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Evaluating the effectiveness of environmental taxes: A Case study of carbon pricing in the UK as a tool to reducing Greenhouse Gases Emissions

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Abstract

This paper evaluated the effectiveness of environmental taxes and adopted a case study approach which used carbon pricing in the UK as a tool to reducing Greenhouse Gases Emissions. The objectives of the research are to determine the effect of carbon pricing on greenhouse gases emissions in the United Kingdom, evaluate how fossil energy depletion affect greenhouse gases emissions in the United Kingdom and ascertain the effect of total energy consumption from different energy mix on greenhouse gases emissions in the United Kingdom. The paper used an ex post facto research design and the estimated model was estimated using the ordinary least squares regression technique. The data were sourced from different sources and covered the period between 2010 and 2023. The findings of the study revealed that carbon pricing is an effective tool for reducing greenhouse gases emissions in the UK while renewable energy is also a significant tool for reducing greenhouse gases emissions. Based on these findings, the study recommends that the government should consider increasing the carbon price incrementally over time to ensure that it continues to effectively discourage high-emission activities.

Keywords: Carbon Pricing; Greenhouse gases; Emission; United Kingdom; Environmental Taxes

1. Introduction

The introduction of carbon pricing as an environmental tax has become a central mechanism for reducing greenhouse gas (GHG) emissions globally, particularly in the United Kingdom (UK), where policies like the Carbon Price Floor (CPF) target emissions from high-pollution sectors. Carbon pricing operates by assigning a cost to carbon emissions, incentivizing companies and consumers to reduce their carbon footprints. Studies indicate that such pricing mechanisms are among the most effective tools to drive down emissions in sectors like power generation, where they prompt a shift from coal to cleaner energy [1] and have led to significant decarbonization results in the UK power sector [2]. Although effective, the pricing level and economic impacts of such policies require careful consideration, as higher prices may increase overall decarbonization but introduce economic challenges [3].

The primary problem addressed by this research is evaluating the effectiveness of carbon pricing as an environmental tax in reducing greenhouse gas emissions in the United Kingdom. Carbon pricing, including mechanisms such as carbon taxes and emission trading systems, is widely regarded as a cost-effective strategy to curb emissions by internalizing the environmental costs of carbon dioxide (CO_2) emissions. However, while numerous studies argue that carbon pricing has significant potential to reduce emissions and foster low-carbon transitions, its actual impact on substantial emission reductions remains debated [4, 1, 5].

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Research suggests that carbon pricing has had measurable effects in the UK's power sector, resulting in substantial decreases in coal dependency and an increase in cleaner gas-fired generation. For example, following the introduction of the Carbon Price Floor, UK power sector emissions decreased significantly by up to 49% between 2013 and 2017 [2]. However, studies also point to limitations, such as the need for steeper carbon prices or supplementary policies to achieve the deep decarbonization required by climate goals, indicating that carbon pricing alone may be insufficient for reaching long-term targets [6].

The problem, therefore, lies in assessing whether the existing carbon pricing policies in the UK are sufficient to induce significant and sustained reductions in greenhouse gas emissions or whether they need to be supplemented by additional policies to address potential gaps in efficacy and economic equity [7]. This research aims to provide a comprehensive evaluation of the effectiveness of carbon pricing as a tool for environmental tax policy, examining both its direct impact on emissions and broader implications for sustainable economic practices in the UK. In line with the foregoing, the study seeks to achieve the following objectives:

- Determine the effect of carbon pricing on greenhouse gases emissions in the United Kingdom
- Evaluate how fossil energy depletion affect greenhouse gases emissions in the United Kingdom
- Ascertain the effect of total energy consumption from different energy mix on greenhouse gases emissions in the United Kingdom

2. Literature Review

2.1. Conceptual Clarifications and Review

2.1.1. Environmental Taxes

Environmental taxes are financial charges imposed on activities, goods, or services that negatively impact the environment. These taxes are designed to internalize the environmental costs of pollution or resource depletion, encouraging businesses and individuals to adopt more sustainable behaviours. Common types include carbon taxes, fuel taxes, and waste disposal fees.

In the United Kingdom, environmental taxes are key instruments designed to reduce carbon emissions and encourage sustainable practices across sectors. Among these taxes, the **Climate Change Levy (CCL)**, introduced in 2001, targets business energy consumption, with the aim of reducing greenhouse gas emissions by taxing electricity, gas, and fossil fuels used by businesses. Studies show that while the CCL has incentivized some reductions in emissions, its impact has been mixed, partially due to exemptions for energy-intensive sectors that limit the policy's effectiveness [8]. Another major environmental tax policy, the **Fuel Duty Escalator (FDE)**, was implemented in the 1990s to progressively raise fuel duties, creating incentives for reduced fuel use and emissions. However, the FDE faced significant public resistance, which eventually led to a halt in its escalation, illustrating the social and political challenges of environmental taxation [9].

Essentially, while environmental taxes in the UK aim to balance economic incentives with emissions reduction, their long-term success is influenced by policy design, public support, and adjustments to economic factors, such as oil prices and industry exemptions [10].

2.1.2. Energy Mix

The energy mix is the combination of different energy sources used to meet a region or country's energy needs. It includes fossil fuels (e.g., coal, oil, natural gas), nuclear energy, and renewable sources (e.g., wind, solar, hydroelectric). A country's energy mix impacts its greenhouse gas emissions profile and energy security.

2.1.3. Carbon Pricing

Carbon pricing is a policy tool that assigns a monetary value to carbon dioxide (CO_2) emissions, effectively making polluters pay for the environmental impact of their greenhouse gas emissions. The two main types are carbon taxes (a fixed price per ton of CO_2) and emissions trading systems (ETS), where a market price is set through tradeable emissions allowances.

2.1.4. Main types of carbon pricing

An emissions trading system (ETS) allows emitters to exchange emission units to fulfil their emission objectives. To meet their emission targets cost-effectively, regulated businesses may either use internal abatement strategies or purchase emission units in the carbon market, contingent upon the comparative prices of these alternatives. An ETS generates a market price for GHG emissions by establishing supply and demand for emissions units. The primary categories of Emission Trading Systems (ETSs) are cap-and-trade and baseline-and-credit (World Bank, 2024).

• Cap-and-trade systems impose a cap on emissions inside the Emissions Trading System (ETS), distributing emissions allowances, either at no cost or via auctions, corresponding to the established limit.

• Baseline-and-credit systems establish baseline emissions levels for specific regulated companies, granting credits to those that reduce their emissions below this threshold. These credits may be transferred to other entities that surpass their baseline emission levels.

A carbon tax establishes a price on carbon by specifying a tax rate on greenhouse gas emissions or, more frequently, on the carbon content of fossil fuels, expressed as a price per tonne of CO2 equivalent. A carbon tax differs from an ETS in that the emission reduction result is not predetermined, whereas the carbon price is established. A crediting system allocates GHG emission reductions from project- or program-based activities, which may be marketed locally or internationally. Crediting mechanisms issue carbon credits based on an accounting methodology and maintain their own registry. These credits may be utilised to fulfil compliance with international agreements, domestic regulations, or corporate social responsibility goals pertaining to greenhouse gas mitigation [11].

Results-Based Climate Finance (RBCF) is a financing method in which disbursements occur subsequent to the delivery and verification of specified outputs or results associated with climate change management, such as reductions in emissions. Numerous RBCF projects seek to acquire documented reductions in GHG emissions while simultaneously alleviating poverty, enhancing access to clean energy, and providing health and community advantages.

Internal carbon pricing is a mechanism employed by an organisation to inform its decision-making regarding climate change impacts, risks, and opportunities.

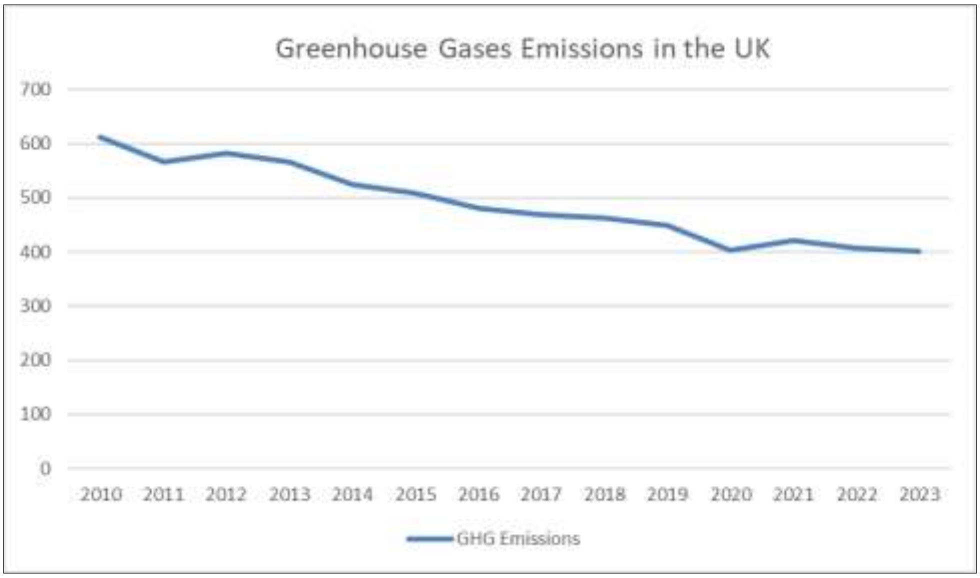
The selection of carbon pricing mechanisms by governments is contingent upon national conditions and political dynamics. In the realm of obligatory carbon pricing measures, emissions trading systems (ETSs) and carbon taxes are the predominant forms. The appropriate sort of initiative is contingent upon the particular circumstances and environment of a jurisdiction, and the instrument's policy aims must coincide with the overarching national economic priorities and institutional capabilities.

The UK Emissions Trading Scheme (ETS) is a cap-and-trade system in which enterprises compete for carbon allowances, with the total amount of allowances (the cap) and demand determining the carbon clearing price at auction. Government receipts are calculated by multiplying the auction price by the quantity of permits sold. The UK ETS commenced on 1 January 2021, coinciding with the conclusion of the transition period following the UK's departure from the EU, so supplanting the UK's involvement in the EU ETS, which began in 2005. In the fiscal year 2024-25, we project that the UK ETS will generate £3.6 billion. This constitutes 0.3 percent of total receipts, around £120 per household, and 0.1 percent of national income according to the Office for Budget and Responsibility [12].

2.1.5. Greenhouse Gas Emissions

Greenhouse gas emissions refer to the release of gases, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), into the atmosphere that trap heat and contribute to global warming. These emissions originate from various sources, including fossil fuel combustion, industrial activities, and agriculture, and are a primary driver of climate change. The chart in fig 1 shows the historical data of greenhouse emissions in the UK from 2010 to 2023.

The UK has made significant strides in reducing greenhouse gas (GHG) emissions across various sectors from 2010 to 2023. Driven by policy measures aimed at cutting reliance on fossil fuels, emissions decreased notably, particularly in the power generation sector where coal use dropped in favour of renewables. Between 2010 and 2019, emissions fell steadily from 611.5 million tonnes ($MtCO_2e$) to 401.5 $MtCO_2e$. The pandemic in 2020 further lowered emissions to 404.01 $MtCO_2e$, a level partially sustained despite economic recovery efforts that saw a modest increase to approximately 421.05 $MtCO_2e$ by 2021.



Source: Department for Energy Security and Net Zero

Figure 1 Historical Data of GHG in the UK

The UK's focus on carbon reduction policies, including renewable energy integration and carbon pricing, has yielded a 46% overall decline in emissions since 1990. By 2021, CO_2 emissions remained the primary GHG, but their reduction was augmented by decreases in methane and nitrous oxide emissions due to improved waste management and agricultural practices. Energy sector reform, waste reductions, and industry shifts reflect broader environmental commitments that are projected to continue lowering GHGs, albeit with recent fluctuations due to post-pandemic economic adjustments and policy renewals.

3. Theoretical Literature Review

3.1. The Pigouvian Tax Theory

The Pigouvian Tax Theory is a foundational concept in environmental economics, introduced by British economist Arthur C. Pigou in the early 20th century. This theory addresses how economic activities can create negative externalities, or costs imposed on society and the environment that are not accounted for in the market price of goods or services. According to Pigou, when left unchecked, these externalities lead to market inefficiencies, as producers and consumers do not bear the full social costs of their actions [13].

Pigou argued that to correct the inefficiency caused by externalities, governments should implement a tax equal to the marginal social cost of the negative externality. By doing so, the price of a good or service rises to reflect its true societal cost. This "Pigouvian tax" thus aims to "internalize" the external costs, encouraging businesses and consumers to adjust their behaviour in a way that reduces harm to society and the environment. For a Pigouvian tax to be effective, it must be set at a rate that aligns with the cost of the negative externality it seeks to mitigate. In the context of carbon emissions, the ideal tax rate would equate to the estimated social cost of carbon, which includes damages from climate change, health impacts, and other environmental degradation. By accurately setting this rate, the tax can encourage meaningful reductions in emissions without imposing unnecessary economic burdens [14].

Pigouvian taxes create financial incentives for adopting cleaner technologies and practices. By increasing the cost of carbon-intensive activities, such as fossil fuel consumption, these taxes encourage investment in renewable energy, energy efficiency improvements, and shifts toward sustainable practices. Over time, these behavioural shifts can drive systemic changes in industries and markets, promoting a transition to low-carbon economies. In the context of carbon pricing in the UK, Pigouvian tax theory supports the use of a carbon tax to reduce greenhouse gas emissions. Carbon taxes, designed as per Pigou's principles, help reflect the true environmental and social costs of carbon emissions. By increasing the cost of carbon-heavy fuels, the tax incentivizes both companies and individuals to shift to cleaner energy sources and adopt emission-reducing practices. The revenue generated can also be reinvested into sustainable infrastructure, further amplifying the positive impact on emissions reduction [14].

3.2. Empirical Literature Review

Dinan [15] compared carbon taxes to cap-and-trade systems in terms of economic efficiency and cost-effectiveness, finding that a well-calibrated carbon tax aligns closely with emission reduction goals by establishing a clear price path that adjusts as emissions decline. This study suggests that a tax-based approach may offer predictable outcomes for greenhouse gas reduction.

Metcalf [16] designed a revenue-neutral carbon tax model aimed at reducing U.S. emissions while offsetting regressivity concerns through tax credits. The analysis highlighted that this design could reduce emissions without significant economic disruptions, showcasing how carbon tax revenues can be redistributed to increase public support for environmental taxation.

Hájek et al. [17] analyzed the impact of carbon taxes on the energy sector across selected European countries and concluded that higher tax rates directly correlate with emission reductions in fossil-fuel-intensive industries. This study provides evidence that carbon taxes effectively incentivize shifts to renewable energy sources and reduce greenhouse gas production.

Tvinnereim and Mehling [18] investigated carbon pricing within the context of deep decarbonization, noting that while carbon taxes contribute to emission reductions, achieving net-zero goals requires complementary policies, like innovation support and technology mandates. This study underlines the importance of a policy mix for effective, long-term emissions management.

Gugler et al. [19] focused on the UK's Carbon Price Support (CPS) policy in the power sector, reporting significant emissions decrease of 55% within five years. Their findings indicate that even moderate carbon pricing can effectively reduce emissions if it creates an economic advantage for cleaner technologies.

4. Methodology

This study adopted the expo facto research design due to the nature of the variables of the study. The data were sourced from secondary sources such as the World Bank, UK Office for Budgets and Responsibility, and Department of Energy Security and Net Zero. The period covered for the study ranges from 2010 to 2023, that is about fourteen years.

The functional and econometric models for this study are given respectively as follows:

$GHG = f(CBP, ERD, FOS, RNW)$ (Functional Model)

$GHG = \alpha + \beta_1 CBP + \beta_2 ERD + \beta_3 FOS + \beta_4 RNW + \mu$ (Econometric Model)

Where GHG is Green House Gases Emission, CBP is Carbon Pricing (proxied by UK Carbon tax), ERD is Energy Depletion, which is the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years). It covers coal, crude oil, and natural gas. FOS is the consumption of fossil fuel energy in the UK, RNW is consumption of renewable energy in the UK, μ is the random term. α is the intercept of the model. The specified model above is estimated using the ordinary least squares regression technique.

5. Results and Discussion

In this section, the results of the model estimation are presented and discussed starting with the descriptive statistics before moving to the regression technique.

From the table, Greenhouse Gas Emissions (GHG) show a mean value of 489.41 with a median of 474.89, indicating a slight rightward skew in the distribution, as suggested by the positive skewness value of 0.28. The maximum GHG emission recorded is 611.57, while the minimum is 401.58, revealing a substantial range of emissions in the data set. The standard deviation of 71.48 suggests moderate variability in GHG emissions across observations. The kurtosis value of 1.75 indicates a distribution that is flatter than a normal distribution, suggesting a relatively low occurrence of extreme values.

Carbon Pricing (CBP) has a mean of 26.40 and a median of 23.59, which also exhibits a positive skewness of 0.95, suggesting that higher carbon prices are less frequent but present in the data. The maximum carbon price is 52.56, whereas the minimum is 7.50, which reflects significant variation in carbon pricing over the study period. The standard deviation of 12.97 indicates that the values of carbon pricing can vary substantially from the mean, with a kurtosis of 3.21, which is close to a normal distribution.

Table 1 Descriptive Statistics

	GHG	**CBP**	**ERD**	**FOS**	**RNW**
Mean	489.4128	26.39644	1.36E+10	2081.889	218.8158
Median	474.8905	23.58899	1.44E+10	2062.740	219.9823
Maximum	611.5703	52.56000	2.51E+10	2848.373	316.3440
Minimum	401.5842	7.500000	6.53E+09	1439.453	103.3797
Std. Dev.	71.47935	12.97209	5.78E+09	436.1250	72.86347
Skewness	0.277504	0.950592	0.377947	0.150589	-0.203497
Kurtosis	1.754015	3.206492	2.118322	1.885267	1.725148
Jarque-Bera	1.085299	1.676189	0.786761	0.777781	1.044687
Probability	0.581206	0.432534	0.674772	0.677809	0.593129
Observations	14	11	14	14	14

Source: Author’s Computation (2024)

Energy Depletion (ERD), represented as the ratio of the stock of energy resources to the remaining reserve lifetime, shows a mean value of 1.36 × 10^10 and a median of 1.44 × 10^10. The skewness of 0.38 indicates a slight rightward skew, while the kurtosis of 2.12 suggests a relatively platykurtic distribution, which means fewer extreme values compared to a normal distribution. The range, from a minimum of 6.53 × 10^9 to a maximum of 2.51 × 10^10, indicates variability in energy resource availability across the observations.

Fossil Fuel Consumption (FOS) averages at 2081.89, with a median close at 2062.74, demonstrating a minor skewness of 0.15, indicating a roughly symmetrical distribution. The maximum fossil fuel consumption reaches 2848.37, while the minimum is 1439.45. The standard deviation of 436.13 indicates significant variability in fossil fuel consumption patterns, with a kurtosis of 1.89 suggesting a flatter distribution, indicating fewer extreme outliers.

Renewable Energy Consumption (RNW) exhibits a mean of 218.82 and a median of 219.98, with a slight negative skewness of -0.20. This suggests a tendency towards higher consumption values, though the difference is minimal. The maximum renewable energy consumption is 316.34, compared to a minimum of 103.38, highlighting a diverse energy consumption landscape. The standard deviation of 72.86 further emphasizes variability, while the kurtosis of 1.73 indicates a distribution with fewer extreme values compared to a normal distribution.

Table 2 Ordinary Least Squares Regression

Dependent Variable: GHG				
Method: Least Squares				
Sample (adjusted): 2013 2023				
Included observations: 11 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	404.1774	125.0049	3.233291	0.0178
CBP	-2.337482	0.335687	-6. 963271	0.0000
ERD	1.33E-09	8.14E-10	1.633935	0.1534
FOS	0.080694	0.036164	2.231346	0.0471
RNW	-0.427308	0.209659	-2.038106	0.0377

R-squared	0.980906	Mean dependent var	463.0039
Adjusted R-squared	0.968177	S.D. dependent var	54.33708
S.E. of regression	9.693131	Akaike info criterion	7.683667
Sum squared resid	563.7407	Schwarz criterion	7.864529
Log likelihood	-37.26017	Hannan-Quinn criter.	7.569659
F-statistic	77.06054	Durbin-Watson stat	1.765490
Prob(F-statistic)	0.000027		

Source: Author's Computation (2024)

The regression analysis shows that Carbon Pricing (CBP) has a negative effect on GHG emissions with a coefficient of -2.337 and a p-value of 0.0000, this shows that carbon pricing (CBP) is highly significant, indicating that increases in carbon pricing are associated with a decrease in GHG emissions. This suggests that the carbon price is effective as a tool to discourage emissions-intensive activities. Energy Depletion (ERD) has a positive effect on GHG emissions. Energy resource depletion (ERD) does not show a significant impact on emissions within this period, emphasizing the need for policies to focus on carbon pricing and renewable energy expansion to counterbalance the fossil fuel consumption that continues to drive emissions upward.

Similarly, Fossil Fuel Consumption (FOS) positively impacts greenhouse gases emissions. The positive coefficient (0.0807) and significant p-value (0.0471) suggest that increased fossil fuel use directly raises GHG emissions, reinforcing the need for stringent measures to limit fossil fuel dependency. This result underscores the policy need to further restrict fossil fuel use and incentivize shifts to alternative energy sources.

Conversely, Renewables (RNW) has a coefficient of -0.4273 with a significant p-value (0.0377), showing that an increase in renewable energy capacity correlates with lower emissions. This highlights the effectiveness of policies supporting renewable energy deployment. Increased support for renewables can thus be a cornerstone in reducing emissions, in line with national climate goals.

The intercept, with a coefficient of 404.1774 and a p-value of 0.0178, is statistically significant, suggesting that even in the absence of other factors, baseline emissions in this period are high. This might represent the lingering effects of historical industrial and energy practices, which have left high emissions levels in the absence of interventions. The R-squared value of 0.9809 indicates that 98% of the variance in GHG emissions is explained by these variables, suggesting the model's robustness. However, the Durbin-Watson statistic of 1.7655 suggests some potential autocorrelation, which might require further diagnostic checks. The model's overall high F-statistic and low p-value (0.000027) suggest strong significance overall, affirming that these variables jointly impact GHG emissions.

The findings reinforce the importance of continuing and intensifying carbon pricing, fossil fuel restrictions, and renewable energy subsidies to achieve meaningful reductions in emissions. Carbon pricing emerges as a particularly effective policy tool. However, to maximize impact, integrating ERD outcomes into active policies faster could improve its significance as an emissions reducer. Transition policies that prioritize renewables and disincentivize fossil fuels are essential, aligning with the UK's commitments to emissions targets and helping to establish a resilient, low-carbon economy.

5.1.1. Diagnostic Tests

The tests for serial correlation and heteroskedasticity are shown in Table 3 as follows

The diagnostic tests in Table 3 assess the validity of the regression model's assumptions. From the Breusch-Godfrey Serial Correlation LM Test, the F-statistic (0.2077, p = 0.8207) and Obs*R-squared (1.0350, p = 0.5960) indicate that there is no significant serial correlation in the residuals. The high p-values suggest that autocorrelation is not a concern, confirming that errors are independently distributed across observations. Likewise, the Heteroskedasticity Test (Breusch-Pagan-Godfrey) result; F-statistic (3.3426, p = 0.0913) and Obs*R-squared (7.5927, p = 0.1077) show marginal evidence against homoskedasticity but are not statistically significant at conventional levels. Additionally, the Scaled Explained Sum of Squares (p = 0.9771) strongly supports homoskedastic errors, indicating that error variances are fairly consistent. In summary, these diagnostics suggest that the regression model meets assumptions of no serial correlation and homoskedasticity, reinforcing the reliability of the model's coefficients and overall inference.

Table 3 Diagnostic Tests

Test	Statistic	Value	Probability
Breusch-Godfrey Serial Correlation LM Test	F-statistic	0.207733	Prob. F(2,4) = 0.8207
	Obs*R-squared	1.035028	Prob. Chi-Square(2) = 0.5960
Heteroskedasticity Test: Breusch-Pagan-Godfrey	F-statistic	3.342552	Prob. F(4,6) = 0.0913
	Obs*R-squared	7.592706	Prob. Chi-Square(4) = 0.1077
	Scaled explained SS	0.462122	Prob. Chi-Square(4) = 0.9771

Source: Author's Computation (2024)

5.2. Conclusion and Recommendations

The study highlights the effectiveness of carbon pricing as a primary policy instrument in reducing greenhouse gas (GHG) emissions in the UK, with a significant inverse relationship between carbon pricing and emissions. However, the limited impact of energy resource depletion (ERD) suggests that resource scarcity alone does not significantly drive reductions, while fossil fuel consumption remains a positive driver of emissions. The role of renewable energy is also critical, as its expansion is associated with substantial emissions reductions. These findings support a broad-based approach, focusing on carbon pricing, energy transition, and sustainable resource management to achieve emission targets.

5.3. Recommendations

- Strengthen Carbon Pricing Policies: Given its clear impact on emissions reduction, the government should consider increasing the carbon price incrementally over time to ensure that it continues to effectively discourage high-emission activities.
- Accelerate Renewable Energy Investments: Expanding funding for renewable energy projects, particularly in regions heavily reliant on fossil fuels, can reinforce the downward trend in emissions while promoting a sustainable energy economy.
- Reduce Fossil Fuel Dependency: Introducing stricter regulations and incentives to phase out fossil fuel usage across industries can help mitigate emissions and drive further adoption of cleaner energy alternatives.
- Promote Sustainable Resource Management: Although ERD was not a significant emissions driver, policies aimed at optimizing resource use and increasing energy efficiency can help address potential future shortages while supporting overall sustainability efforts.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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