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Impact of Clean Energy Policies on Electricity Sector Carbon Emissions in the EU-28

Gustavo Pineiro-Villaverde [1,*] and María Teresa García-Álvarez [2]

1 Doctoral Program in Economic Analysis and Business, Faculty of Economics and Business, Campus Elvina s/n, University of A Coruna, 15071 A Coruna, Spain
2 Department of Business, Faculty of Economics and Business, Campus Elvina s/n, University of A Coruna, 15071 A Coruna, Spain; mtgarcia@udc.es
* Correspondence: gustavo.pineiro@udc.es

Abstract: The European Union (EU) has developed important efforts in enacting various clean energy policies in order to reduce greenhouse gas (GHG) emissions in the last decades. Both supply-side and demand-side changes are required in the energy systems in the period of 2020–2030 and going towards 2050. In this context, a better understanding of the effects of these specific clean energy actions on reducing GHG emissions may be especially of interest for allowing policymakers to know the strengths and weaknesses of various climate-related power sector policies. This paper adds to the literature by presenting the effects of both supply-side and demand-side policies and empirical evidence of the impact of these policies on the reduction in carbon emissions. This analysis was done by means of a panel data set and several regression models that contribute to explaining the link between clean energy policies applied in the EU and carbon emissions over the period of 2000–2019. The results show that while supply-side policies have shown a positive and effective impact on the reduction in GHG emissions, on the demand side, more aggressive policy efforts are needed.

Keywords: clean energy policies; carbon dioxide emissions; energy sector; renewable energy; energy taxes; panel data

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1. Introduction

The EU has implemented different policies in order to reduce the impact of climate change in the last decades. The reduction in CO_2 emissions from the energy sector has been a key issue in the European energy and climate change policies, as this sector has been the main producer of greenhouse gas (GHG) emissions (more than 80%) [1]. In this context, climate policies and energy have been greatly integrated into the EU, where policies related to the use of efficient energy and the development of clean production technologies have been greatly used in the climate change framework [2].

In 2007, the EU highlighted the importance of ensuring that global average temperature increases do not exceed pre-industrial levels by more than 2 °C [3]. Subsequently, the 2020 Climate and Energy Package [4] was approved, which set the strategies and policies related to energy and climate policies up to 2020. It was based mainly on the development of renewable energies (RES-E), complemented by measures of energy efficiency. More specifically, it established the following three key targets: (i) 20% cut in GHG emissions (from 1990 levels), (ii) 20% of EU energy from renewables, and (iii) 20% improvement in energy efficiency.

Although climate change was the main driver of the 2020 Climate and Energy Package, energy policy challenges were also extensively treated in this context. The following three main goals were set in the EU energy policy: supply security, sustainability, and competitiveness. Thus, different actions were developed, such as the promotion of RES-E in order to achieve their large-scale deployment, the promotion of technologies of carbon capture, and storage of the investment or investment in nuclear energy in member states that wished to do so [5]. Likewise, from the side of the demand, energy efficiency has been an essential issue for achieving 2020 targets. These targets should be achieved from all economic sectors, but the power sector has been expected to play a main role in the achievement of both (GHG emissions and RES-E) [6].

Subsequently, the EU adopted the 2030 Framework for Climate and Energy [7], the aim of which is to meet a more secure, sustainable, and competitive energy system and to help the EU to achieve its long-term 2050 GHG reduction target. In this context, the following goals were set: (i) 40% cut in GHG emissions (from 1990 levels), (ii) (at least) 27% of EU energy from renewables, and (iii) (at least) 27% energy savings. Policies related to RES-E development, energy efficiency, and sustainability were emphasized again. This framework was developed on the basis of the 2020 Climate and Energy Package and it is also in line with the longer-term perspective established in the roadmap for moving to a competitive low-carbon economy by 2050 [8] and the Energy Roadmap 2050 [9].

More recently, in December 2019, the EU presented the European Green Deal [10], which aims to make Europe climate neutral by 2050. In order to achieve its decarbonisation objectives, the European Commission adopted a set of proposals to make the EU's climate, energy, transport, and taxation policies fit for reducing net GHG emissions by at least 55% by 2030, compared to 1990 levels. Additionally, the Commission proposed to increase the binding target for renewable sources in the EU's energy mix to 40% and to increase energy efficiency targets and make them binding to achieve an overall 36–39% reduction in final and primary energy consumption. Figure 1, extracted from the report *Trends and projections in Europe 2020* prepared by the European Environment Agency (EEA) [11], shows the evolution of GHG emissions in the EU since 1990, and the different reduction objectives set.

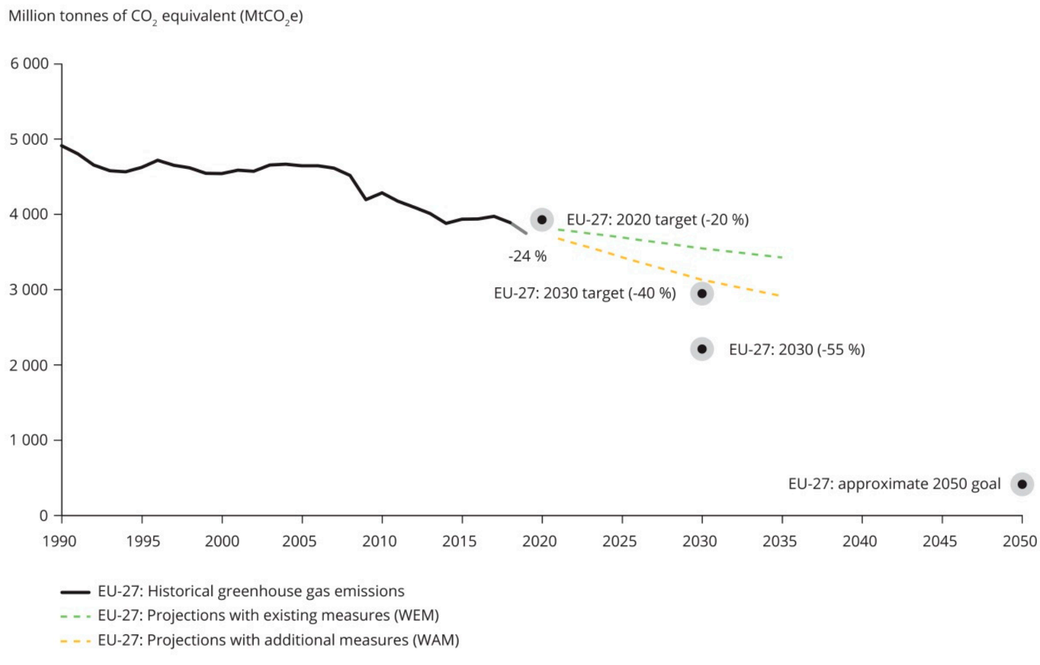

Figure 1. Greenhouse gas emission targets, trends, and member states' MMR projections in the EU, 1990–2050. Reprint with permission [11]; 2020, Publications Office of the European Union.

From a global point of view, different studies have focused on determining the key factors for a reduction in GHG emissions. Rehman et al. [12] studied the effect of energy consumption, economic development, and population growth on CO_2 emissions in Pakistan by means of a grey relational analysis. They concluded that the increase in GHG emissions, especially those related to the transportation sector, is strongly linked to population growth. In addition, ref. [13], by means of a non-homogenous discrete grey model, analysed which sectors will be the main generators of GHG emissions in the medium term.

Furthermore, ref. [14] analysed the relationships among GHG emissions, income level, and consumption of renewable and non-renewable energy in Mexico for the period of 1990–2015. The study showed a strong relationship between economic growth (related to GDP) and the use of non-renewable energies, with increasing GHG emissions.

Regarding the situation of the United States, characterised by being one of the main GHG emitters in relative terms (carbon dioxide emissions per person), ref. [15] studied the impacts of clean energy policies on total carbon emissions, electricity consumption, and carbon intensity. Its conclusion, after a study with a panel data set for 48 continental states from 1990 to 2008, is that more aggressive demand-side policies are needed.

Sun et al. [16] reviewed the clean electricity policies of the EU, Australia, China, India, and the United States, since the power industry and policymakers in almost all countries are focused on clean energy development. The study showed the diversity of the scope, intensity, and comprehensiveness of clean energy policies.

With regard to the role of carbon taxation, several studies [17,18] have analysed its effectiveness worldwide. They have shown that although carbon and fuel taxes seem to be effective in reducing CO_2 emissions in various countries, the implementation of these policies entails serious difficulties in many cases.

Focusing on the case of the EU, and since the energy sector is the one that has contributed the most to GHG emissions, the analysis of the effects of climate change policies in this sector can be of interest for obtaining a better understanding of what specific policies involve a reduction in GHG emissions. As explained below, previous literature has shown that the analyses have mainly been based on climate policies related to the supply side, and consequently, had too narrow a focus. In addition, dynamic approaches do not precisely provide the effects of each specific policy.

In this context, the main contribution of this paper, and where its novelty lies, is the approach to both the supply and demand energy policies in the EU and their impact on the reduction in GHG emissions and electricity consumption. This information could allow policymakers to know the strengths and weaknesses of various climate-related power sector policies and will be especially relevant in future climate change policymaking in order to achieve the targets set.

Much of the previous literature, in order to assess the effectiveness of climate and energy policies, has presented the effects of different policies on RES-E investments or RES-E capacity [19]. As shown in Figure 2, according to [20], there is wide diversity regarding support schemes in the EU. Some countries, such as France, Germany, and Spain, have different types of support schemes operating in combination (for example, for different types of renewable technology). In this context, ref. [21] studied the effects of RES-E support policies on the development of these clean production technologies in 23 member states over the period of 1990–2007 by using a panel-corrected standard error estimator. The conclusion was that some RES-E support policies (quota obligations, product labelling, research, and development programs) were not drivers towards RES-E development. Nevertheless, incentives/subsidy policies (including feed-in systems (FISs)) were effective in promoting RES-E. On the other hand, ref. [22] analysed the effects of FIS policies on promoting leader RES-E in 26 member states for the period between 1992 and 2008. Using the panel data method, they did not find robust evidence that the mere existence of this policy had driven wind energy development.

García-Álvarez et al. [23] studied the effects of FISs and quota obligation policies on the solar photovoltaic installed capacity in the EU-28 for the period between 2000 and 2014. The method was a pooled ordinary least square regression clustered on the country level. Their results indicated that only FISs had significant impacts on the solar photovoltaic installed capacity. Nevertheless, the main design features of this policy—tariff size and contract duration—did not have a significant effect on the development of this RES-E. However, ref. [24] investigated the effect of feed-in systems (FISs) on the investment in wind and solar photovoltaic energy by means of the panel data method in the EU-27 over the period of 1992–2015. Their results indicated that the mere existence of an FIS policy did not necessarily increase wind and solar photovoltaic investment, but policy design features were often more important for increasing RES-E investment.

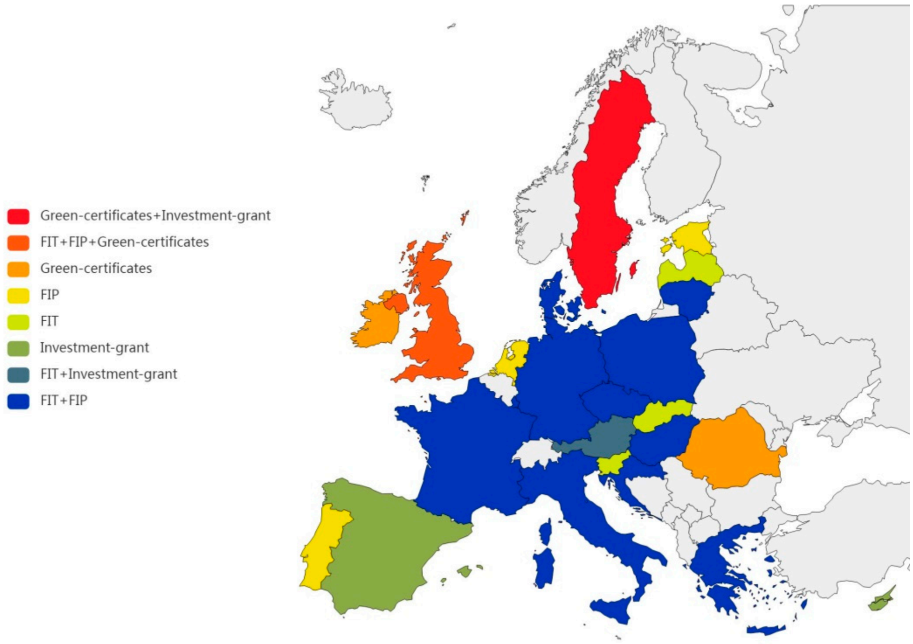

Figure 2. Diversity of RES-E support schemes in the EU. Source: Own elaboration from [20].

Therefore, there is no unanimity about the effects of RES-E support policies on RES-E development in the EU. Moreover, a suitable proxy of the decarbonisation in the power sector cannot be given by increased RES-E capacity, greater RES-E generation, or higher RES-E investment. Thus, a mere increase in RES-E capacity without reducing electricity generation based on fossil fuels cannot be a solution to climate change [19].

Ultimately, from a climate change perspective, what matters is if the policies are effective in reducing GHG emissions rather than if they increase RES-E. In this context, as several interdependent variables affect electricity market behaviour, and therefore, CO_2 emission evolution, various approaches have been used with the aim of analysing the contribution of different technical and socio-economic factors.

Karmellos et al. [6] studied, by means of a decomposition analysis model, the driving factors of CO_2 emissions from the electricity sector in the EU-28 in the period of 2000–2012. They considered five driving factors—activity level, electricity intensity, electricity generation efficiency, fuel mix, and electricity trade. Their results showed that electricity intensity reduction was the main factor in times of economic growth, whilst the contribution of the rest of the factors happened later. Similarly, ref. [25] analysed the effects of RES-E and non-RES-E, real income, and trade openness on CO_2 emissions on the environmental Kuznets curve model for the EU between 1980 and 2012 by using panel estimation techniques robust to cross-sectional dependence. They concluded that RES-E and trade reduced CO_2 emissions, while non-RES-E contributed to environmental degradation.

Furthermore, ref. [26] studied, by means of the panel data method, the effects of both environmental regulation and awareness on CO_2 emissions in 17 EU countries (Austria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Poland, Portugal, the Slovak Republic, Spain, Sweden, and the United Kingdom) over the period from 1995 to 2017. Environmental tax revenue was used as a proxy of the stringency of environmental regulation, and the accumulated number of RES-E support policies was used as a proxy of environmental awareness. The results showed that both variables (environmental regulation and awareness) were effective in reducing CO_2 emissions.

By means of index decomposition analysis, ref. [27] studied the drivers of CO_2 emissions for electricity generation in the EU over two subperiods, 2000–2007 and 2007–2015. Their results showed that changes in the fossil fuel mix, by means of the replacement of coal by gas, and efficiency improvements in electricity use were the main drivers of CO_2 reductions in the period of 2000–2007. However, in the period of 2007–2015, RES-E development, as well as efficiency improvements in both fossil electricity production and use became the main drivers of the decrease in CO_2 emissions.

More generally, ref. [28] estimated, over the period of 2000–2019, the impact of RES-E energy, bioenergy efficiency, biofuels, urbanization, population, and real gross domestic product (GDP) per capita on CO_2 emissions in EU countries by using the panel data method. The results showed that clean production technologies, as well as bioenergy factors, were negatively correlated with CO_2 emissions. However, urbanization, population, and real GDP per capita were positively correlated with such emissions.

In addition, dynamic approaches were also developed in order to study dynamic changes. In this context, ref. [29] investigated the distribution dynamics of energy consumption and CO_2 emissions, their intensities, as well as the carbonization index, over the period of 1970–2010 in 23 European member states. The method was based on the dynamics of cross-section distributions. The results showed that the convergence patterns hypothesis was not valid. Thus, major differences were observed in member states according to climate type with respect to the analysed variables. Hence, the importance of national and European energy and climate policies can be implemented in terms of the non-convergence paradigm. Similarly, ref. [30] determined, by means of hierarchical methods, the tendency of changes related to energy decarbonisation, as well as distinguished typological groups of EU member states with similar dynamics in this research field. The analysis was applied to 26 member states (except Malta and Great Britain) between 2000 and 2018. Their results showed that the implementation of climate policy by the individual countries was the main factor in reducing CO_2 emissions. Nevertheless, they found two groups of member states—those that were reluctant to dynamically reduce CO_2 emissions (Central and Eastern European countries) and those member states that supported a strong climate policy (the rest of the EU countries).

At this point, and as mentioned above, previous literature [6,26–29] has shown that the analyses were mainly based on climate policies related to the supply side, and dynamic approaches do not precisely provide the effects of each specific policy. Therefore, the objective of this study was to go a little further in the study of the supply and demand energy policies in the EU, analysing their impact on the reduction in GHG emissions and on electricity consumption. This information will allow policymakers to have a better understanding of the effectiveness of the aforementioned policies in order to achieve the targets set.

2. Materials and Methods

In this section, the sample, the hypotheses, the variables, and the methodology used in the empirical assessment are discussed.

2.1. Sample

In order to develop the empirical analysis, the database of the Statistical Office of the European Commission (Eurostat) was examined for the period between 2000 and 2019 (28 countries, 560 observations). The data were chosen from previous literature in both clean energy supply-side and demand-side policies on GHG emissions, presented in Section 1. The period of analysis starts in 2000, as the European Union's clean energy policies related to reducing carbon emissions in the electricity sector acquired great relevance in this decade. More specifically, most supply-side policies, related to RES-E support policies, were introduced in the EU early on in the decade. Similarly, demand-side policies related to energy taxes have acquired great relevance from the early 2000s in order to promote more responsible energy consumption. The study period ends in 2019 because most of the data were provided by Eurostat until that year.

With the aim of avoiding missing values in the estimates and to have the same sample size in all models, the cases for which there was no information on any of the variables were not considered in the analysis. As a result, an unbalanced panel of countries and observations was obtained.

2.2. Hypothesis

Taking the arguments of previous literature into consideration, the research hypotheses were proposed.

Both supply-side and demand-side policies are potentially relevant to reducing carbon emissions. These emissions can be divided into electricity consumption and carbon intensity, where the latter variable is defined as carbon emissions per unit of energy consumed [31].

The objective of supply-side policies is to modify the generation fuel mix from a carbon-intensive portfolio to a low-carbon portfolio by means of an increase in RES-E sources [32]. In the last decades, RES-E support policies have been implemented in the EU with the aim of encouraging these clean production technologies, which are characterised by having zero or few GHG emissions.

There are two main RES-E support policies in the EU—FISs and renewable portfolio standards (RPSs). An FIS sets a fixed payment for electricity produced from RES-E, which can be a retribution based on a pre-set price (feed-in tariff) or based on the wholesale electricity price plus an incentive. An RPS sets the obligation of producers/distributors/consumers to maintain a specific RES-E quota in their energy consumption. This study considered both policies of the two main RES-E in the EU—wind energy and photovoltaic (PV) solar energy.

The effect of RES-E support policies on GHG emissions from the generation of electricity is based on a two-step causal chain—the fuel mix is affected by the FIS/RPS and the sectors' carbon intensity is shaped by the fuel mix [15].

In this context, the first hypothesis proposed is as follows:

Hypothesis 1 (H1). *Support policies (FIS and quota obligation) of the two main RES-E (wind and PV) reduce carbon intensity in the electricity sector.*

Likewise, demand-side policies can also have an impact on carbon emission reductions. These policies reduce global energy demand by facilitating a shift towards more sustainable consumption patterns [33].

The European Energy Efficiency Directives have established various instruments in order to reduce energy consumption, in which energy taxes have been highlighted due to their potential to encourage energy savings and conservation from the consumption side [34]. Their functioning is based on surcharges for electricity consumption, which is expected to affect individual consumption behaviour.

Taking the above-mentioned arguments into account, the following hypotheses are proposed:

Hypothesis 2 (H2). *Energy tax policies reduce carbon intensity.*

Hypothesis 3 (H3). *Energy tax policies reduce electricity consumption.*

Finally, the effect of these clean energy policies on carbon emission reduction was considered by proposing the following hypothesis:

Hypothesis 4 (H4). *Clean energy policy tools reduce electricity carbon emissions.*

2.3. Variables

2.3.1. Dependent Variables

A total of three models were developed in order to obtain a better understanding of the effects of both supply-side and demand-side policies on GHG emissions, which are explained in Section 2.4. In this context, the following dependent variables were used:

Per capita carbon emissions and carbon intensity were considered proxy variables of GHG emissions [15,35,36]. Per capita carbon emissions were measured as GHG emissions in the energy sector divided by the population (tonnes per capita) (EMISSIONS). Carbon intensity was measured as the ratio between energy-related GHG emissions and the gross inland consumption of energy (index, 2000 = 100) (CARBINTENSITY).

Electricity consumption per capita was also used as a dependent variable in other specifications of the models, following the method of [15]. Electricity energy consumption per capita (MWh per capita) refers to the energy needs of a country (ELECT_CONSUMPTION).

2.3.2. Explanatory Variables

The explanatory variables were grouped into three types—policy variables, fuel mix variables, and economic variables.

Policy variables make reference to clean energy policies from both the supply side and the demand side—wind energy support policies (WIND_FIS, WIND_RPS), PV solar energy support policies (PV_FIS, PV_RPS), and energy tax policies (TAX_POL). These clean energy policies were measured with five binary variables (with 1 indicating the adoption of the policy in that year, and 0 otherwise) [15].

Fuel mix variables make reference to the contribution of different energy sources (coal, natural gas, RES-E, hydro, nuclear) in total gross electricity supply (in %) (CONTRIBUTION_COAL, CONTRIBUTION_GAS, CONTRIBUTION_RESE, CONTRIBUTION_HYDRO, CONTRIBUTION_NUCLEAR). In this context, it is necessary to consider that clean energy policies (especially FISs and RPSs) seek to change the power generation portfolio, towards a "carbon-light" portfolio, especially in the long run. The coefficients obtained in the models ought to capture the direct impact of these policies. However, these clean energy policies can also affect the fuel mix of power generation by means of their indirect impacts on GHG emissions (or electricity consumption and carbon intensity) [6,27].

Economic variables make reference to economic activity measures. In this context, gross domestic product (GDP) was considered, as economic growth determines electricity demand and consumption patterns. GDP per capita was considered in the model and makes reference to the total value of all goods and services produced less the value of goods and services used for intermediate consumption in their production (Eurostat) (GDP) (in Euros per capita). A prosperous economy can involve an increase in electricity demand and, therefore, GHG emissions will not be reduced without specific clean energy actions. Nevertheless, an economic contraction will result in both consumption and GHG emissions reductions [28]. Likewise, the unemployment rate was considered a proxy of business vitality (in percentage) (UNEMPLOYMENT), for which a high rate is related to underused production capacity, with a consequently reduced electricity demand [15].

Finally, the control variables are related to socioeconomic factors linked to electricity demand. In this context, heating degree days, cooling degree days, and electricity prices variables were introduced in the models.

Heating degree days were calculated as the weather-based technical index used to describe the need for the heating energy requirements of buildings (from Eurostat) (number) (HEATING_DAYS). Cooling degree days were based on a weather-based technical index used to describe the need for the cooling (air-conditioning) requirements of buildings (from Eurostat) (number) (COOLING_DAYS). Both heating degree and cooling degree days are greatly related to energy demand [35–37].

Industrial electricity prices make reference to the average national price for medium-sized industrial consumers (annual consumption between 500 and 2000 MWh) (Euros per kilowatt hour) (ELECT_PRICES). Greater electricity prices can result in more sustainable consumption patterns. It is expected that electricity prices are negatively related to electricity consumption and carbon intensity [15].

2.4. Models

In order to test the hypotheses previously proposed, a panel data set for the 28 countries with a time range from 2000 to 2019 was used with the STATA13 program. In addition, with the aim of controlling problems of endogeneity in the proposed models, explanatory and control variables were lagged by one year. Before going in depth with the models to verify the hypotheses, Hausman tests were performed to decide whether it was more appropriate to use fixed-effect or random-effects models [38].

In this context, three models were estimated to analyse the influence of clean energy policies, along with other variables, on GHG emissions per capita, carbon intensity, and electricity consumption per capita. Fixed-effect regression models were employed to test the hypotheses. The use of a fixed-effect model generated consistent estimations when unobserved country-level variables and the error term were correlated. The model is formulated as follows:

$$Y_{it} = a_i + \beta X_{it} + \varepsilon_{it}, \quad (1)$$

where "i" is the country and "t" is the year of the observation. Y_{it} is the dependent variable—GHG emissions per capita in Model 1; electricity sector carbon intensity in Model 2; electricity consumption per capita in Model 3.

X_{it} denotes the explanatory and control variables, ε_{it} is the error term, and a_i is a country-specific intercept.

In the three models studied, the three types of explanatory variables were used—policy variables, fuel mix variables, and economic variables.

3. Results

The descriptive statistics are shown in Table 1. 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. When there is a perfect linear relationship among the predictors, the estimates for a regression model cannot be uniquely computed. Given this, a multicollinearity study (analysis of the variance inflation factors (VIF)) was carried out in order to rule out, if necessary, any of the predictors. As a result, the variable RPS_PV (related to PV solar support policies) shows significant collinearity, and therefore, it was discarded.

Table 1. Descriptive statistics.

Variable	Obs [1]	Mean	Std. Dev.	Min	Max
EMISSIONS	560	7.453	3.424	2.879	24.77
CARBINTENSITY	560	93.459	9.220	57.6	124.5
ELECT_CONSUMPTION	560	5.973	3.118	1.839	16.546
ELECT_GENERATION	560	6.098	2.991	1.179	17.746
ELECT_PRICES	512	82.168	26.330	0	221.65
FIS_WIND	560	0.687	0.463	0	1
RPS_WIND	559	0.1466	0.354	0	1
FIS_PV	560	0.630	0.483	0	1
RPS_PV	560	0.126	0.333	0	1
TAX_POL	336	208.304	78.462	77.53	454.67
GDP	308	27,027.89	17,807.49	4930	102,200

Table 1. *Cont.*

Variable	Obs [1]	Mean	Std. Dev.	Min	Max
UNEMPLOYMENT	537	8.778	4.413	2	27.5
CONTRIBUTION_COAL	560	0.359	0.300	0	0.963
CONTRIBUTION_GAS	560	0.353	0.274	0	0.984
CONTRIBUTION_RESE	448	16.947	11.531	0.102	56.391
CONTRIBUTION_HYDRO	504	0.255	0.289	0	1
CONTRIBUTION_NUCLEAR	504	0.178	0.234	0	0.819
HEATING_DAYS	520	2745.075	1079.274	322.36	6179.75
COOLING_DAYS	520	121.008	182.323	0	812.18

[1] Observation after discarding missing values: 259.

As mentioned above, Hausman tests were conducted in order to select between fixed-effects or random-effects models. The null hypothesis established that there is no systematic difference between the coefficients estimated by the two methods. According to the results (X^2 (13d.f.) = 316.75 for Model 1, X^2 (13d.f.) = 34.78 for Model 2, X^2 (13d.f.) = 37.53 for Model 3), in the three models, this hypothesis was rejected, indicating the suitability of a fixed-effects model. To control for possible heteroscedasticity problems, the proposed models used robust standard errors.

A summary of the results of the three fixed-effects panel regression models is included in Table 2.

Table 2. Results of the fixed-effects panel regression analysis.

Variables	Model 1 [1]	Model 2 [2]	Model 3 [3]
	Coef. (Std. Err.)	Coef. (Std. Err.)	Coef. (Std. Err.)
ELECT_PRICES	0.0076 (0.0071)	0.0376 (0.0468)	−0.0006 (0.0013)
FIS_WIND	−0.7501 *** (0.2058)	−6.7478 *** (1.1495)	−0.1817 ** (0.0705)
RPS_WIND	−1.1225 *** (0.1648)	−4.8025 *** (1.0255)	−0.3243 *** (0.0618)
FIS_PV	−0.3883 ** (0.1625)	−0.6199 (1.2852)	−0.0812 * (0.0469)
TAX_POL	−0.0021 (0.0023)	0.0033 (0.0118)	0.0003 (0.0011)
GDP	−0.0001 (0.00004)	−0.0001 (0.0002)	−0.00001 (0.00001)
UNEMPLOYMENT	−0.0924 *** (0.0242)	0.1816 (0.1326)	−0.0613 *** (0.0139)
CONTRIBUTION_COAL	0.7388 (0.9798)	2.8162 (7.5818)	0.6535 *** (0.2276)
CONTRIBUTION_GAS	−0.1190 (0.6440)	−7.9525 (5.9808)	0.4490 *** (0.1219)
CONTRIBUTION_RESE	−0.1477 *** (0.0301)	−1.4057 *** (0.2345)	−0.0084 (0.0104)
CONTRIBUTION_HYDRO	−5.3265 *** (1.7361)	−10.5319 (10.7604)	−1.8567 *** (0.3186)
CONTRIBUTION_NUCLEAR	−0.3234 (0.3569)	−6.9023 * (3.8825)	0.2755 * (0.1561)
HEATING DAYS	0.0007 *** (0.0001)	0.0019 * (0.0011)	0.0002 ** (0.0001)
COOLING DAYS	0.0003 (0.0007)	0.0083 ** (0.0039)	8.702e−06 (0.0003)
CONSTANT	12.1219 *** (1.7580)	119.2596 *** (10.6770)	6.4437 *** (0.5780)
Observation	259	259	259
Country fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
R-squared (within)	0.693	0.695	0.610

[1] DV: emissions; [2] DV: carbon intensity; [3] DV: electricity consumption. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$ (two-tailed). Standard errors are given in parentheses.

Regarding the support policies (FIS and quota obligation) of the two main RES-E (wind and PV solar energy) and their impact on carbon intensity in the electricity sector, the results of Model 2 support Hypothesis 1 in the case of wind energy, as both FIS_WIND ($\beta = -6.748$ $p = 0.000$) and RPS_WIND ($\beta = -4.802$ $p = 0.000$) have a negative and statistically significant influence. In the case of PV solar energy, although the sign of the coefficient goes in the direction that would be expected, the analysis shows that Hypothesis 1 is not supported, as the variable FIS_PV is not statistically significant (p = 0.634). This means that a reduction in carbon intensity might be expected through the introduction of support policies of RES-E. The significance of the support policies for wind energy, compared to those developed for photovoltaic solar energy, may come from the fact that its installed power is considerably higher. The results obtained in this study, for the case of the EU, are in line with those obtained by [15] for the case of the United States.

Regarding energy taxes policies and their link with carbon intensity and electricity consumption, both Hypotheses 2 and 3 are not supported by the analysis. According to the results obtained from Models 2 and 3, the variable TAX_POL is not statistically significant (p = 0.782 in Model 2 and p = 0.809 in Model 3). Similar results have been obtained in previous studies in the case of the EU [39,40], as well as Latin America [41] and the United States [15]. On the other hand, results obtained by [18] for the Netherlands showed a slight difference, in the sense that an energy tax has a small impact on household energy demand in the short term.

Finally, Hypothesis 4 raised a possible relationship between the establishment of clean energy policies and the reduction in electricity carbon emissions. In this sense, according to Model 1, support energy policies have a negative (in the sense of reduction) and statistically significant effect on electricity carbon emissions (FIS_WIND, $\beta = -0.750$ p = 0.001; RPS_WIND, $\beta = -1.123$ p = 0.000; FIS_PV, $\beta = -0.388$ p = 0.025). This result leads us to accept Hypothesis 4. On the contrary, this hypothesis is not supported in the case of energy taxes policies, as the variable TAX_POL is, again, not statistically significant (p = 0.384). Both results indicate a relationship analogous to the one proposed by [6,27] for the EU, and the one indicated by [15] for the United States, reinforcing its validity.

Other interesting results can be extracted from the analysis of the proposed models, examining what was obtained in the case of the control variables. A more in-depth discussion of these results is presented in Section 4.

4. Discussion and Conclusions

The EU has developed important efforts in enacting various clean energy policies in order to reduce GHG emissions in the last decades. In this context, actions related to the development of RES-E, the encouragement of energy efficiency, and sustainable development have been highlighted [3,4,7,8]. Thus, both supply-side and demand-side changes are required in the energy systems in the period of 2020–2030 and going towards 2050 [42].

Obtaining a better understanding of the effects of these specific clean energy actions on reducing GHG emissions may be especially of interest. This information could be incorporated into policymaking in order to facilitate the achievement of the climate change goals set by the EU.

Nevertheless, the previous literature has been mainly focused either on analysing a specific policy in particular (when GHG emissions are conditioned by both the supply side and the demand side) or studying its effectiveness on alternative measures (such as the growth of clean energy industries) but not its ability to decrease carbon emissions. In this context, this paper adds to the literature by presenting the effects of both supply-side (FIS, RPS) and demand-side (energy taxes) policies and empirical evidence of the impact of these policies on the reduction in carbon emissions.

In this context, the objective of this study was to analyse both supply and demand policies in order to obtain a better understanding of what specific measures are successful in curbing GHG emissions. This information could allow policymakers to know the strengths and weaknesses of various climate-related power sector policies and will be especially relevant for future climate change policymaking in order to achieve the targets set.

At this point, we address in more depth the interpretation of the results obtained, focusing especially on the key findings regarding the impact of clean energy policies.

Model 1, where GHG emissions were used as the dependent variable, revealed interesting effects. As mentioned in Section 3, Hypothesis 4 stated that the implementation of clean energy policies leads to a reduction in GHG emissions. According to the results obtained, it can be concluded that the adoption of support policies for renewables from the supply-side point of view, at least in terms of the types used in the EU (FIS and RPS), has a significant impact on the reduction in total carbon emissions. In this sense, in the case of wind energy, there is a greater incidence than in the case of photovoltaic solar energy since the installed wind power and contribution is much higher. On the other hand, if we focus on the fuel mix of power generation, we can conclude that the share of RES-E and hydro has a significant impact on the reduction in emissions.

Additionally, we can verify the influence, to a much lesser degree, of the unemployment rate and the demand for energy for heating in the variation of GHG emissions. In this sense, an increase in the unemployment rate is associated with less economic activity and, in addition, with a reduction in electricity demand and, therefore, in carbon emissions [15,28]. In the case of the increase in the demand for energy for heating, a slight effect is observed in the increase in GHG emissions, in line with the results from [35,37].

Model 2 considered carbon intensity as a dependent variable. This model was used to test the effectiveness and influence of RES-E support policies (supply side) on the objective of reducing carbon intensity, as proposed in Hypothesis 1. The results lead us to conclude that the introduction of RES-E support policies in the EU has had a very significant impact on reducing carbon intensity in the period of 2000–2019. These policies have been particularly effective in the case of wind energy. In the case of PV solar energy support policies, it can be concluded that they have also had a certain impact but to a lesser degree due to the lower contribution of this technology to the mix of power generation (5% in 2020 compared to 14% for wind energy).

In addition, Models 2 and 3 were used to test the impact of energy taxes policies (demand side) on the achievement of two different objectives, namely the reduction in carbon intensity in Model 2 and the reduction in energy consumption in Model 3. In both cases, we can conclude that, up to now, energy tax policies from the demand-side point of view do not seem to have a relevant impact on reducing GHG emissions, carbon intensity, or energy consumption. It seems that energy taxes alone cannot promote more sustainable energy consumption patterns or substantially modify household behaviour that can lead to a significant reduction in energy consumption or in carbon emissions.

In summary, it can be stated that when comparing the performance of both supply and demand policies in the EU, it can be observed that supply-side policies have been clearly more effective in terms of reducing carbon intensity, but not so much in terms of global emissions, as the global consumption of electricity has increased.

Therefore, considering these results and those obtained in other countries, as a first recommendation for stakeholders, we can hope that the maintenance and strengthening of the supply-side policies can help the EU to achieve the objectives set out in the European Green Deal. In this sense, it is necessary to continue with policies to promote renewable energy generation and enhance energy efficiency if effective climate mitigation is to be achieved. Previous studies [6,15,27] have reflected on the impact of FISs and RPSs in the development of clean energy industries. The purposes of these clean energy policies include the mitigation of carbon emissions, to stimulate green economic development, and to secure a diversified energy supply. This research makes a contribution to the literature by means of empirical evidence of the carbon reduction effects of these policies. Another measure that could contribute to strengthening the impact of RES-E would be a commitment to technological improvement through investment in research, development, and innovation. This could result in improving the energy efficiency of generation facilities and reducing their environmental impact.

As another recommendation, it could be necessary to rethink energy tax policies due to their lack of effectiveness in reducing energy demand (as it has been shown in [15,40,41] and in the results obtained in this paper). Reinforcing actions and more aggressive policy efforts might, therefore, be necessary to mitigate carbon emissions in the EU. Hale [43] showed that consumers' environmental awareness is the main driver for creating sustainable consumption and pointed out the need to deepen policies related to this issue. In this sense, the adoption of public policies to promote environmental awareness (for example, by promoting school campaigns on responsible energy consumption) might be an effective complementary measure for energy taxes. Likewise, ref. [44] showed that in terms of communication, significant gaps persist when addressing public concerns, and a way to promote consumers' awareness is through communication improvement. The message should be easy to read, simple to understand, and succinct. Other measures could be the maintenance and improvement of subsidies for the energy efficiency of existing buildings, the promotion of passive houses, or an increase in investment for the replacement of inefficient appliances.

Regarding the limitations of this study, it is necessary to acknowledge that the sample did not include a large number of countries, which may have affected the results by using the panel data method. Likewise, the analysis of the effects of supply-side policies related to RES-E support policies might be more exhaustive, as the choice of design elements in these policies could be as important for promoting RES-E as the choice of the specific policy. Further research should consider these issues by expanding the analysis to a larger sample, such as the case of the (Organization for Economic Co-operation and Development (OECD) countries in order to increase the number of observations. Moreover, regarding supply-side policies, the analysis should incorporate two additional design elements (amount and contract duration) in order to obtain a better understanding of the main strengths and/or weaknesses of each policy in reducing CO_2 emissions.

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