COLLECTION OF PAPERS
NEW ECONOMY
Volume 2, No. 1, 2024

THE EFFECT OF RENEWABLE OBLIGATIONS ON ELECTRICITY PRICES – ESTIMATES FOR THE UK

Socotar Diana – Laura[1], Gabor Manuela Rozalia[1, 2, 3]

Received 14.03.2024. | Send to review 04.04.2024. | Accepted 28.08.2024.

Original Article

[1] ED1 – Economic Science Department, Faculty of Economics and Law, "G.E. Palade" University of Medicine, Pharmacy, Science and Technology of Târgu Mureș, Târgu Mureș, Romania

[2] Department of Economic Research, Centre for Law, Economics and Business Studies, "G.E. Palade" University of Medicine, Pharmacy, Science and Technology of Târgu Mureș, Târgu Mureș, Romania

[3] IOSUD – Doctoral School, "G.E. Palade" University of Medicine, Pharmacy, Science and Technology of Târgu Mureș, Târgu Mureș, Romania

Corresponding Author:
Socotar Diana – Laura

Email:
manuela.gabor@umfst.ro

JEL Classification:
K32, L51, P18, Q42, Q48

Doi:
10.61432/CPNE0201015d

UDK:
347.4/.5:621.311(477)

ABSTRACT

As global warming escalates, largely fueled by greenhouse gas emissions from electricity generation, European nations have enacted regulations to encourage the use of renewable energy sources (RES-E). This paper provides a detailed analysis of how adjustments in Renewable Obligations, specifically quota obligations and the prices of Renewable Obligation Certificates (ROCs), influence electricity prices in the UK, spanning two separate periods: 2011-2013 and 2021-2023, using a regression analysis. In the first period, we observe a significant positive association between the prices of ROCs and the market price of electricity, underscoring the direct influence of ROC pricing mechanisms on energy costs. However, the data does not support a similar impact from quota obligations, suggesting that while ROC prices are integral to electricity price formation, quotas do not exhibit a directly proportional effect. In contrast, in the second period the scenario changes. Here, quota obligations become significant, indicating a growing influence on electricity prices as the UK's energy policy evolved. In this later period, the effect of ROC prices on electricity prices is not significant. This research contributes to the ongoing discourse on the economic implications of RES-E policies and their burden on consumers. The insights gathered herein provide a foundational understanding of the impacts that RES-E regulations have on electricity prices, serving as an essential resource for policymakers and energy economists alike.

Key words: *renewable energy, green certificates, electricity prices, renewable obligations, energy economics*

1. INTRODUCTION

Environmental concerns have been growing exponentially in the past decades. The release of dangerous gases into the atmosphere, such as CO_2, caused by the generation of electricity is a threat to our ecosystem. Furthermore, reserves of oil and gas are exhaustible and present efforts towards mending the situation can only prolong and not avoid it. Although plenty has changed in the last decades, such as a tendency of turning towards alternative energy sources, burning fossil fuels is still the main method of generating power (Bose, 2010). Known substitutes for such reserves are either renewable energy sources (RES-E) or nuclear energy, however, because of the dangers involved in processing the latter, there is a strong preference towards the former. Additionally, this transition aligns with broader European initiatives, notably the European Green Deal. Launched by the European Commission, the Green Deal aims to reduce net greenhouse gas emissions by 55% by 2030 and make Europe a climate-neutral continent by 2050 (European Commission, 2020). Its objectives include a significant reduction in greenhouse gas emissions, investing in cutting-edge research and innovation, and preserving Europe's natural environment.

The need for government intervention is thus, clear. In this paper the specifics of these interventions will be analyzed and the focus will be shifted to how these affect consumers. Therefore, the main goal of this paper is to observe the effect that the regulations imposed on the use of renewable energy have on power prices, mainly electricity. The analysis will be focused on data from the United Kingdom. The UK has made significant strides towards integrating renewable energy sources into its national grid, driven by both environmental concerns and energy security. Among the mechanisms introduced was the Renewable Obligation Certificate (ROC) system, which obliges energy suppliers to source a certain percentage of their power from renewable sources (Ofgem, 2023). As a critical component of the UK's energy policy, ROCs aimed to encourage renewable energy production and contribute to the reduction of carbon emissions.

However, the impact of these obligations on electricity prices remains a contentious issue. While some argue that such schemes raise electricity costs for consumers, others believe they can stabilize or even reduce prices by increasing energy supply diversity and reducing dependency on imported fuels. Furthermore, previous studies have mainly focused on the advantages and possible drawbacks of the certificates trading system, many of them not being concerned with the impact they have on consumers. Hence, this is exactly what this research will focus on.

This paper seeks to address the debate by analyzing the effect of the ROC quota system on electricity prices within the UK market. In order to measure these effects, data from the UK were gathered for the periods 2011-2013 and 2021-2023 on the prices of electricity and several variables that might influence these prices, whilst the regulated levels of renewable energy that are required have been observed.

Our approach includes a detailed analysis of historical price data, the regulatory framework, and other determinants of electricity prices. By examining these elements, the paper aims to provide a comprehensive view of how the ROCs have influenced electricity pricing dynamics, specifically how legislation has affected the end consumers.

The significance of understanding this impact cannot be overstated. For policymakers, a clear analysis helps in crafting informed energy policies that balance economic, environmental, and social goals. For the energy industry and consumers, it informs investment and consumption decisions in an increasingly green economy. From a societal point of view, the importance of this topic is colossal because the methods of generating electricity release CO_2 into the atmosphere along with other greenhouse gases, which is one of the main causes of global warming (Bose, 2010). The reduction of such emissions would require the use of renewable sources, such as wind, solar, tidal energy etc.

The rest of the paper has the following structure: in the subsequent section the available literature will be reviewed in order to shed some light on the regulations that are in use at present in Europe with a detailed analysis for the UK, which will be followed by a description of power markets in general and its characteristics. Next, sample selection will be discussed and the key variables will be introduced. The subsequent step is to introduce the model and the regression that will be used for two time periods separated by a decade. The last sections of this paper will introduce the results, which will be followed by a discussion.

2. LITERATURE REVIEW

2.1. LIBERALIZATION OF POWER MARKETS

Under the influence of neoliberal ideologies, the energy market began transitioning toward a capitalist framework in the late 20th century. Directives from the late 1990's set the stage for market liberalization, competition, and the introduction of new market mechanisms in the electricity sector (Parcebois, 2008). The restructuring was designed to break down monopolistic structures, encourage private investment, and introduce market dynamics to an industry traditionally under government control. Consequently, electricity prices are no longer dictated by state control but are influenced by market forces."

Despite these significant market reforms, the UK power market maintains a concentration of influence within the 'Big 6' electricity suppliers. Together, they serve a total of 72% of the market consisting of both industrial and domestic consumers. These suppliers are, in order of their market share: British Gas (18.23%), OVO Energy (15.34%), E.ON UK4 (12%), EDF Energy (10.73%), Scottish Power (9.11%), npower (6.53%) (Ofgem, 2023). Although dominant, their collective market share has seen a decrease from 2009, as a growing number of consumers have shifted to independent, emerging companies that have gained traction, particularly among environmentally conscious consumers for their commitment to renewable energy.

Before continuing, a distinction needs to be made between suppliers and producers of energy. Electricity is generated by producers and is then bought at a wholesale price by the suppliers, such as the ones mentioned above, which subsequently pay network and government policy costs and sell it for a market price to consumers.

2.2. TYPES OF REGULATIONS: OVERVIEW FOR EUROPE

In 2001, the European Commission released a Directive that pushed its members to drastically increase the share of electricity coming from RES-E from 12% to 21% by 2010 (Held & Ragwitz, 2006). Nevertheless, the member countries had different approaches towards achieving these goals.

Some of the main strategies that were implemented are the Feed-in-Tariff systems (FIT) and the Quota obligations system based on Tradable Green Certificates (TGC). The feed-in tariff system involves paying a set rate to renewable energy producers for the electricity they generate, typically differentiated based on technology and installation size (Connor et al., 2015). This system provides financial incentives to renewable energy producers, encouraging the adoption of renewable energy sources and supporting their integration into the energy market. On the other hand, the quota system mandates that energy suppliers acquire a specified quota of electricity from renewable sources to sell to consumers (Connor et al., 2014). This system creates demand for renewable energy among suppliers, compelling them to either purchase renewable energy or pay a penalty for falling short of the quota.

While the feed-in tariff system focuses on incentivizing renewable energy production through guaranteed payments, the quota system emphasizes meeting renewable energy targets through market mechanisms and penalties for non-compliance. These systems play complementary roles in driving the transition to a more sustainable energy landscape by promoting renewable energy generation and ensuring the integration of renewables into the electricity market.

The feed-in-tariff system has been particularly successful in countries like Germany, Spain, Portugal, Denmark, and various other EU nations, where it has significantly increased the utilization of renewable energy sources (Krajačić et al., 2011). The quota system is most notably implemented in the UK. The latter is the focus of this paper.

In their paper, Held & Ragwitz compared the efficiency of the FIT versus the quota system, using two main criteria: effectiveness of deployment, measured by the increase in RES-E capacity, and economic efficiency represented by competitive and decreasing costs of renewable energy generation (2006). They conclude that an FIT system is more efficient and has an overall lower cost for society than a quota system. Moreover, Lipp (2007) found evidence suggesting that the feed-in tariff (FIT) policy is more cost-effective than the quota system, indicating that the FIT system may offer better economic efficiency in incentivizing renewable energy production compared to the quota system while a study by comparing support schemes for renewable energy deployment in the UK and Germany found that the feed-in tariff reduced costs to consumers and led to larger deployment of renewable energy (Butler & Neuhoff, 2008). This suggests that the FIT system may be more effective in driving renewable energy deployment and achieving scale compared to the quota system.

However, the quota system is still being implemented. One of the drawbacks of this system will be tested in this paper. The rest of the paper will focus on the quota system for renewable energy obligations in the UK.

2.3. UK'S RENEWABLE OBLIGATION SYSTEMS

The British Government decided to take a more "market based" approach towards renewable energy policies and thus avoided the FIT systems (Toke & Lauber, 2007). In order to achieve this, the government implemented "Renewable Obligations", which mandates that electricity suppliers in the UK must procure an increasing proportion of their electricity from renewable sources or make payments for certificates instead (Canbulat et al., 2021). Since its' implementation in 2002, the quota of the percentage of electricity that must come for renewable sources has risen from 3% to a whopping 11% by 2012 and further a 49% currently (Ofgem, 2024).

Renewable Obligation Certificates (the equivalent of Tradable Green Certificates for other European countries) are issued for producers who generate electricity from renewable sources; one ROC is issue for every MWh of electricity. Subsequently, these ROCs can be bought by suppliers in the necessary quantities to prove that they met their legal obligations. The ROCs are traded on a separate market and their price is determined by a monthly auction, in which the winner is the lowest bid (Allan et al., 2011). The auction process further exemplifies why the existing system should, at least in theory, provide renewable energy at the lowest possible cost.

If electricity suppliers fail to comply or do not meet the quota, they have to compensate for the shortage of ROCs by paying a penalty, also called the "buy-out" price. The penalty is usually the price of a ROC minus 10% (Ofgem, 20024). A specific trait of the British system is that the penalties are accumulated in a buy-out fund, which is then redistributed to RES-E generators. The system of recycled penalties has received widespread criticism because it provides an incentive to keep the amount of renewable energy low and therefore drive ROC prices up in order to prevent suppliers from fulfilling their quota (Held & Ragwitz, 2006).

The Renewable Obligation scheme has been a fundamental policy tool in the UK from 2002 to 2017 (Li, Liu & Shao, 2020). It was initially designed to encourage the generation of electricity from renewable sources, however, it is closed to all new generating capacity as of April 1, 2017 (Ofgem, 2023). The scheme continues to place an obligation on electricity suppliers to present a certain number of Renewables Obligation Certificates (ROCs) to Ofgem, based on their electricity supply to customers. This means that while no new generating stations can join the RO, existing accredited stations continue to generate ROCs, and suppliers are still required to meet their obligations under the scheme for the time being. Balaman et al. found that RO are a key mechanism for providing financial support to renewable electricity sources (2019) while Connor et al. suggest that RO has significantly contributed to the growth of large-scale renewable electricity generation in the UK (2014).

The basics of the British system are described above, however several changes have been made along the years. The most notable one is the The UK's banding system, providing differentiated support levels for various renewable technologies based on their maturity and cost-effectiveness (Allan et al., 2011). This approach has aimed to ensure a balanced development of different renewable energy sources and to drive innovation in the sector (Gürkan & Langestraat, 2014).

Furthermore, the RO scheme was closed to new generating capacity in 2017, but it still applies to existing eligible renewable generators (Ofgem, 2023). The main government scheme for supporting renewable energy generation is now the Contract for Difference (CfD) scheme, which guarantees renewable energy producers a fixed price for their electricity by paying the difference if market prices are lower (UK Government, 2024).

2.4. POWER MARKETS

In order to move on to the analysis of the data set, the characteristics of power markets in general need to be examined in more detail. Three key features that describe markets for electricity will be discussed below.

First of all, a special feature of electricity is that it cannot be stored or transported and as a consequence, supply and demand have to be permanently in equilibrium (Klessmann, 2008). Consequently, market prices are fully determined by supply and demand and every factor that influences either of the two will have an impact on the price.

Second of all, demand for electricity is highly inelastic (Klessmann, 2008). This is because it would be problematic for consumers to readjust their consumption of electricity every time prices change. Also, electricity spot prices are quoted either daily or hourly and therefore it is quite likely that most consumers, especially domestic ones, are unaware of the price changes that occur.

Lastly, since electricity markets were privatized they became highly competitive. Consequently, market prices are fully determined by supply and demand; in compliance with economic theory (Xu & Nijmura, 2004). Every factor that influences either of the two will have an impact on the price.

Some of the fundamental factors that would influence electricity prices would the cost of production and fuel prices, weather conditions, temperature and seasonal effects (Girish et al, 2013). Furthermore, the level of government regulation on electricity would also impact the supply. These effects will be tested in the following sections.

3.METHODOLOGY

3.1. DETERMINANTS OF ELECTRICITY PRICES

The attributes highlighted earlier were pivotal in the development of our model. Because increases in both ROC prices and quotas change the cost structure of electricity suppliers, it is fair to assume that some of these changes will be transferred to consumers through the prices of electricity. Therefore, the model in this paper will focus on estimating how much of the variations in electricity prices are due to Renewable Obligations. For these estimates to be as valid as possible, other determinants of electricity prices that could be a potential cause for these changes need to be accounted for.

As mentioned in the preceding section, all factors that affect the supply or demand for electricity will be reflected in the prices. Of course, there are countless such factors and taking all of them into consideration would be impossible. As a result, in order to model electricity price fluctuations several of the most important factors will be incorporated. The model will consist of an OLS regression that will include the variables presented in this section.

To begin with, the attention will turn towards determinants of electricity demand. First of all, one such deterministic factor is economic health, which can be observed by indicators such as GDP growth rates. Second, as discussed by Huisman, one explanation for sudden spikes in electricity prices are changing weather conditions, especially abnormal ones (2008). It should be clear that weather affects demand since unusually high or low temperatures would increase the use of cooling or heating systems respectively by consumers, which would in turn raise the consumption of electricity and therefore the demand. One other variable that could measure weather conditions is wind speed. However, this factor is also a determinant of the supply of electricity, since more wind would benefit the production of renewable energy.

Other main determinants of supply are the raw materials that are used in the production of electricity. Electricity is mostly generated by heat energy created by burning substances such as gas or oil (Bose, 2010). Hence, natural gas and crude oil prices are the next two determinants of supply included in the model.

Last but not least, the main question of this paper, as introduced in the beginning, must not be forgotten . The regression that will be used has the role of estimating the effect of Renewable Obligations on electricity prices. Therefore, the last factors that are included in the model are those of interest. In order to quantify renewable energy regulations data has been collected on the prices of Renewable Obligations Certificates and on the yearly quota of renewable energy that is set yearly by the government. Since the obligations have to be met by suppliers and they increase their production costs, naturally, they are determinants of the supply of electricity.

3.2. DATA COLLECTION

So as to perform the regression analysis, the paper looks at data from the UK across periods: business days between 2011-2013 and 2021-2023. Since there is no existing database that includes all the variables of interest, each of them has been collected from individual sources. This section is dedicated to explaining how the dataset has been compiled.

First of all, historical daily electricity and gas prices were gathered from the Office for national statistics. for electricity, the prices are quoted in £/MWh and are calculated as a weighted average of the half hour prices during 07:00 and 23:00 London time. Gas prices are quoted in

£/Therm (equivalent of 29.3 kwh). Second of all, the database for daily crude oil prices in Europe, quoted in $/barrel, was acquired from the official Energy Information Administration website.

Moreover, extended data from the London Weather Center can be found on online, which provides recordings of historical weather conditions. The relevant values that have been extracted from this dataset are maximum and minimum daily temperatures, as well as the average daily wind speed. The temperatures are measured in Celsius degrees whereas wind speed is in km/h. As for GDP growth rates, values were collected from www.ec.europa.eu, however they are annual (not daily) and quite stable over the 3 years of data included in the research. Because there is not enough variation in GDP growth rates, they were eventually excluded from the regression. Lastly, data about the buy-out prices and the yearly quota of renewable energy for ROCs can be found on the OFGEM website.

The final dataset used for the regression contains 744 observations for the first period, and 757 for the second period. A table of the summary statistics for each period is presented below.

Table 1. Summary statistics for the periods 2011-2013 and 2021-2023

Variable	Obs	Mean	Std. Dev.	Min	Max
2011-2013					
Electricity price (£)	744	53.59	6.93	39.13	92.72
ROC buyout price (£)	744	44.47	3.11	39.5	51.24
quota (%)	744	15.49	3.38	11.1	20.6
Gas price (£/therm)	744	61.62	5.42	50.67	72.57
Oil price ($/barrel)	744	110.46	6.90	88.69	128.14
Max daily temperature (C)	744	15.14	6.55	0	34
Min daily temperature (C)	744	7.46	4.96	-5	19
Wind speed (km/h)	744	13.09	6.07	4	90
GDP growth (%)	744	1.8	0.43	1.2	2.2
2021-2023					
Electricity price (£)	757	141.78	91.95	17.69	777.90
ROC buyout price (£)	757	53.46	3.33	50.05	59.01
quota (%)	757	48.42	1.04	46.90	49.20
Gas price(£/therm)	757	142.36	89.50	12.60	536.93
Oil price ($/barrel)	757	84.74	15.74	50.37	133.18
Max daily temperature (C)	757	15.72	6.69	-1.20	39.10
Min daily temperature (C)	757	8.43	5.28	-5.10	21.10
Wind speed (km/h)	757	4.68	2.62	0.00	15.10
GDP growth (%)	757	4.38	3.51	0.10	8.70

Straight away, we can observe some distinctions. The first period shows more variability in the quota obligations and the buyout price, so our predictions might be clearer there.

3.3. THE MODEL

By now, there is sufficient theoretical background as well as empirical data in order to proceed with introducing the OLS regression that will give the estimates on how changes in renewable energy regulations affect electricity prices, and therefore will measure the impact they have on consumers.

To begin with, new variables were generated as the natural logarithms (log) of each set of prices respectively. This is necessary since the prices for electricity, gas, oil and ROCs are measured in different units. Also, by doing this the coefficients on the new variables will represent percentage changes as opposed to unit changes which are more relevant when it comes to prices in general. As a result, the regression will consist of the log of electricity price as the dependent variable and will have as regressors variables that describe the Renewable Obligations, such as the log of ROC price and the quota and other relevant control variables such as the log of the gas and oil price, wind and temperature.

Because oil and gas are used in the generation of electricity and take part in the production costs, an increase in their prices should also drive up the electricity price. Hence, a positive relationship is expected between them. As for the wind, the effect is ambiguous and would be difficult to predict since it affects both the demand and the supply of electricity. Furthermore, in order to introduce temperature in the regression, two different methods have been used, both of which will be discussed below. Consequently, two main regressions were carried out; their effectiveness is discussed in the next section.

For the first regression, an assumption is made that the electricity prices depend on temperatures differently conditional on the season. As a result, 3 separate dummy variables were created for winter, summer and spring. Thus, the final form of the regression is:

$$\boldsymbol{lpel} = \beta_0 + \beta_1 * lproc + \beta_2 * quota + \beta_3 * lpgas + \beta_4 * lpoil + \beta_5 * wind + \\ + \beta_6 * winter + \beta_7 * summer + \beta_8 * spring + \varepsilon \quad (1)$$

For the second regression, a new variable for temperature (t) was created. In order to clarify how t was defined, an additional assumption needs to be made, that spikes in prices

occur when temperatures reach extreme values. This assumption is plausible because increasing the quantity of electricity in a day enough to have an effect on the price would imply temperatures whose difference from the average in the corresponding periods are large. Therefore, the variable for temperature was defined as the minimum daily temperature for autumn and winter months and the maximum daily temperature for spring and summer months (March to August).

Furthermore, as explained above, low minimums and high maximums would impact the prices more than values that are closer to the average. This implies a dependence of electricity prices on the variable for temperature that could be described by a parabolic shape with a minimum point. Hence, it is safe to assume a quadratic relationship between the two, which will be included in the regression accordingly. So, the second regression will have the following form:

$$\boldsymbol{lpel} = \beta_0 + \beta_1 * lproc + \beta_2 * quota + \beta_3 * lpgas + \beta_4 * lpoil + \beta_5 * wind + \\ + \beta_6 * t + \beta_7 * t^2 + \varepsilon \quad (2)$$

The methodology will be implemented for two time periods : 2011-2013 and 2021-2023. The period 2011-2013 was selected to ensure the Renewable Obligation (RO) scheme had reached a level of maturity, thereby avoiding fluctuations associated with its initial implementation. Additionally, technology banding was introduced in 2009, so we chose a time period after this introduction so as to analyze the system under consistent regulatory conditions for both timeframes. The second period, 2021-2023, was chosen as it provides the most recent data, enabling us to determine if the observed trends persist as the UK transitions to Contracts for Difference (CfDs). In each of the four cases (2 time periods with two regressions each) we will be testing whether the coefficients on the quota level and the buy-out-price of TGFs are significant. By examining these coefficients, we aim to address our primary question: whether more stringent renewable energy obligations lead to an increase in electricity prices.

4. RESULTS

To proceed with the findings, the results will be analyzed for the two time periods separately, followed by a comparison of the findings.

4.1. RESULTS FOR THE PERIOD 2011-2013

The results of the regressions for the 2011-2013 period are summarized in Table 3 below. The 5% significance of each coefficient is signaled by the "*" sign. As we can see, in regression

(1) with the dummy variables for season, all coefficients on the control variables are significant. In contrast, for regression (2) in which the variable t was used for temperature , the coefficient on the log of oil price was not found significant.

Moreover, the coefficient on the price of gas is positive and significant for all regressions so an increase in gas prices will increase electricity prices, as expected. Furthermore, there seems to be a negative relationship between oil and electricity prices in regression (1). Additionally, the coefficient on the variable wind is negative and significant in all three cases which means that the shift in supply caused by increased wind speed outweighs the shift in demand. As for weather conditions, we observe positive coefficients on the dummy variables, which means that the impact on electricity prices is higher in winter, summer and spring than it is in autumn. For regression (2), we found significant effects of both t and t^2, with a positive coefficient on t^2, which indeed infers a parabolic dependence with a minimum, as predicted.

Because of the insensitivity of regression (1) towards the actual values for temperatures, this simplistic approach seems slightly inferior to the other method. A quadratic relationship between the extreme daily temperatures (maximums or minimums) and the electricity prices appears to be a more plausible description of reality.

Table 2. Regression results for the period 2011-2013

Variable	Coefficient	Std. Error	t-value	P-value	95% CI Lower	95% CI Upper
Regression (1)						
constant	0.243	0.455	0.53	0.594	-0.65	1.136
ln of gas price (lpgas)	0.855	0.072	11.91	0.000*	0.714	0.996
ln of oil price (lpoil)	-0.15	0.066	-2.26	0.024*	-0.280	-0.020
ln of ROC buyout price (lproc)	0.258	0.070	3.69	0.000*	0.121	0.395
Quota	-0.003	0.002	-1.48	0.139	-0.007	0.001
Wind	-0.004	0.001	-5.89	0.000*	-0.005	-0.002

Variable	Coefficient	Std. Error	t-value	P-value	95% CI Lower	95% CI Upper
spring	0.065	0.012	5.46	0.000*	0.041	0.089
summer	0.037	0.014	2.64	0.009*	0.010	0.065
winter	0.028	0.011	2.47	0.014*	0.006	0.050
Regression (2)						
constant	-1.687	0.443	-0.38	0.703	-1.038	0.701
ln of gas price (lpgas)	0.663	0.068	9.80	0.000*	0.530	0.795
ln of oil price (lpoil)	-0.024	0.670	-0.37	0.715	-0.156	0.107
ln of ROC buyout price (lproc)	0.415	0.070	5.95	0.000*	0.278	0.552
Quota	0.002	0.002	1.10	0.271	-0.017	0.006
Wind	-0.003	0.001	-5.40	0.000*	-0.005	-0.002
Temperature (t)	-0.005	0.002	-3.65	0.000*	-0.008	-0.003
Temperature squared (tsquared)	0.0002	0.0001	2.89	0.004*	0.0001	0.0003

More specifically, according to the result, the biggest impact on the price occurs during spring months, which is in violation of the assumption that prices are affected when temperatures reach abnormal values; this is more likely to happen in summer or winter than in spring. Since regression 2 seems to presents what appears to be an accurate relationship between temperature and prices, it will be used for the interpretation of results in the rest of the paper.

Finally, we can turn our attention towards the estimations for the variables of interest: the log of ROC price and the quota. As we can observe from the regression results, the hypothesis, the coefficient on the log of the ROC price (lproc in the table 2, regression (2)) is approximately

0.417. Because logarithms were used, the meaning is that a 1% increase in the price of ROCs leads to a 0.417% increase in the piece of electricity. In other words, almost half of the extra costs incurred by a rise in the certificate prices is transferred to electricity prices and therefore incurred by consumers instead of suppliers. The effect is quite large and should at least raise some suspicion towards the efficiency and the cost-effectiveness of the British Renewable Obligations system.

4.2 RESULTS FOR THE PERIOD 2021-2023

In the previous section, we concluded that regression 2 is more valid for our experimental design, hence it is the only one that we have run for this section. Furthermore, since GDP fluctuations have been unusually high in the time period studied, we have added a GDP factor in the regression. The results are in table 3 below.

Table 3. Results of the regressions for the period 2021-2023

Variable	Coefficient	Std Error	t-value	P-value	95% CI Lower	95% CI Upper
constant	1.787	2.579	0.693	0.488	-3.275	6.850
ln of gas price (lpgas)	0.725*	0.023	31.280	<0.001	0.680	0.771
ln of oil price (lpoil)	0.127	0.080	1.599	0.110	-0.029	0.283
ln of ROC buyout price (lproc)	-0.797	0.472	-1.689	0.092	-1.723	0.129
Quota	0.050*	0.019	2.607	0.009	0.012	0.088
GDP growth	-0.010	0.007	-1.544	0.123	-0.023	0.003
Wind	-0.034*	0.004	-8.593	<0.001	-0.042	-0.026
Temperature (t)	-0.020*	0.004	-4.872	<0.001	-0.028	-0.012
Temperature squared(tsquared)	0.001*	0.000	5.376	<0.001	0.000	0.001

Similarly to the previous period analyzed, We see that the price of gas remains a significant predictor with a strong positive coefficient. Furthermore, the direction of the effects of wind and temperature are also maintained compared to the first period, while the crude oil price shows some positive influence but is not statistically significant.

Contrarily to the previous analysis, in this case the coefficient on the buy-out price of TGS is not significant, however the positive effect of more stringent regulations on electricity process is still observable through the coefficient on the 'quota' variable, which is significant at the 5% level.

5. DISCUSSION

The relevance of this research lies in its direct engagement with the complex question of how policy instruments, specifically renewable energy obligations, impact electricity pricing - a matter of significant importance to economic stability, environmental sustainability, and social welfare. As nations globally grapple with the challenges of transitioning to renewable energy, understanding the economic implications of such policies is critical. This study is particularly relevant in the context of growing concerns about climate change and the pressing need to reduce carbon emissions. By analyzing the financial outcomes associated with renewable energy policies, the research helps illuminate the path to a low-carbon future, highlighting the potential economic hurdles and enabling better-informed decisions.

This study builds upon existing research by providing a detailed empirical analysis of how Renewable Obligations impact electricity prices in the UK. While previous studies have focused on the general advantages and disadvantages of renewable energy policies, our research examines the temporal effects of policy adjustments over two distinct periods. By taking the periods ten years apart, we demonstrate the evolving influence of renewable energy policies on market prices and consumer costs. This analysis underscores the importance of continuously updating policy frameworks to adapt to changing market conditions and technological advancements.

As regulations impose that electricity needs to be generated from both conventional and renewable sources and the latter can be assured by purchasing ROCs, it is clear that the two markets are linked. Therefore, it makes sense that price changes in one market would induce the same in the other. In order to understand the effect that the ROC market has on electricity prices, two defining characteristics for every market will be investigated: quantity and price. In the UK, the quantity of ROC that each suppliers needs to purchase is expressed by the quota and is set by the government. Afterward, the price is set by the market. In our analysis of the first period (2011-2013) we can observe that changes in the quota do not affect electricity prices significantly, contrary to ROC prices, which have a sizeable impact, illustrating the cost burden of renewable obligations on consumers. Contrarily, the opposite is seen for the second period (2021-2023), with quotas having a significant effect, demonstrating that stringent renewable energy regulations still contribute to higher electricity prices.. The findings could be due to the fact that the ROC prices had a much smaller variation in the second period, which was not enough to study the effects on electricity prices on it. Also, we must keep in mind that the quota level and the buy-out-price tend to increase together as the government urges suppliers of electricity in the direction of renewable energy; therefore the positive effect of stricter regulation on electricity prices might be captured by one or the other.

Furthermore, the results from the analysis of the 2011-2013 and 2021-2023 periods provide valuable insights into the factors influencing electricity prices in the UK. For the 2011-2013 period, gas prices consistently show a significant positive impact on electricity prices, indicating that increases in gas prices directly drive up electricity costs. Wind speeds, conversely, exhibit a significant negative effect, suggesting that higher wind speeds, which enhance wind power generation, help to reduce electricity prices by increasing supply. The quadratic relationship between temperature extremes and electricity prices further emphasizes that both very high and very low temperatures lead to price spikes, highlighting the importance of weather conditions. In the 2021-2023 period, the positive relationship between gas prices and electricity costs remains significant, reinforcing the pivotal role of gas prices in the energy market. Although the oil price shows a positive influence, it is not statistically significant in this period, indicating some variability in its impact over time. Wind speed continues to have a significant negative effect on electricity prices, consistent with the earlier period.

These findings underscore the complex interplay of multiple factors, including gas prices, wind, temperature variations, and renewable energy policies, in shaping electricity prices over time. Policymakers must consider these dynamics to strike a balance between advancing renewable energy objectives and managing electricity costs for consumers.

Lastly, we must mention that the years 2021-2023 were far from typical. Following the COVID- 19 pandemic's profound impact on global energy markets, there was a mix of factors that disrupted energy supply chains and affected electricity prices. Numerous publications have documented how the pandemic led to significant volatility in energy prices due to supply chain disruptions, changes in consumption patterns, and a shift towards renewable energy sources as part of a green recovery effort. The International Energy Agency (IEA) reported that global energy demand dropped significantly, with electricity consumption falling sharply during lockdowns (2020). Gollakota and Shu (2022) noted that the pandemic resulted in a steep drop in oil prices and an imbalance in energy demand due to restricted travel and reduced industrial activity. However, they also observed that renewable energy systems maintained or even increased their output, underscoring the resilience of renewables during the crisis. This shift in investor mindset from conventional fuels to renewable energy was also highlighted, suggesting a potential long-term impact on energy markets (Gollakota & Shu, 2022).

Moreover, the conflict in Ukraine, which began in 2022, led to unprecedented spikes in energy prices, particularly in Europe. The war significantly impacted the availability and cost of natural gas, a key input in electricity generation, due to sanctions and reduced gas flows from Russia to European countries. This situation likely compounded the usual market forces, however there are still no final data on the full impact of the war in Ukraine.

Such extraordinary circumstances must be taken into account when interpreting the regression results from the second period, as they may reflect the unique and extreme market conditions of that time rather than the typical influence of renewable energy obligations on electricity prices. Thus, the lack of significance in some explanatory variables could also be attributed to the unusually high fluctuation of electricity prices during this period.

6. CONCLUSION

Electricity generation is an essential cause of pollution and global warming. A possible remedy for the present situation is the use of renewable sources, which in most European countries is regulated by the government. In the United Kingdom, the approach in use is the Renewable Obligations system, which consist of two parts: a quota imposed on supplier set by the British Government that concerns the quantity of electricity generated from RES-E and Renewable Obligations Certificates that attest the fulfillment of obligations; these certificates are traded on a separate market.

This research marks a step forward in the empirical examination of renewable energy policies and their economic ramifications. It calls for ongoing analysis to refine our understanding and ensure that the pursuit of environmental objectives is accompanied by sound economic outcomes for all stakeholders.

The paper gave an analysis on the impact of renewable energy regulations on fluctuating electricity prices in the UK. The question was answered by creating a dataset prices for the years 2011-2013 and 2021-2023 with the quotas and the prices of ROCs along with observations on four other variables that could potentially explain changes in electricity prices. Subsequently, a regression was performed using OLS with electricity prices as the dependent variable and the above factors as regressors.

The results for the first period showed that the yearly quota does not significantly affect electricity prices. In contrast, a relationship was found between ROC and the dependent variable, mainly a 1% increase in the former leads to close to half percent increase in the latter.

The opposite was found in our analysis of the second period. Our cumulated work leads us to believe that there is definitely and effect between renewable energy regulations and electricity prices. Furthermore, a consistent observation across both periods is the statistical significance of certain factors—namely the price of gas, daily wind values and extreme temperature events—which have demonstrated a steadfast influence on electricity prices. The persistence of these factors as significant predictors suggests their potential as key indicators in forecasting electricity price trends.

In addition to examining the impacts of Renewable Obligations on electricity prices, this study contributes to broader economic theory and policy discussions by providing insights into how renewable energy regulations can influence market dynamics and consumer costs. The findings of this study can inform future policy decisions, particularly in designing more effective and equitable renewable energy support mechanisms.

Overall, this research underscores the need for ongoing policy refinement to balance the goals of environmental sustainability, economic efficiency, and consumer protection. By continuously monitoring and adapting renewable energy policies, the UK can ensure a smooth and equitable transition to a low-carbon future.

Overall, our findings indicate that the existing Renewable Obligation (RO) system, which includes a market for Tradable Green Certificates, might not be optimal. The analysis suggests that this mechanism may not be the most effective solution for advancing the UK's renewable energy goals. In response to these challenges and in pursuit of more efficient and targeted renewable energy support, the UK is in the process of transitioning towards a different system. A significant step forward in this transition is the increasing reliance on Contracts for Difference (CfDs). This system aims to provide more stable and predictable incentives for renewable energy production.

The UK's ongoing transition from the Renewable Obligation (RO) system to Contracts for Difference (CfDs) underscores the importance of our findings. The observed inefficiencies and significant consumer cost impacts associated with ROC prices highlight the need for a more stable support mechanism. CfDs, which offer fixed-price contracts to renewable energy generators, aim to mitigate the price volatility and market uncertainties that were prevalent under the RO system. Our results, demonstrating the substantial impact of ROC prices on electricity costs, provide empirical support for this policy shift. By protecting developers from volatile wholesale prices and shielding consumers from fluctuating certificate prices, CfDs can promote a more efficient and equitable integration of renewable energy into the market. Thus, our study not only informs current policy decisions but also reinforces the strategic direction towards CfDs as a means to enhance the economic viability and sustainability of the UK.

REFERENCES

Allan, G., Gilmartin, M., McGregor, P., & Swales, J. (2011). Levelised costs of wave and tidal energy in the UK: Cost competitiveness and the importance of "banded" Renewables Obligation Certificates. *Energy Policy*, 39(1), 23-39.

Balaman, Ş. Y., Scott, J. A., Matopoulos, A., & Wright, D. G. (2019). *I*ncentivising bioenergy production: Economic and environmental insights from a regional optimization methodology.*Renewable Energy*, 130, 867-880.

Bose, B. (2010*)*. Global Warming: Energy, Environmental Pollution, and the Impact of Power Electronics. *IEEE Industrial Electronics Magazine*, 4(1), 6-17.

Butler, L., & Neuhoff, K. (2008). Comparison of feed-in tariff, quota and auction mechanisms to support wind power development. *Renewable Energy*, 33(8), 1854-1867.

Canbulat, S., Balci, K., Canbulat, O., & Bayram, İ. Ş. (2021). Techno-economic analysis of on-site energy storage units to mitigate wind energy curtailment: A case study in Scotland. *Energies*, 14(6), 1691.

Connor, P., Baker, P., Xenias, D., Balta-Ozkan, N., Axon, C. J., & Cipcigan, L. (2014). Policy and regulation for smart grids in the United Kingdom. Renewable and Sustainable Energy. *Reviews*, 40, 269-286.

Connor, P., Xie, L., Lowes, R., Britton, J., & Richardson, T. (2015). The development ofrenewable heating policy in the United Kingdom. *Renewable Energy,* 75, 733-744.

European Commission. (2020). The European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green- deal_en

International Energy Agency. (2020). Global Energy Review 2020: The impacts of the COVID-19 crisis on global energy demand and CO2 emissions. https://www.iea.org/reports/global-energy-review-2020

Gollakota, A. R. K., & Shu, C. M. (2022). Covid-19 and energy sector: Unique opportunityfor switching to clean energy. *Gondwana Research*, 114, 93-116.

Gürkan, G., & Langestraat, R. (2014). Modeling and analysis of renewable energy obligations and technology bandings in the UK electricity market. *Energy Policy*, 70, 85-95.

Held, A., Ragwitz, M., & Haas, R. (2006). On the success of policy strategies for the promotion of electricity from renewable energy sources in the EU. *Energy & Environment,* 17(6), 849-868.

Huisman, R. (2008). The influence of temperature on spike probability in day-ahead power prices. *Energy Economics,* 30(5), 2697-2704.

Klessmann, C., Nabe, C., & Burges, K. (2008). Pros and cons of exposing renewables to electricity market risks—A comparison of the market integration approaches in Germany, Spain, and the UK. *Energy Policy*, 36(10), 3646-3661.

Krajačić, G., Duić, N., Tsikalakis, A. G., Zoulias, M., Caralis, G., Panteri, E., & Carvalho, M.

G. (2011). Feed-in tariffs for promotion of energy storage technologies. *Energy Policy*, 39(3), 1410-1425.

Li, J., Liu, G., & Shao, J. (2020). Understanding the ROC transfer payment in the Renewable Obligation with the recycling mechanism in the United Kingdom. *Energy Economics*, 87, 104701.

Lipp, J. (2007). Lessons for effective renewable electricity policy from Denmark, Germany, and the United Kingdom. *Energy Policy,* 35(11), 5481-5495.

Ofgem. (2023). Renewables Obligation (RO).
https://www.ofgem.gov.uk/environmental-and-social-schemes/renewables-obligation-ro

Ofgem. (2024). Renewables Obligation (RO): Buy-out price, mutualisation threshold andmutualisation ceilings 2024/2025. *Ofgem*.
https://www.ofgem.gov.uk/publications/renewables-obligation-ro-buy-out-price-mutualisation-threshold-and-mutualisation-ceilings-2024-2025

Percebois, J. (2008). Electricity liberalization in the European Union: Balancing benefits and risks. *The Energy Journal*, 29(1), iv-20.

Toke, D., & Lauber, V. (2007). Anglo-Saxon and German approaches to neoliberalism and environmental policy: The case of financing renewable energy. *Geoforum*, 38((4), 677-687.

UK Government. (2024). Contracts for Difference (CfD) scheme. GOV.UK.
https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference

Xu, H., & Niimura, T. (n.d.). Short-term electricity price modeling and forecasting using wavelets and multivariate time series. *IEEE PES Power Systems Conference and Exposition*, 2004.