel prices and renewable energy costs, choice of technologies in the specific supply mix, capital expenditures per technology, market conditions in general in relation to economic growth and demand in the specific country etc.

Figure 1 depicts the relationship between average retail electricity prices and average renewable energy sources for electricity (RES-E) share (the factor that this study will focus on). This figure does not imply causality from any direction to the other, but it shows a certain level of a positive correlation between the two indicators that is worth examining further.

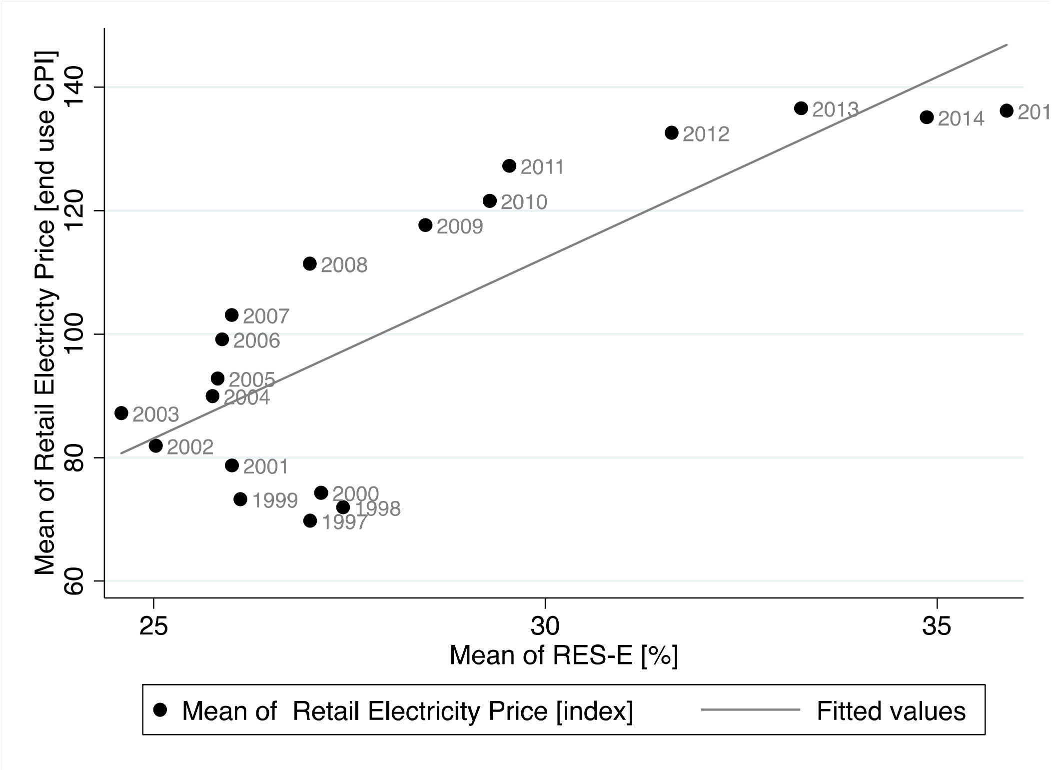

Figure 1: Correlation between average retail electricity prices and average renewable electricity share for all OECD countries 1997-2015 [Source: own calculations from IEA and World Bank (2018)]

Numerous renewable policies are financed by levees, increasing the consumer price. The electricity price to end-users comprises of energy – which is 43% of the total price in Europe 2012-, distribution (30%), energy tax (13%), and value-added tax (14%) [8]. As a result of increased retail prices and decreasing cost of rooftop solar photovoltaic (PV), household self-consumer or behind-the-meter electricity generation is increasing, ultimately resulting in an implicit feed-in-tariff called net metering. The increased behind-the-meter generation does not eliminate the need for grid connection and the reliability that comes with it [8]. Inefficiencies within the retail price, such as the tariff structures inability to allow for dynamic pricing as well as taxation, give incorrect price signals to the consumer. Producers are encouraged to disclose the cost structure more openly, depicting the actual value of the product to consumers [8].

The purpose of this study is to examine the effect of the continuously increasing share of Renewable Energy Sources (RES) in the energy mix on retail electricity prices in 34 OECD countries from 1997 to 2015, considering the change in electricity market structure for the 23 EU countries. The study contributes to the literature by including a sample with more countries than those examined in Moreno, López, and García-Álvarez [9] broadening the country group from EU countries to include OECD countries as only EU countries fall under the emission trading scheme (EU- ETS). The study uses a more recent dataset (up to 2015), and hence contributes by including 1) the last decade's developments in renewable energy technology and its consequences to cost and prices of RE, and 2) the global financial crisis and its aftermath, allows us to view the subsequent constraints on investment. The study does not claim to make a technical contribution to the energy field. However, the contribution of the paper is that the examination of the OECD country group might challenge the results for the EU countries (that are relatively similar). The comparison and contrast of the two groups can provide a variety of policy implications as the OECD group includes countries with a variety of electricity supply mixes and market structures that affect electricity prices.

Section 2 analyzes the current OECD electricity market and renewable policies, providing background to the issue at hand, followed by a detailed literature review in section 3. Section 4 discusses the panel data techniques employed to estimate the model. To do so, we will test for the presence of unit roots, if the results of the test conclude on a stationarity series, a pooled estimation will follow. Alternatively, Pedroni's [10,11] panel cointegration test, which allows for "heterogenous short-run dynamics," will be pursued. We discuss the estimation results, followed by concluding remarks and a discussion in section 5.

2. Literature review

Previous literature is inconclusive over the effect of the renewable energy share in the energy mix on retail electricity price, as country-specific regulatory policy and market structure have a significant impact on retail electricity prices [4]. Ballester and Furió [12] found that in the Spanish case, an increasing share of renewable energy results in lower retail electricity prices for the period 2010 to 2013 if they consider "peak and off-peak prices" separately. The opposite is true for the period 2002 to 2009 due to less severe employment of renewable technologies and higher prices associated with these technologies during this period. The weight of RES increased from 29% to 59% from 2008 to 2013, consisting of up to 80% of the daily supply on occasion since 2011. The authors employed a model adopted by [13], which is a "stochastic process with mean reversion that includes a discrete jump process" which allows for price volatility to be captured. They concluded that the relationship between the RES-E share and electricity prices is only significant for peak prices; significant positive relationships between thermal (coal and oil-gas), nuclear, hydroelectric, pumping hydroelectric, combined cycle, renewables and price volatility have been found; renewables are negatively correlated with upward jumps in peak prices, and no significant relationship has been found considering off-peak prices.

Würtzburg et al. [14], amongst others [15–17], studied the merit-order effect of the renewable energy share on wholesale electricity prices. Würtzburg et al. [14] thoroughly reviewed previous literature, which allowed them to isolate trends and patterns. They found that the merit-order effect is much larger for smaller markets as opposed to larger markets. Conducting an empirical analysis, they found that for each Gigawatt hours (GWh) of average hourly predicted renewable energy generation, the day-ahead electricity price was reduced by 2% for the German-Austrian market. Their results are in line with simulation-based approaches. This price effect is not directly transferred to the consumer retail price. The authors found that Germany's withdrawal from nuclear energy did not affect the merit order effect. They found weak evidence supporting string merit-order effects for high electricity demand, possibly due to the use of fossil fuels during these periods. Sańenz de Miera et al. [17] states that this decrease in marginal cost to the producer may offset the initial setup cost and act as an incentive to invest in renewable technologies.

Atems and Hotaling [18] examine the effects of renewable and non-renewable electricity on economic growth for a panel of 174 countries for the period 1980 to 2012 while controlling for education, trade, government expenditure along with other social indicators known to affect growth. The methodology consisted of a comparison between Ordinary Least Squares OLS, Fixed effects, baseline system General Method of Moments (GMM), two-step GMM, and alternative system GMM approach for robustness. The coefficients of the control-variables of the two-step GMM approach is consistent with previous literature. The results conclude that both renewables and non-renewables are positively correlated with economic growth at a 5% level of significance. While the inefficiency of the electricity grid is shown to have a significant negative relationship. As such, developing countries can address climate change by introducing renewable energy sources into the energy mix without concern of deterring economic growth as long as the proper policies are in place. Tampakis et al. [19] found that renewables energy is appropriate for ensuring energy security in isolated areas as well as having significant impacts on energy balances and environmental protection.

Imura and Cross [20] analyze the effects of renewable energy on household electricity prices in liberalized electricity markets in 7 OECD countries. The results indicate a "strong path dependency" for household electricity prices, while market reforms resulted in more significant price decreases than policy anticipated. There is no significant relationship between higher prices and increased renewable deployment. The authors suggest that renewables are more likely to be traded with neighbouring countries than deployed by the host country due to the merit order effect.

This study's approach aligned with the research conducted by [9], who developed an econometric panel data model to estimate this relationship for the European Union from 1998 to 2009. They performed the Hausman test to see if fixed effects or random effects are more appropriate and concluded on fixed effects to control for country-specific policy. They found that a 1% increase in renewable energy results in a 0.018% increase in household electricity prices. Noting that while the effect is small, it is most notably influenced by market financed RES-E support schemes. Public RES-E support schemes may effectively mitigate the retail price increase, which has been limited to what is deemed truly necessary [21]. Our research builds on that of [9] to see if the degree and magnitude of the effect of renewable energy on household electricity prices are similar for 1997 to 2015 than it was for 1998 to 2009. Improvements in technology, increased competition, and international project developers have been singled out as key drivers in the cost reduction of renewable technologies [22]. Could the decreased price of renewable technologies offset the effect of the reduction of public RES-E support schemes on household electricity prices?

3. Methodology and Data

3.1 Theoretical Framework

This study's methodology is based on one of the models employed by [9]. Our model is defined in equation (1), where electricity generated from renewable sources as a percentage of total gross electricity production (RESE), gross domestic product per capita, measured in constant 2010 US dollars (GDPPC), greenhouse gas emissions by the energy sector as a percentage of total greenhouse gas emissions (EIE), energy dependency (ED), and the market share of the largest electricity generator (EGC) are determinants of retail electricity prices:

$$\ln(y_{i,t}) = \alpha_i + \beta_1 \ln(RESE_{it}) + \beta_2 \ln(GDPPC_{it}) + \beta_3 \ln(EIE_{it}) + \beta_4 ED_{it} + \beta_5 \ln(EGC_{it}) + u_{it} \quad (1)$$

RES-E provides information regarding the share of renewable energy sources employed for electricity[3]. Theory suggests that a positive relationship exists as multiple public support schemes contribute towards RE projects. The impact of *RES-E* on electricity prices is important given the reduction of public support schemes. Historically the price associated with employing renewable technologies has been high when compared to the price of traditional fossil fuel energy sources. Moreno et al. [9] found that a 1% increase in *RES-E* led to a 0.018 per cent increase in household electricity prices at a 1% level of significance. *GDPPC* provides a measurement of relative economic activity for each country and will act as a demand proxy capturing the structure and level of economic development. A positive relationship is expected between a higher level of *GDPPC* and retail electricity prices; this is aligned with the findings of [9] of a significant 1.345 per cent increase. *EIE* is included as EU countries engage in an Emissions trading scheme, fluctuations in this variable have a direct effect on the marginal cost of energy production, and as such, we expect to see a positive relationship, as with [9] with a 0.025 significant parameter estimate. *ED* indicates the degree to which the countries are dependent on energy imports, which are linked to the price of natural resources and therefore links to the price of electricity. The European Union is highly dependent on energy imports, although *ED* is expected to yield a negative impact as EU policy aims to increase electricity imports between member states in an attempt to reduce electricity prices [23]. This is contradictory to the findings of [9], where a 1% increase in ED leads to a 0.004 per cent increase in

[3] We would like to mention here that the list of factors affecting the renewable energy share for electricity are not exhaustive to the ones included here (for example, the availability of resources and energy intensity). This study follows the theoretical approach by Moreno et al.[9] and we decided to keep the specification of their study.

electricity prices. *EGC* (Electricity Generation Concentration) measures the market share of the largest electricity generator in the market; therefore, an increase in this variable would indicate a reduction in competition. Theory suggests that a positive relationship should exist, as an increase in market share infers higher prices. However, [24,25] found that this was not the case, as a loss of economies of vertical integration occurs. Both these studies support the findings of [9] of a significant negative relationship of a 1% increase in EGC, leading to a 0.005 per cent reduction in electricity prices.

3.2 Econometric methodology

The Im, Pesaran, and Shin [26] panel unit root test is used to determine the univariate characteristics of the series, thereby confirming or rejecting stationarity, the test allows for heterogeneous autoregressive coefficients. [27] and [28] indicate that the equation used to test for a common unit root is:

$$y_{it} = \rho_i Y_{i_{t-1}} + \delta X_{it} + \varepsilon_{it} \tag{2}$$

Where i=1, … , N for each country in the data span; t=1, … , T is the year; X_{it} represents the combined exogenous variables, including two way fixed effects; ρ_i depicts the autoregressive coefficients and ε_{it} the disturbance term. [27,28] explain that Im et al. [26] uses the mean of the Augmented Dickey-Fuller (ADF) unit root test "while allowing for different orders of serial correlation:"

$$\varepsilon_{it} = \sum_{j=1}^{p=1} \varphi_{ij} \varepsilon_{it\text{-}j} + u_{it} \tag{3}$$

Substitution (2) into (1):

$$y_{it} = \rho_i Y_{i_{t-1}} + \sum_{j=1}^{p=1} \varphi_{ij} \varepsilon_{it_{-j}} + \delta X_{it} + u_{it} \tag{4}$$

Where ρ_i now indicates the number of lags and the null and alternative hypothesis is as follows:

$$H_0\text{: } Panel\ contains\ a\ unit\ root$$

$$H_1\text{: } Panel\ is\ stationary$$

To ensure the robustness of the unit root test results, we also conducted the Levin, Lin and Chu t-statistics, the Breitung t-statistic, the Im, Pesaran and Shin W-statistic, the ADF Fisher Chi-square, and the PP Fisher Chi-square test. If we reject the null hypothesis, therefore concluding on a stationary series, we will proceed with a pooled estimation. If not, we have to proceed with Pedroni's [10,11] panel cointegration test, which allows for cross-country interconnections to determine a long-run relationship between our variables.

$$y_{it} = \alpha_i + \delta_i t + \gamma_{1i}\ln(RESE_{it}) + \gamma_{2i}\ln(GDPPC_{it}) + \gamma_{3i}\ln(EIE_{it}) + \gamma_{4i}ED_{it} + \gamma_{5i}\ln(EGC_{it}) + \varepsilon_{it}$$

(5)

Where i = 1, … , N for each country in the data span; t=1, … , T is the year; $\alpha_{it}$and δ_i represents country-specific time-invariant effects, and ε_{it} represents the estimated residuals deviations from the long-run value. Where,

$$H_0: Panel\ exhibits\ no\ cointegation$$

$$H_1: Panel\ is\ cointegated$$

And the unit root test,

$$\varepsilon_{it} = \rho_i \varepsilon_{i_{t-1}} + w_{it} \quad (6)$$

Pedroni [10,11] makes use of four statistics: panel ν, panel ρ, panel PP and panel ADF-statistic. Large positive values signify rejection in the panel ν statistic, where lager negative values indicate rejection in panel ρ, panel PP and panel ADF-statistic. "These statistics allow for heterogeneous fixed effects and deterministic trends and also for heterogenous short-run dynamics." Pedroni [10,11] found that panels with T=20, the ADF group and ADF panel statistic, followed by the panel ρ statistic generally fair the best concerning power, size, and reliability, while the panel and group PP are somewhere between the ADF panel and panel ρ statistic.

If we reject the null hypothesis of no cointegration with the Pedroni test, the Hausman test will be conducted to conclude whether a pooled or fixed effects estimation will follow. If the Hausman test concludes on a fixed-effects model, we will proceed with a two-way fixed effects estimation, since we assume that each country and year has specific and unique time-invariant characteristics that influence the significant differences in household electricity prices amongst the 34-OECD countries. As such, we control for the assumed correlation between the error term and our explanatory variables, denoted by α_i, and is treated as a regression parameter [29].

3.3 Dataset

The data utilized in this evaluation were obtained from the International Energy Agency (IEA), the World Bank, OECD, and Eurostat databases (the source of each indicator is described in Table 1, last column). Since data availability for wholesale electricity prices is restricted, only retail electricity prices will be examined form 1997-2015. Data availability for electricity price is not reported for the entire data span, and EGC is only available for EU countries (1997-2015), leading to an unbalanced panel dataset. The dependent variable is retail electricity prices in index form along with renewable energy share, electricity generation concentration, GDP per capita, energy industry emissions, and energy dependence as explanatory variables.

Table 1: Descriptive statistics of the variables

	Mean	SD	Min	Max	OBS	Sources
Retail electricity price [Real end use consumer price index]	105.9	75.3	3	638.7	623	IEA [30]
RES-E [%]	28.2	27.5	0.04	100	665	World Bank [31]
GDP per capita [CUS$]	36497.52	21479.79	5857.01	111968.3	665	World Bank [32]
EIE [%]	27.8	13.8	0.06	73	636	OECD [33]
ED [%]	18.6	130.5	-843.5	98.6	645	World Bank [34]
EGC [%]	54.1	25.2	15.3	100	352	Eurostat [35]

4. Empirical results

As discussed in the Methodology section, the unit root test proposed by [26] was done to determine the stationarity of the variables. In each case (except for ln(EGC) and ln(GDPPC) regarding trend and intercept), the null hypothesis was accepted; as such, each series in the panel dataset contains a unit root and is non-stationary as shown in Table 4 (see Appendix). Given the results, we proceeded by testing for the existence of cointegration; results are represented in Table 2. Where each model has ln(Retail Price) as the dependent variable followed by the following explanatory variables: Model (1) ln(RES-E); Model (2) ln(RES-E), ln(GDPPC); Model (3) ln(RES-E), ln(GDPPC), and ln(EIE); Model (4) ln(RES-E), ln(GDPPC), ln(EIE) and ED; Model (5) ln(RES-E), ln(GDPPC), ln(EIE), ED, and ln(EGC). [28] explains that these statistics "are based on the average values of the individual autoregressive coefficients linked with the unit root test for each country in the panel." Within all deterministic structures, the PP-statistics indicates the rejection of the null hypothesis of no cointegration at a 1% level of significance. As such, the results confirm a long-run relationship between retail electricity prices and electricity generated from renewable sources, including the control variables such as market share for the 34 OECD countries. Given the results of the Hausman test, a two-way fixed effects estimation followed (Table 3), to account for heterogeneity between cross- and year-sections while seeing the effects of each control variable as our number of cross-sections change significantly when controlling for market structure.

Table 2: Panel cointegration test results

		Model 1		*Model 2*		*Model 3*	
		Panel	**Group**	**Panel**	**Group**	**Panel**	**Group**
Intercept and Trend	V-Statistic	8.553***		11.704***		12.709***	
	Rho-Statistic	1.005	3.216	2.357	4.845	2.320	5.273
	PP-Statistic	-2.040*	-0.639	-0.889	0.656	-4.374***	-3.199***
	ADF-Statistic	-6.410	-0.665	0.831	0.328	0.028	-0.957
Intercept	V-Statistic	-1.592		1.824**		-0.031	
	Rho-Statistic	0.489	1.101	-0.201	1.663	1.903	2.797
	Pp-Statistic	-1.719*	-3.901***	-3.431***	-2.802***	-1.457*	-4.034***
	ADF-Statistic	0.159	-1.155	-2.962***	-1.218	-0.461	-0.297
None	V-Statistic	-4.187		0.642		-0.654	
	Rho-Statistic	0.994	2.714	-0.014	2.174	-0.104	2.499
	PP-Statistic	-1.204	-1.835**	-2.244**	-1.989**	-4.114***	-3.759***
	ADF-Statistic	-0.472	-0.7255	-0.579	-0.548	-1.927**	-0.809
		Model 4		*Model 5*			
		Panel	**Group**	**Panel**	**Group**		
Intercept and Trend	V-Statistic	9.797***		-0.208			
	Rho-Statistic	3.149	6.294	4.329	6.412		
	PP-Statistic	-6.741***	-4.110***	-3.587***	-1.168		
	ADF-Statistic	-1.616*	0.734	0.011	1.124		
Intercept	V-Statistic	1.262		-1.105			
	Rho-Statistic	2.207	3.794	2.570	4.339		
	PP-Statistic	-2.856***	-3.958***	-3.213***	-5.114***		
	ADF-Statistic	-2.609***	-0.406	0.523	-0.389		
None	V-Statistic	-0.784		-1.391			
	Rho-Statistic	1.432	3.582	1.931	3.977		
	PP-Statistic	-2.557***	-2.852***	-2.929***	-3.269***		
	ADF-Statistic	1.100	-0.283	-0.369	-0.475		

Notes: *(**)[***] denotes 1% (5%) and [10%] levels of statistical significance → The null hypothesis of *No cointegration* is rejected

Model (1), (2) and (3) all have positive and statistically significant coefficients for RES-E, indicating that electricity generated from renewable sources does have a significant effect on retail electricity prices when controlling for GDP per capita, and energy industry emissions. Once we include energy dependence in Model (4), the coefficient for RES-E remains positive but is not statistically significant in the 34 OECD countries.

Table 3*:Two-way fixed effects estimation*

	(1) OECD	(2) OECD	(3) OECD	(4) OECD	(5) EU
ln(RES-E)	0.0535** (0.005)	0.0399** (0.033)	0.0376* (0.055)	0.0272 (0.163)	0.0462** (0.005)
ln(GDPPC)		0.650*** (0.000)	0.726*** (0.000)	0.895*** (0.000)	0.429*** (0.000)
ln(EIE)			-0.0751* (0.100)	-0.0334 (0.461)	0.157* (0.093)
ED				0.000261 (0.532)	-0.000220 (0.811)
ln(EGC)					-0.0912** (0.049)
cons	3.914*** (0.000)	-2.633** (0.014)	-3.174** (0.004)	-5.029*** (0.000)	-0.466 (0.669)
N	623	623	601	581	349
adj. R2	0.578	0.604	0.606	0.631	0.762
BIC	-127.2	-160.5	-156.1	-165.1	-363.0
F	47.61*** (0.000)	50.00*** (0.000)	46.49*** (0.000)	47.39*** (0.000)	55.19*** (0.000)
Hausman test	4.643*	15.563***	14.952***	17.998***	32.358***

Notes: *(**)[***] denotes 1% (5%) and [10%] levels of statistical significance

Staying true to Moreno et al. [9], the results indicate the need to control for electricity generation market share, represented by Model (5). Model (5) reduces our number of cross-sections from 34 to 23 since the data for EGC is only available for EU countries. The variables expressed in natural logarithms can be expressed in terms of elasticities. We see that all variables are statistically significant, except for ED, of which the sign is consistent with expectations. A 1% increase in the share of RES-E results in a 0.046% increase in the share of retail electricity prices; the coefficient is slightly larger than [9]. A 1% increase in GDP per capita leads to a 0.429% increase in retail electricity prices, while a 1% increase in EIE leads to a 0.157% increase. The effect of EIE is much larger than in [9], indicating that the effect of emission trading schemes increased from 2007 to 2015. EIE does not have a significant effect in Model (4), which contains the OECD countries of which not everyone has an emissions trading scheme in contrast to Model (5), which contains only EU countries all employing an emissions trading scheme. ED has a negative sign, illustrating that more countries have become energy exporters, but is not statistically significant. A 1% increase in EGC leads to a 0.091% decrease in retail electricity prices, indicating that increased market power led to a price reduction contradictory to perfect competition theory, but in line with the findings of Moreno et al. [9] as they explained that countries with higher market concentration have more government subsidies decreasing electricity prices. All the results except for ED are in line with that of Moreno et al. [9].

All in all, to answer the study's main research question, the estimation confirms a positive coefficient from the share of renewable energy to average retail electricity prices which means that an increase in the share led to increases in the prices for the 34 OECD countries for the period 1997-2015. For this sample and the same period, GDP per capita was also a positive contributor to retail electricity prices while the emissions generated by the energy industry do not have a robust impact on the dependent variable (negative in the one model but become insignificant as soon as the energy market structures EGC are taken into consideration).

5. Conclusion and Policy Implications

The purpose of this paper was to determine the effect of the increasing renewable electricity share on retail electricity prices for 34-OECD countries, considering the change in market structure for 23 EU countries in a panel data framework from 1997 to 2015. The study employed standard panel data techniques by following the theoretical framework as proposed by Moreno et al. [9]. To do so, the analysis also took in to account other factors such as GDP per capita, greenhouse gas emissions by the energy sector, energy dependence and, electricity market concentration.

The unit root tests confirmed non-stationarity and hence, we proceeded with the Pedroni panel cointegration test that confirmed the hypothesis of a long-run relationship among all variables in all model specifications chosen. The two-way fixed effects estimation results confirmed the a priori theoretical expectations of a positive coefficient of the share of renewable energy meaning that an increase (decrease) in this share led to an increase (decrease) of retail electricity prices for the sample of 34 OECD countries, ceteris paribus [positive coefficient]. This relationship remained the same in the majority of the model specifications of the analysis. These results hold important implications for future policies encouraging renewable energy sources and understanding price signals as a consumer. The current increase of RES-E on electricity prices is marginal and is mostly due to the electricity market financed RES-E support schemes [9]. IRENA [5] projected that renewable energy sources would be price competitive with fossil fuels within the next two years; we suspect that with future data, the relationship will eventually be negative. Encouraging private RES-E support schemes could effectively mitigating the increases in retail electricity prices, bringing about this relationship sooner. As RES-E support schemes increased the renewable generation capacity and further increases in the share of RES-E could bring about price reductions. Emissions trading schemes by the energy industries only hold a significant effect for EU countries. Most countries' energy dependency changed over the period, declining in both energy exports and imports [37] and holds no significant effects for retail electricity prices in this analysis.

On other interesting results, an increase (decrease) in electricity market concentration led to a decrease (increase) in retail electricity prices, ceteris paribus [negative coefficient]. The impact of renewable energy on retail prices differs across market structures, from regulated monopolized markets to competitive markets. This is evident from the results in Model (4), where the coefficient on RES-E is positive but insignificant compared to the results of Model (5) where we control for market structure. Countries with higher levels of market concentration within the electricity sector typically receive more government subsidies, which have to be used efficiently to observe retail price reductions. The need to control for the market structure is also observed through greenhouse gas emissions by the energy sector of which the effect is much larger than in Moreno et al. [9] for EU countries, indicating a more substantial impact of Emission trading schemes from 2007 to 2015. As phase 1 of the EU-ETS was launched in 2005, trading volumes increased from 321 million to 1.1 billion in 2006 and 2.1 billion allowances in 2007 respectively, whereas, in 2012, trading volumes reached 7.9 billion [36]. The negative sign on energy dependency in Model (5-EU countries) compared to the positive sign in Model (4-OECD countries) could be due to low-cost fossil fuel imports by European countries as the EU is, on average more energy dependant than OECD counties. The majority of these findings support the results of [9]. However, the coefficient for Energy Dependency is negative and statistically insignificant, where that of [9] was positive and significant. As mentioned before, this could be the result of EU policy encouraging energy imports between member countries.

The role of clean energy sources toward global decarbonization is inescapable in reaching climate goals. Therefore, the results hold important implications for future policies encouraging renewable energy sources and understanding price signals as a consumer. Strengthening renewable electricity generation could shield against threats to electricity security, as well as providing efficient and affordable access to electricity aligned with Sustainable Development Goal 7. Battery storage systems are key to facilitating variable renewable energy progression and enabling energy system flexibility. Energy storage investment has increased significantly in recent years, induced by technology cost reductions as a result of the increased production of electric vehicles [38]. Battery storage systems aids in improving energy efficiency by preserving excess energy supply and by "balancing power grids" that is required to accommodate the increasing renewable energy share, resulting in lower electricity prices for consumers [38]. Consumers should benefit directly through future price reductions as well as through environmental improvement regarding air quality etc. Renewable energy sources require effective supply and demand matching, encouraging investment while phasing out support schemes in the long-run. The electricity market and regulatory framework need to be adjusted to accommodate flexible responses from the network to compensate for renewable intermittency [8]. Increases in electricity prices to reflect the social cost towards the consumer should act as a signal to move towards cleaner energies, as the marginal cost associated is low while the environmental benefit is high. Technological improvements, economies of scale, and increased competition have made it possible for renewable energy to be integral in the global energy supply mix today. Progressive improvements in technology have made significant dents in accessibility and affordability, with the potential to be even more cost-effective in the future. Overall our results indicate a range of between 0.03 -0.046% increases in the retail electricity price for a 1% increase in the renewable energy share in the supply mix, controlling for all other factors. Policymakers should be conscientious of the short-run consequences of altering the energy supply mix, considering both economic and social reasons with the bonus of environmental benefit in developing countries, whereas, in developed countries, the shift might be purely environmentally motivated.

Appendix

Table 4: Panel unit root test results

Variable	Form	Method	Statistic	P-Value	Conclusion
ln(RETAIL PRICE)	Trend and intercept	LLC	-1.445	0.074	Non-stationary
		Breit t	7.032	1.000	Non-stationary
		IPS	2.561	0.995	Non-stationary
		ADF-Fisher	43.719	0.984	Non-stationary
		PP-Fisher	48.951	0.946	Non-stationary
	Intercept	LLC	-6.388	0.000	Stationary
		IPS	0.045	0.518	Non-stationary
		ADF-Fisher	116.06	0.0003	Stationary
		PP-Fisher	189.909	0.000	Stationary
	None	LLC	11.337	1.000	Non-stationary
		ADF-Fisher	2.680	1.000	Non-stationary
		PP-Fisher	3.115	1.000	Non-stationary
ln(RES-E)	Trend and intercept	LLC	-2.094	0.018	Stationary
		Breit t	1.040	0.851	Non-stationary
		IPS	0.294	0.581	Non-stationary
		ADF-Fisher	70.994	0.444	Non-stationary
		PP-Fisher	100.514	0.0098	Stationary
	Intercept	LLC	1.793	0.964	Non-stationary
		IPS	4.308	1.000	Non-stationary
		ADF-Fisher	36.093	0.999	Non-stationary
		PP-Fisher	53.707	0.926	Non-stationary
	None	LLC	1.337	0.909	Non-stationary
		ADF-Fisher	22.305	1.000	Non-stationary
		PP-Fisher	24.892	1.000	Non-stationary
ln(GDPPC)	Trend and intercept	LLC	-4.409	0.000	Stationary
		Breit t	-2.690	0.004	Stationary
		IPS	-1.911	0.028	Stationary
		ADF-Fisher	82.378	0.148	Non-stationary
		PP-Fisher	68.511	0.528	Non-stationary
	Intercept	LLC	-7.004	0.000	Stationary
		IPS	-1.064	0.144	Non-stationary
		ADF-Fisher	85.934	0.095	Non-stationary
		PP-Fisher	205.900	0.000	Stationary
	None	LLC	8.758	1.000	Non-stationary
		ADF-Fisher	4.050	1.000	Non-stationary
		PP-Fisher	1.581	1.000	Non-stationary
ln(EIE)	Trend and intercept	LLC	-4.937	0.000	Stationary
		Breit t	4.169	1.000	Non-stationary
		IPS	0.179	0.571	Non-stationary
		ADF-Fisher	75.999	0.237	Non-stationary
		PP-Fisher	91.952	0.028	Stationary
	Intercept	LLC	-3.061	0.001	Stationary
		IPS	-0.647	0.259	Non-stationary
		ADF-Fisher	77.679	0.198	Non-stationary
		PP-Fisher	78.792	0.174	Non-stationary
	None	LLC	0.826	0.796	Non-stationary
		ADF-Fisher	43.806	0.990	Non-stationary
		PP-Fisher	62.160	0.676	Non-stationary
ED	Trend and intercept	LLC	-3.272	0.001	Stationary

		Breit t	2.642	0.996	Non-stationary
		IPS	0.366	0.643	Non-stationary
		ADF-Fisher	62.44	0.667	Non-stationary
		PP-Fisher	71.225	0.371	Non-stationary
	Intercept	LLC	-0.107	0.458	Non-stationary
		IPS	2.154	0.984	Non-stationary
		ADF-Fisher	56.293	0.848	Non-stationary
		PP-Fisher	56.364	0.842	Non-stationary
	None	LLC	-2.014	0.022	Stationary
		ADF-Fisher	75.872	0.240	Non-stationary
		PP-Fisher	82.652	0.109	Non-stationary
ln(EGC)	Trend and intercept	LLC	-5.445	0.000	Stationary
		Breit t	-0.4167	0.339	Non-stationary
		IPS	-1.743	0.041	Stationary
		ADF-Fisher	83.603	0.0003	Stationary
		PP-Fisher	117.833	0.000	Stationary
	Intercept	LLC	-2.836	0.002	Stationary
		IPS	-0.738	0.230	Non-stationary
		ADF-Fisher	69.166	0.015	Stationary
		PP-Fisher	82.517	0.001	Stationary
	None	LLC	-3.777	0.001	Stationary
		ADF-Fisher	69.536	0.0141	Stationary
		PP-Fisher	114.082	0.000	Stationary

Table 5*: Nomenclature section*

Acronym	*Formal Title*
ADF	Augmented Dickey-Fuller
COP	Conference Of the Parties
EC	European Commission
ED	Energy Dependency
EGC	Electricity Generation Concentration
EIE	Energy Industry Emissions
EU	European Union
EU-ETS	European Union Emission Trading Scheme
ETS	Emission Trading Scheme
GDPPC	Gross Domestic Product Per Capita
GMM	General Method of Moments
GWh	Gigawatt hours
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
PV	Photovoltaic
RES	Renewable Energy Sources
RES-E	Renewable Energy Sources for Electricity
SDG7	Sustainable Development Goal 7
UNFCCC	United Nations Framework Convention on Climate Change

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