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RESEARCH ARTICLE

# Can Environmental Taxes Accelerate Carbon Emission Reduction? The Role of Renewable Energy and Economic Factors

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**Abstract**
Carbon dioxide ($CO_2$) is an important cause of Greenhouse Gas (GHG) emissions, thus acts a crucial role in global warming and climate change. Environmental taxes have been considered the foremost powerful strategic tool for abating greenhouse gases, which tax carbon emissions to rise energy productivity, lessen environmental issues, and contribute to environmental preservation by adopting undesirable externalities in the shape of environmental pollution. In this context, this study investigates the impact of environmental taxes on carbon dioxide emissions in 26 EU countries by considering other environmental related factors includes foreign direct investment, energy consumption and economic growth. Data for the period of 2000 to 2024 is analyzed using panel quantile regression approach. The findings indicate that carbon emissions are significantly reduced by environmental taxes, FDI and renewable energy. However, in the sample countries, energy use and GDP are the major drivers for carbon dioxide emissions. The findings additionally validate the environmental Kuznets curve in EU countries. The findings of this study bear substantial policy implications for the sampled countries, particularly regarding the encouragement of renewable energy consumption and the implementation of environmental taxes policy measures.

**Keywords:** Environmental taxes; economic growth, renewable energy consumption; energy intensity; foreign direct investment; EU countries

## 1. Introduction

Environmental degradation stands as a profound threat to humanity, human well-being is not only impacted but likewise economic wealth (World Bank, 2016). The pursuit of economic advancement has led to more energy consumption, consequently resulting in the damaging increase of carbon dioxide in the atmospheric, precipitating global warming and climate change. According to the IEA (2019), the energy sector surpasses 80% of CO2 emissions alone which is the two-thirds of the total greenhouse gases. According to IEA (2019), CO2 emissions stand as the chief driver behind global warming and climate change, with broad implications for human health, economic growth, and environmental degradation. Numerous empirical studies underscore the adverse effects of CO2 emissions on the economy. As a remedy for reducing CO2 emissions, environmental taxes and policies are swiftly emerging as cornerstones of environmental sustainability. However, the report

recognizes that environmental taxes encompass more than mere tools aimed at mitigating the inimical impacts of climate change and global warming. Likewise, it is acknowledged that relying solely on environmental levies may not adequately diminish the harmful effects of CO2 emissions. A notable policy tool, the carbon tax, commonly referred to Emissions Trading Scheme (ETS), stands out as a key strategy to curtail GHG. Carbon pricing, which involves assigning a cost to greenhouse gas (GHG) emissions, is widely acknowledged as one of the utmost effective tactics for decreasing emissions (Haites, 2018; IBRD, 2017; Tol, 2013). The imposition of carbon taxation system which charges a fee by aiming to incentivize businesses toward environmentally advantageous technologies. Ultimately, these efforts aspire to transition from fossil fuels to renewable energy sources, working toward the ultimate objective of a carbon-neutral society. At the forefront of environmental policy lies the promotion of renewable energy alongside numerous environmental regulations. The advancement of green technologies, both at national levels and global collaboration, holds pivotal significance within energy policy, presenting the optimal path for sustainable development and the aspiration of a society free from emissions. Various ongoing studies are dedicated to substituting conventional technology with environmentally friendly solutions (International Energy Agency, IEA 2019). Due to the global scale of concern surrounding global warming, fostering collaboration for the innovation of green technology, specifically addressing this issue, stands as a defined objective within the UN Sustainable Development Goals. The main objective of the paper is to evaluate the effectiveness of environmental taxes in curbing CO2 across 26 EU member nations spanning for the time period 2000 to 2024. This study encompasses other variables such as energy consumption, foreign direct investment, economic growth, energy intensity, trade, and transportation. Acknowledging the potential of environmental taxes in mitigating CO2 by recognizing the association amid sustainable economic growth and renewable energy adoption, this research pioneers the integration of environmental taxes alongside these factors in a unified model employing quantile regression. Notably, existing literature has extensively examined the effect of environmental taxes on CO2, often positioning them as fundamental in emission reduction strategies. However, recent evidence is mixed. (He, Zhang et al. 2023) found that environmental taxes reduce CO2 emissions in 36 OECD countries. (Özmen and Mutascu 2025) showed that energy taxes reduce emissions in 23 EU countries, while transport taxes increase them. (Gao and Fan 2023) used panel quantile regression for 26 EU countries and found mixed effects across quantiles. In contrast, (Babakhonov, Qosimova et al. 2026) found a positive link between environmental taxes and CO2 emissions in 25 EU countries. So the evidence for the EU is still not clear. In this study we contend that renewable energy consumption can leads to green growth in presence of environmental taxes that can reduce carbon emissions. Likewise, we include foreign direct investment, energy intensity, and passenger transport in this investigation which has not been considered before. Adding to the literature on the topic, environmental taxes along economic growth is important to be studied. Imposing environmental taxes on economic activities can reduce emission however economic activities are also important for the countries. In this regard, energy consumption is an important factor as energy consumption is needed for economic growth whereas the usage of nonrenewable energy harmful to be used for economic activities. If using renewable energy sources for economic activities, which can safeguard environmental quality by reducing carbon emissions and raising economic growth, thus imposing environmental taxes is useful. Likewise, if economic growth raises carbon emissions, the examination of the environmental Kuznets curve for the sample countries needs to be investigated in this model. Such investigation on the implementation of environmental taxes policy on activities along economic growth and energy consumption have never been studied before. This study contributes to the literature by adding these factors to have more useful conclusion and recommendations. This study yields significant policy implications for EU countries concerning environmental taxes, the promotion of green growth, and the patterns of energy consumption.

The remaining parts of this research are organized as follows: section 2 comprises the literature review, the methodology is in Section 3, results and discussions are described in Section 4, and Section 5 incorporates the study's conclusions and policy recommendations.

## 2.Literature review

The topic of environmental worsening aspects continued the midpoint of consideration in the prior studies. A multitude of studies have employed long-term cointegration methodologies to investigate the efficacy of various factors including environmental taxes, eco-innovations, and renewable energy in mitigating carbon emissions across both individual economies and diverse groups of economies. For example, an investigation undertaken by (Xie and Jamaani 2022) to observe the nexus between environment-related tax, energy productivity, green innovation, renewable energy, gross domestic product, and CO2 emissions, in the context of the G-7 nations throughout a time span 1990–2020 and found that environmental taxes within high-income nations considerably enhance environmental quality primarily through mitigating carbon emissions. (Štreimikienė, Samusevych et al. 2022) explored the association between environmental taxes and carbon emissions for six European countries for the period of 1994-2019 and found that as environmental taxes increases, carbon emission decreases. In another study (Amin, Altinoz et al. 2020) analyzed the impact of economic development, urbanization, and renewable energy on carbon emissions from the transportation sector of European union for the period of 1980-2014. Their findings reveal that in transportation sector, the rise in renewable energy usage decreases carbon emissions. (Adams, Boateng et al. 2020) on the association amid urbanization, transportation energy usage, and carbon emissions in 19 Sub-Saharan African countries from 1980–2011 through the IV-GMM predictor. Their result show that carbon emission upsurges when transportation energy usage increases. (Ali and Khan 2023) investigated the influence of GDP, technological progress, and FDI in relationship with carbon emissions by considering the mediating role of economic freedom for global panel during 2000 to 2020 through two step generalized method of moments. The results indicate that GDP and FDI increase carbon emissions. In another study conducted by (Anwar, Siddique et al. 2021) to examine the nexus between energy, income and environment for ASEAN countries. The study reveals that 1% rise in renewable energy usage leads to a reduction in carbon emissions through 0.17%. Furthermore, they found that GDP also increases carbon emissions. (Weili, Khan et al. 2022) studied the relationship between financial development, ICT, economic growth, energy consumption, and carbon emissions in the Belt and Road nations for time period spanning 2000 to 2019 using DGMM and SGMM. The results indicate that financial development, ICT, FDI, energy consumption, and economic growth surge carbon emissions, whereas use of renewable energy and trade decrease it. In case of Mexico, (He, Adebayo et al. 2021) explored the association between financial development, globalization, economic growth, trade openness, and energy usage on carbon emissions. Their findings reveal that economic growth and energy consumption worsen the quality of environment whereas trade does not significantly influence on the quality of environment. (Wu, Xu et al. 2020) studied the relationship amid energy consumption, environmental regulations, and carbon emissions using GMM. The findings indicate that the increasing energy usage has crucial role in encouraging carbon emissions, but the encouraging influence decreased as the level of regulation of environment enhanced. The impacts of green growth and environmental taxes on CO2 emissions were examined by (Dogan, Hodžić et al. 2022) including sustainable indicators for 25 environmentally sensible countries spanning the years 1994 to 2018 by employing advanced panel data analysis models. According to the results of the quantile regression, key factors in decreasing CO2 emissions are renewable energy, energy efficiency, and environmental taxes. (Rafique, Fareed et al. 2022) explored using the autoregressive distributed lag (ARDL) approach the association between environmental taxes, economic growth, and ecological footprint in 29 OECD economies. Their results reveal that in OECD countries, economic growth,

environmental taxes, FDI, renewable energy, energy use, urbanization, and industrialization considerably influence ecological footprint. (Ullah, Luo et al. 2023) studied the association between ecological sustainability and environmental taxes for the time period 1995/Q1 to 2018/Q4 using G-7 green economies by using Quantile-on-Quantile regression. The results indicate asymmetric and mixed influence of the environmental taxes on ecological degradation through different quantiles. Though, at upper-middle quantiles, ecological encouraging influence is observed in these economies. In the study of (Wan, Miao et al. 2022) explored the efficiency of environmental taxes natural resources, and green financing in mitigating carbon emissions in China. They analyzed data spanning from 2000 to 2019 using the Bootstrap ARDL method. The results show that environmental taxes, natural resource management, and green financing abate CO2 emissions. (Nwani, Usman et al. 2023) studied 20 European countries from 1995 to 2019 using consumption-based measures. They found that higher energy and carbon intensity raise CO2 emissions. Renewable energy lowers these intensities. They also found an inverted U-shaped link between income and emissions. (Bilalli, Shahini Gollopeni et al. 2024) studied nine developed European countries from 2002 to 2019. Renewable energy reduced CO2 emissions significantly, but the effect of FDI was not significant. (Kwilinski, Lyulyov et al. 2024) looked at transport sector emissions in EU countries from 2007 to 2020. They found that more renewable energy use goes along with lower transport emissions. (Leitão 2025) used FMOLS, DOLS, quantile regression and system GMM for 38 OECD countries from 1995 to 2022. Renewable energy and trade lowered emissions. (Ben Abd Alah and Ojekemi 2025) used a quantile-on-quantile method with quarterly data for Brazil from 1990 to 2020. GDP and FDI raised emissions, while renewable energy reduced them. The reducing effect was strongest at high emission levels. (Yeboah, Feng et al. 2026) used QARDL and GMM for 10 Sub-Saharan African countries from 2000 to 2019. Environmental taxes reduced emissions in the middle and upper quantiles. Energy use and GDP raised emissions in all quantiles.

## 3.Methodology

Using conventional regressions may lead to either overestimation or underestimation of coefficients, failing to consider the diverse nature of the data (Binder and Coad 2011). Consequently, this research employ the quantile regression (QR) for panel data, introduced by (Koenker and Bassett 1978) aimed at circumventing the limitations inherent in traditional regression methodologies. Notably, quantile regression offers the advantage of flexibility in slope across the data distribution. Moreover, it yields more precise and robust findings, particularly in scenarios involving heavy-tailed distributions and outliers (Bera, Galvao et al. 2016). An additional advantage lies in the capability of quantile regressions to delineate the impact of explanatory variables across various quantiles, mitigating the constraints of OLS, which foundations its analysis on the dependent variable's conditional mean. This approach enables while constructing the equation of regression at an random percentile of the dependent variable by integrating the absolutes of minimized residuals (Koenker 2004). Equation (1) introduces the structured framework of the QR analysis, delineating as stated below:

$$Q_{yi}(\tau \mid x_i) = X_i^T{}_{\beta_\tau} \tag{1}$$

Following (Alvarado, Tillaguango et al. 2021), this study employs QR approach to account for the varied slope influences while evaluating the influence of environmental taxes on carbon emissions across various segments of the distribution. Specifically, we describe the conditional mean of the response variable $\tau^{th}$ quantile ($0 < \tau < 1$), formulated as a function of explanatory factors represented by $X_{it}$. The term $X_{it}$ encompasses both the regressor and covariate variables as stated in Table 1.

$$Q_t(CO2_{it} / X_{it}) = \alpha_t + \beta_t X_{it} + \alpha_t \varepsilon_{it} \quad (2)$$

The matrix $X_{it}$ encompasses a collection of independent and control variables (ENR, ETX, FDI, GDP, RE, EI, TRSPT and TR), meanwhile, $\varepsilon_{it}$ incorporates the implicit influences that remain orthogonal to the response variable.

As the individual values extend towards infinity, inconsistencies may arise, yet each cross-section retains a constant observational value. The aim behind the fixed effect lies in mitigating the influence of these unobserved effects. It's noteworthy that the expectation of linearity in these methods does not serve as the basis for the conditional quantile (Canay 2011). To address these concerns, (Koenker 2004) introduced a viable approach involving the treatment of unobservable fixed effects. This approach establishes these effects as parameters, estimating them concurrently with the covariate effects across various quantiles. Within this methodology, the computation issue is minimized by incorporating a penalty term associated with the estimated parameter, allowing for the estimation of the parameter as follows:

$$\min_{(\alpha,\beta)} \Sigma_{k=1}^{K} \Sigma_{t=1}^{T} \Sigma_{i=1}^{N} W_k P_{\tau k} (y_{it} - \alpha_i - x_{it}^T \beta_{(\tau_k)} + \lambda \Sigma_l^N \mid \alpha_l \mid \quad (3)$$

The number of countries is represented by *i* i within the total count (N), whereas t denotes the number of analyzed periods. Correspondingly, K stands for the count of utilized quantiles, and $X_{it}$ delineates the matrix containing the explanatory variables. $P_{tk}$ signifies the loss function of quantile, while $W_k$ pertains to the values assigned to the $k-th$ percentile, essentially governing the distribution proportions across various quantile levels throughout the estimation process. Moreover, $\lambda$ serves as an adjustment parameter instrumental in refining the β estimation while nullifying individual influences (Damette and Delacote 2012). Equation function of the quantile for τ applied to the study variables examined in this paper.

$$Q_{yi}(\tau|\alpha_i, \varepsilon_t, X_{it}) = \alpha_i + \varepsilon_t + \beta_{1\tau} ln\, E\, NR_{it} + \beta_{2\tau} ln\, E\, TX_{it} + \beta_{3\tau} ln\, F\, DI_{it} + \beta_{4\tau} ln\, G\, DP_{it} + \beta_{5\tau} ln\, R\, E_{it} + \beta_{6\tau} ln\, E\, I_{it} + \beta_{7\tau} ln\, T\, RSPT_{it} + \beta_{8\tau} ln\, T\, R_{it} \quad (4)$$

The method established by (Koenker and Bassett 1978), modified by (Canay 2011), serves to address endogeneity originating from fixed time factors by using fixed-effect quantile regression (Koenker 2004). Quantile regressions facilitate parameter estimation using fixed effects, offering an added advantage by enabling heterogeneous changes in the probability of carbon dioxide while simultaneously varying alongside stochastic term. By decomposing the error term into fixed and random components, parameter estimation accounts for within-country variations. Contrary to conventional regressions that compute an individual parameter, QR enable the evaluation of $X_{it}$ impact on $CO2_{it}$ across the quantile τ distribution.

In equation 5, we incorporate GDP and its square, aligning with the Environmental Kuznets Curve (EKC) hypothesis. This hypothesis theorizes that economic growth at first escalates CO2 emissions, yet upon reaching a certain threshold, it transitions toward decrease CO2 emissions.

$$Q_{yi}(\tau \mid \alpha_i, \varepsilon_t, X_{it}) = \alpha_i + \varepsilon_t + \beta_{1\tau} \ln ENR_{it} + \beta_{2\tau} \ln ETX_{it} + \beta_{3\tau} \ln FDI_{it} + \beta_{4\tau} \ln GDP_{it} + \beta_{5\tau} \ln(GDP_{it})^2 + \beta_{6\tau} \ln RE_{it} + \beta_{7\tau} \ln EI_{it} + \beta_{8\tau} \ln TRSPT_{it} + \beta_{9\tau} \ln TR_{it} \quad (5)$$

Where CO2 is proxy for carbon emissions, ENR is energy use, ETX is environmental taxes, FDI is proxy by Foreign direct investment, GDP is the GDP per capita, RE is proxy for renewable energy consumption, EI is the Energy intensity, TRSPT is the transport and TR is the trade.
The variables description is given in table 1, the descriptive statistics is given in table 2 whereas the correlation is presented in table 3.

**Table.1.** Variables description

| Variables | Descriptions | Symbols | source |
|---|---|---|---|
| Carbon dioxide | CO2 emission per capita | CO2 | WDI |
| Energy consumption | Energy use per capita | ENR | WDI |
| Environmental taxes | Environmental taxes | ETX | Eurostat |
| Foreign direct investment | Foreign direct investment inflows | FDI | WDI |
| Economic growth | GDP per capita | GDP | WDI |
| Renewable energy consumption | Renewable energy consumption of total final energy consumption | RE | WDI |
| Energy intensity | Energy intensity level of primary energy | EI | WDI |
| Transport | Transport | TRSPT | WDI |
| Trade | Trade (% of GDP) | TR | WDI |

**Table 2.** Descriptive statistics

| Variable | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| CO2 | 1.942 | .41 | 1.074 | 3.243 |
| ENR | 8.062 | .382 | 7.282 | 9.152 |
| ETX | 8.15 | 1.546 | 4.648 | 11.021 |
| FDI | 22.718 | 1.821 | 11.671 | 27.322 |
| GDP | 10.53 | 1.363 | 7.972 | 15.415 |
| RE | 2.508 | .996 | -2.619 | 3.994 |
| EI | 1.345 | .329 | .278 | 2.239 |
| TRSPT | 1.621 | .682 | -.511 | 2.791 |
| TR | 4.666 | .461 | 3.816 | 5.94 |

**Table 3.** Pairwise correlations

| Variables | CO2 | ENR | ETX | FDI | GDP | RE | EI | TRSPT | TR |
|---|---|---|---|---|---|---|---|---|---|
| CO2 | 1.000 | | | | | | | | |
| ENR | 0.710 | 1.000 | | | | | | | |
| ETX | 0.124 | 0.331 | 1.000 | | | | | | |
| FDI | 0.252 | 0.362 | 0.584 | 1.000 | | | | | |
| GDP | 0.083 | 0.247 | 0.275 | 0.299 | 1.000 | | | | |
| RE | -0.364 | -0.041 | 0.119 | -0.216 | 0.093 | 1.000 | | | |
| EI | 0.123 | 0.267 | -0.223 | -0.217 | -0.133 | 0.111 | 1.000 | | |
| TRSPT | 0.046 | 0.239 | 0.487 | 0.463 | 0.447 | -0.145 | 0.004 | 1.000 | |
| TR | 0.283 | 0.164 | -0.539 | 0.010 | 0.136 | -0.373 | -0.144 | -0.112 | 1.000 |

## 4. Results and discussions

### Stationarity results

In this section, the results presented in Table 4, depicting the outcomes of panel unit root tests. Initially, the data's stationarity was examined through these tests, particularly utilizing the Pesaran augmented unit root tests augmented with cross-section dependence (CIPS & CADF). Addressing cross-panel dependencies, as emphasized by (Appiah, Li et al. 2021), holds critical importance as overlooking such dependencies can yield inefficient and inaccurate results. Employing (Pesaran 2004) cross-section dependence model (CD) was pivotal to rectify this concern. It's notable that identifying cross-section dependence in data series remains a challenge for traditional unit root tests due to limited power. To resolve this problem, (Pesaran 2007) introduced the Pesaran CIPS and CADF unit root tests, allowing for the acknowledgment of cross-section dependence, unlike traditional tests that assume independence between cross-sections.

**Table 4.** Unit root tests

| | CIPS | | CADF | |
|---|---|---|---|---|
| | I(0) | I(1) | I(0) | I(1) |
| CO2 | -1.982 | -4.297*** | -1.664 | -3.401*** |
| ENR | -1.042 | -3.956*** | -0.874 | -2.694*** |
| ETX | -2.243** | -3.986*** | -1.950 | -2.550*** |
| FDI | -3.590*** | -5.488*** | -2.580*** | -3.493*** |
| GDP | -1.800 | -3.143*** | -1.923 | -2.429*** |
| RE | -2.443*** | -4.196*** | -2.433*** | -3.229*** |
| EI | -2.456*** | -4.474*** | -2.156*** | -3.178*** |
| TRSPT | -1.371 | -3.853*** | -1.617 | -3.092*** |
| TR | -1.696 | -2.858*** | -1.937 | -2.352*** |

Note: significance level, ***, **,1%, 5%

### Cointegration test

Following the assessment of stationarity properties, the subsequent step involves analyzing the cointegration relationships among the variables using panel cointegration tests. Post the stationarity evaluation, examining the long-term relationships amid variables becomes crucial through cointegration tests. Table 5 presents the utilization of the Pedroni cointegration to explore the long-run association among environmental taxes, energy utilization, FDI, GDP, renewable energy, energy intensity, transport, trade, and CO2 emissions. Given the variances in error structures and dynamics across panels. (Pedroni 1999, Pedroni 2004) established cointegration test for scrutinizing the existence of a long-run association among these variables. Predicated upon the aspects of heterogeneity and homogeneity, (Pedroni 1999, Pedroni 2004) established seven cointegration statistics for non-stationarity and no cointegration for checking the null hypothesis testing. An equation is involved in the Granger cointegration test applying to N countries, m explanatory variables, and T measurements delineating the cointegration test's framework. The test for cointegration is presented below:

$$Y_{it} = \alpha_i + \sigma_{it} + \Sigma_{j=1}^{m} \beta_{j,i} X_{j,it} + \varepsilon_{it}$$

The variables $Y_{it}$ and $X_{j,it}$ are perceived as being integrated at first-order stages, denoted as I(1). Pedroni categorized seven test statistics into two classes. Various scholars have widely adopted the Pedroni

cointegration to verify the relationship between CO2 and their impacts across different environmental contexts (Ito 2017, Zoundi 2017, Azevedo, Sartori et al. 2018).

The findings of Pedroni cointegration rejects the null hypothesis which is no cointegration among panels and accepting long run cointegration. This demonstrates that the model variables are cointegrated.

**Table 5.** Pedroni cointegration

| | | | |
|---|---|---|---|
| Ho: No cointegration | Number of | panels | = 25 |
| Ha: All panels are cointegrated | Number of | periods | = 19 |
| Cointegrating vector: Panel specific | | | |
| Panel means: Included | Kernel: | Bartlett | |
| Time trend: Included | Lags: | 1.00 (Newey-West) | |
| AR parameter: Panel specific | Augmented | lags: | 1 |
| | Statistic | p-value | |
| Modified Phillips-Perron t | 6.3771 | 0.0000 | |
| Phillips-Perron t | -6.1629 | 0.0000 | |
| Augmented Dickey-Fuller t | -7.9587 | 0.0000 | |

Table 6 present the results of panel quantile regression. In percentiles (5th, 10th, 20th to 90th, and 95th) in the distribution of each dependent variable, the outcomes reveal a notably significant and positive coefficient associated with energy usage across quantiles ranging from the 5th, 10th percentile to the 90th percentile and 95th at 1% level of significance revealing that use of energy increases CO2 emissions. Increase in CO2 emissions can be due to the developmental stage of industries of the economies. The industrial sector heavily relies on conventional energy sources. These countries should focus on using renewable energy sources by allocating resources to research and development (R&D) for renewables (Usman and Hammar 2021). These results are similar with (Yang, Jahanger et al. 2020, Yang, Jahanger et al. 2021, Yeboah, Feng et al. 2026). In analyzing the effect of environmental taxes on CO2, a noteworthy revelation emerges. The association between these variables unveils a negative non-significant across quantiles ranging starting from the 5th-95th percentile. These outcomes are similar to the outcomes of (Wolde-Rufael and Mulat-Weldemeskel 2021). In recent scholarly studies, it has been observed that the implementation of environmental taxes demonstrates a noteworthy reduction in carbon emissions (Hao, Umar et al. 2021, Doğan, Chu et al. 2022, Xie and Jamaani 2022, He, Zhang et al. 2023). FDI coefficient is insignificant negative in all quantiles thus pollution haven hypothesis in the European union is not valid. The European union countries focused on cleaner environment thus by implementing strict laws related to the environment. The negative impact is may due to the usage of renewable sources instead of non-renewable sources. Similarly, (Atici 2012) study revealed effect of FDI on carbon emissions. Spanning from quantile 5th and 10th to the 80th, the coefficient denoting economic growth exhibits both significance and a positive relation with carbon emissions. In higher quantile $90^{th}$ and $95^{th}$ it is positive but non-significant. In the beginning phase of development countries tends to concentrate on heavy production projects by using traditional fuels thus emitting more emissions by neglecting its influence on the environment. Furthermore, from quantile $20^{th}$ to $60^{th}$ the effect is very high. This can be the reason of high standards of living in high income economies. People tend to consume more in developed economies from economic growth. These positive significant results are similar with (Aziz, Sharif et al. 2021, Ben Abd Alah and

Ojekemi 2025) and insignificant results are similar with (Acheampong 2018, Gorus and Aydin 2019). The use of renewable energy consumption (REC) shows adverse effects on carbon emissions, thereby contributing to the mitigation of carbon emissions. The results show that the diminishing function of REC has vital role in decreasing the intensity of energy by improving the quality of the environment. These findings align with the outcomes presented by (Shen, Zhou et al. 2018, Liu, Islam et al. 2020, Gao and Fan 2023, Leitão 2025). Energy intensity positive and significant from lower quantiles 5$^{th}$, 10$^{th}$ to 80$^{th}$ quantile whereas it is positive and insignificant in higher quantiles. As the demand for energy increases, production of energy takes place. Production of energy is directly connected to environmental problems. Energy intensity impact is high from quantile 20$^{th}$ to 60$^{th}$. The reason can be due to the conventional methods of energy production. The positive results are similar with (Lin, Omoju et al. 2016, Nwani, Usman et al. 2023) whereas (Danish, Ulucak et al. 2020) found adverse influence of energy intensity on carbon emissions. The impact of transport is negative and statistically insignificant across the 5th to 80th quantiles while shifting to a positive association in the higher quantiles at 90th and 95th. Trade is positive and non significant in all quantiles.

**Table 6.** Results of Panel Quantile Regression

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| VARIABLES | OLS% | 5% | 10% | 20% | 30% | 40% |
| ENR | 0.819*** | 0.675*** | 0.682*** | 0.694*** | 0.701*** | 0.708*** |
| | (0.039) | (0.155) | (0.133) | (0.099) | (0.082) | (0.068) |
| ETX | -0.036** | -0.091* | -0.081* | -0.065 | -0.056 | -0.047 |
| | (0.017) | (0.066) | (0.056) | (0.042) | (0.035) | (0.029) |
| FDI | -0.023** | -0.002 | -0.002 | -0.002 | -0.002 | -0.002 |
| | (0.009) | (0.008) | (0.007) | (0.005) | (0.004) | (0.003) |
| GDP | -0.006 | 0.184** | 0.172** | 0.153*** | 0.142*** | 0.131*** |
| | (0.009) | (0.091) | (0.077) | (0.058) | (0.048) | (0.040) |
| RE | -0.221*** | -0.113*** | -0.116*** | -0.120*** | -0.122*** | -0.124*** |
| | (0.016) | (0.036) | (0.031) | (0.023) | (0.019) | (0.016) |
| EI | -0.210*** | 0.381** | 0.357** | 0.319*** | 0.298*** | 0.276*** |
| | (0.048) | (0.190) | (0.162) | (0.121) | (0.101) | (0.084) |
| TRSPT | -0.033 | -0.055 | -0.049 | -0.038 | -0.033 | -0.027 |
| | (0.021) | (0.062) | (0.053) | (0.040) | (0.033) | (0.027) |
| TR | -0.034 | 0.063 | 0.062 | 0.059 | 0.057 | 0.056 |
| | (0.044) | (0.115) | (0.098) | (0.073) | (0.060) | (0.050) |
| Constant | -2.698*** | | | | | |
| | (0.298) | | | | | |
| Observations | 500 | 500 | 500 | 500 | 500 | 500 |
| R-squared | 0.689 | | | | | |

Note: Significance level, * p<0.1** p<0.05, *** p<0.01

*Table 6 Continue . . . . . .*

| (7) | (8) | (9) | (10) | (11) | (12) |
|---|---|---|---|---|---|
| 50% | 60% | 70% | 80% | 90% | 95% |
| 0.715*** | 0.722*** | 0.727*** | 0.733*** | 0.740*** | 0.747*** |
| (0.060) | (0.062) | (0.068) | (0.080) | (0.097) | (0.115) |
| -0.037 | -0.028 | -0.021 | -0.013 | -0.004 | 0.004 |
| (0.026) | (0.026) | (0.029) | (0.034) | (0.041) | (0.048) |
| -0.002 | -0.001 | -0.001 | -0.001 | -0.001 | -0.001 |
| (0.003) | (0.003) | (0.003) | (0.004) | (0.005) | (0.006) |
| 0.119*** | 0.108*** | 0.099** | 0.090* | 0.079 | 0.069 |
| (0.035) | (0.036) | (0.040) | (0.047) | (0.056) | (0.067) |
| -0.127*** | -0.129*** | -0.131*** | -0.133*** | -0.135*** | -0.137*** |
| (0.014) | (0.014) | (0.016) | (0.019) | (0.022) | (0.027) |
| 0.251*** | 0.230*** | 0.213** | 0.194** | 0.172 | 0.152 |
| (0.074) | (0.076) | (0.084) | (0.098) | (0.119) | (0.140) |
| -0.020 | -0.014 | -0.010 | -0.005 | 0.000 | 0.006 |
| (0.024) | (0.025) | (0.027) | (0.032) | (0.039) | (0.046) |
| 0.054 | 0.053 | 0.051 | 0.050 | 0.048 | 0.047 |
| (0.044) | (0.046) | (0.050) | (0.059) | (0.071) | (0.084) |
| 500 | 500 | 500 | 500 | 500 | 500 |

Note: Significance level, * p<0.1** p<0.05, *** p<0.01

In Table 7, the findings reveal that energy consumption increases environmental degradation in the European Union. In all quantiles, the findings demonstrate positively significant relationship amid carbon emissions and energy consumption. These results affirm the finding of (Yang, Jahanger et al. 2021). The environmental taxes coefficient exhibits a significant and negative significance from the 5th quantile to the 90th, with a particularly pronounced influence on carbon emissions observed from the 5th to the 70th quantile. The decreasing effect can be noticed in quantile $80^{th}$ and $90^{th}$ whereas non significant in quantile $95^{th}$. This might be due to the environmental taxes are high and implemented in the developed countries whereas the reducing effect in high quantiles in the developing is due to the lower environmental taxes and implementation. These results confirm the outcomes of (Hao, Umar et al. 2021, Doğan, Chu et al. 2022, Özmen and Mutascu 2025). From the 5th quantile to the 8th, the impact of FDI on environmental degradation is both positive and statistically insignificant, whereas non significant negative from $70^{th}$ quantile to $95^{th}$. The possible reason may be in the beginning, FDI is not regulated well due to which the result is positive whereas after sometime government regulates FDI and its impact is negative on environmental degradation. The positive non significant results are similar with (Bildirici 2022, Bilalli, Shahini Gollopeni et al. 2024) and the negative non significant results are similar with (Albulescu, Tiwari et al. 2019). The correlation between economic growth and its significance is notably positive across all quantiles, demonstrating a high level of statistical significance. EKC is strongly valid across all quantiles in the European Union. Result shows that European Union is using renewable energy instead of nonrenewable sources. Furthermore, result demonstrates that European Union has given priority to its environment rather than development. As these countries already crossed the developmental stages thus giving priority to their environment. These outcomes are similar with the findings of (Ike, Usman et al. 2020, Nwani, Usman et al. 2023, Özmen and Mutascu 2025).

**Table. 7.** Results of Panel Quantile Regression

| VARIABLES | (1) OLS% | (2) 5% | (3) 10% | (4) 20% | (5) 30% | (6) 40% |
|---|---|---|---|---|---|---|
| ENR | 0.690*** | 0.591*** | 0.604*** | 0.622*** | 0.631*** | 0.642*** |
| | (0.042) | (0.141) | (0.117) | (0.086) | (0.073) | (0.061) |
| ETX | -0.056*** | -0.168** | -0.156*** | -0.139*** | -0.130*** | -0.120*** |
| | (0.017) | (0.067) | (0.055) | (0.041) | (0.034) | (0.029) |
| FDI | -0.017** | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 |
| | (0.008) | (0.008) | (0.006) | (0.005) | (0.004) | (0.003) |
| GDP | 0.799*** | 0.950*** | 0.918*** | 0.876*** | 0.855*** | 0.829*** |
| | (0.120) | (0.217) | (0.179) | (0.132) | (0.112) | (0.093) |
| $GDP^2$ | -0.034*** | -0.031*** | -0.031*** | -0.030*** | -0.030*** | -0.029*** |
| | (0.005) | (0.008) | (0.006) | (0.005) | (0.004) | (0.003) |
| RE | -0.227*** | -0.095*** | -0.096*** | -0.098*** | -0.099*** | -0.101*** |
| | (0.015) | (0.032) | (0.026) | (0.019) | (0.016) | (0.014) |
| EI | -0.073 | 0.500*** | 0.468*** | 0.425*** | 0.404*** | 0.378*** |
| | (0.051) | (0.164) | (0.135) | (0.099) | (0.084) | (0.070) |
| TRSPT | -0.035* | -0.021 | -0.019 | -0.015 | -0.013 | -0.011 |
| | (0.021) | (0.051) | (0.042) | (0.031) | (0.026) | (0.022) |
| TR | -0.023 | 0.066 | 0.066 | 0.067 | 0.067 | 0.067 |
| | (0.043) | (0.104) | (0.086) | (0.063) | (0.054) | (0.045) |
| Constant | -6.437*** | | | | | |
| | (0.624) | | | | | |
| Observations | 498 | 498 | 498 | 498 | 498 | 498 |
| R-squared | 0.714 | | | | | |

Note: * p<0.1** p<0.05, *** p<0.01

*Table 7 Continue . . . . . .*

| VARIABLES | (7) 50% | (8) 60% | (9) 70% | (10) 80% | (11) 90% | (12) 95% |
|---|---|---|---|---|---|---|
| ENR | 0.651*** | 0.660*** | 0.672*** | 0.681*** | 0.690*** | 0.703*** |
| | (0.055) | (0.056) | (0.065) | (0.076) | (0.091) | (0.112) |
| ETX | -0.111*** | -0.103*** | -0.092*** | -0.083** | -0.074* | -0.063 |
| | (0.026) | (0.027) | (0.031) | (0.036) | (0.043) | (0.053) |
| FDI | 0.000 | 0.000 | -0.000 | -0.000 | -0.000 | -0.000 |
| | (0.003) | (0.003) | (0.003) | (0.004) | (0.005) | (0.006) |
| GDP | 0.808*** | 0.786*** | 0.759*** | 0.738*** | 0.716*** | 0.687*** |
| | (0.085) | (0.087) | (0.101) | (0.118) | (0.140) | (0.172) |
| $GDP^2$ | -0.029*** | -0.029*** | -0.028*** | -0.028*** | -0.027*** | -0.027*** |
| | (0.003) | (0.003) | (0.003) | (0.004) | (0.005) | (0.006) |
| RE | -0.102*** | -0.102*** | -0.104*** | -0.105*** | -0.106*** | -0.107*** |
| | (0.012) | (0.013) | (0.015) | (0.017) | (0.021) | (0.025) |
| EI | 0.356*** | 0.334*** | 0.307*** | 0.286*** | 0.263** | 0.234* |
| | (0.064) | (0.065) | (0.076) | (0.088) | (0.105) | (0.130) |
| TRSPT | -0.009 | -0.007 | -0.005 | -0.003 | -0.001 | 0.000 |
| | (0.020) | (0.020) | (0.024) | (0.028) | (0.033) | (0.041) |
| TR | 0.068* | 0.068 | 0.068 | 0.068 | 0.069 | 0.069 |
| | (0.041) | (0.041) | (0.048) | (0.056) | (0.067) | (0.083) |
| Constant | | | | | | |
| Observations | 498 | 498 | 498 | 498 | 498 | 498 |
| R-squared | | | | | | |

Note: * p<0.1** p<0.05, *** p<0.01

Across all quantiles, the significance of renewable energy is notably high. The findings illustrate a prevalent utilization of renewable energy sources within the EU countries. These results are in line with (Sinha and Shahbaz 2018). In all quantiles, a positive relationship between energy intensity and CO2, indicating a consistent influence across all quantiles. Result demonstrates that energy production through fossil fuels increases environmental degradation. These results are in line with (Dogan, Ulucak et al. 2020). Transport is negative non significant across all quantiles whereas trade is significant across all quantiles except median.

## 5. Conclusion and policy recommendations

This research delves into the influence of environmental taxes, renewable energy consumption, economic growth, energy efficiency, transportation, and international trade on CO2 within 26 EU nations spanning the years 2000 to 2024. The analytical approach incorporates unit root tests, cointegration, and panel quantile regression methods. The results indicate a substantial decrease in CO2 through implementation of environmental taxes, particularly evident in the first quantile. Foreign direct investment and the use of renewable energy contribute to emission reduction, while increased economic growth and energy consumption are associated with higher carbon dioxide emissions. Additionally, statistically significant negative coefficient of the squared of economic growth supports the validness of the environmental Kuznets curve in EU countries. The determinants of CO2 are acknowledged complicated and diverse. Nevertheless, in the context of this discourse, our focus narrows to environmental taxes, renewable energy, and energy intensity, considering the variables of foreign direct investment and economic growth. Our analysis incorporates three distinct environmental tax proxies, each exerting a unique influence on the level of CO2 emitted within specific quantiles. The utilization of renewable energy emerges as a facilitator in curtailing CO2 within the member nations of the EU. Moreover, our findings highlight economic growth as the main determinant influencing the total CO2 output in the sampled nations. Notably, insights from the squared term of economic growth reveal a decline in emissions after reaching a specific threshold in these countries. The integration of alternative energy sources remains pivotal for the principal objective of reducing CO2 emissions.

In EU nations context, a shift from conventional economic growth to a sustainable green trajectory necessitates a strategic emphasis on the usage of renewable energy. Sole reliance on environmental taxes proves insufficient for achieving carbon neutrality, underscoring the imperative of prioritizing and promoting renewable energy sources. Consequently, the transition to green growth, facilitated by the increased utilization of renewable energy arises as a pivotal approach in emission reduction in EU nations. While environmental taxes may exhibit efficacy, their effectiveness amplifies when coupled with heightened adoption of renewable energy and the pursuit of green growth. Acknowledging the limitations of environmental taxes alone, attention should be directed comprehensively towards the widespread integration of renewable energy consumption and technological advancements in energy within the sampled countries. The study's revelations further underscore the advantageous impact of supporting renewable energy initiatives and green projects in mitigating environmental degradation. The scope of this present analysis confines itself to the sampled countries, chosen for their environmentally conscious practices and commitment to attaining carbon neutrality. However, the applicability of such a study extends beyond these specific nations, warranting future research endeavors encompassing diverse countries with unique characteristics. Additionally, the exclusion of certain governance metrics in the current study prompts consideration for their inclusion in subsequent investigations, offering avenues for a more comprehensive understanding of these factors.

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