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# THE RELATIONSHIP BETWEEN INDUSTRIAL PRODUCTION AND GREEN GROWTH OF OECD COUNTRIES

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***Abstract***

*Industrial advancement is the key pillar of countries' economic development. In addition to this, sound industrial policies are equally important for countries' industrialization, and paramount to these policies is their alignment with the principles of sustainable development, particularly in promoting a transition towards a green economy. Central to this transition is the simultaneous pursuit of enhancing human well-being and fostering economic growth while mitigating environmental risks. Accordingly, the main purpose of this study is to make an empirical analysis on the relationship between industrial activity with the green growth factor, namely production-based CO2 emissions. The study includes OECD countries for the period 1990-2021. To examine the relationship between industry and an environmental and resource productivity variable, the panel regression models are employed. The results reveal that there is a significant positive relationship between value added in industry and production-based CO2 emissions. Therefore, policy interventions should aim to dissociate industrial growth from carbon emissions through targeted measures such as technological innovation, resource efficiency, and regulatory frameworks promoting cleaner production practices. These findings highlight the urgency for governments to integrate sustainability considerations into their industrial policies to foster green growth and ensure a resilient and environmentally sustainable future.*

***Keywords:*** *industry; green growth; environmental sustainability; panel regression; OECD*
***JEL Codes:*** *L60, Q50, C33*

## Introduction

Industrial production involves the large-scale transformation of raw materials into finished goods, driving economic growth and technological advancement (Krugman, 2009; Rodrik, 2008; Rodrik, 2011; Gordon, 2016). However, the traditional industrial production model has been closely linked to environmental degradation, characterized by heavy reliance on fossil fuels, high energy consumption, and the generation of pollutants.

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Historically, the industrialization process primarily prioritized profit maximization within a so-called competitive market environment, largely neglecting environmental concerns (Moore, 2017). This attitude particularly prevailed in developing countries, often prioritizing profit maximization without due consideration for the environment and well-being of the population. Many countries have pursued production expansion without adequate attention to environmental sensitivity, driven by the fear of falling behind in competitiveness.

Although the Industrial Revolution brought positive changes to the industrialized world, it undeniably negatively impacted the environment. Reduction of natural resources, carbon emissions, pollution, and associated human health problems resulting directly from industrial achievements have had devastating consequences. The impacts of global warming are already an undeniable reality confronting humanity every day, resulting in escalating worldwide environmental concerns (Manzurova and Pashova, 2019).

Thus, industrial practices must undergo a transformation towards more environmentally sustainable approaches. This shift emphasizes promoting sustainable development and embracing the concept of "green growth" rather than prioritizing profit maximization at any cost.

The idea of green growth represents a paradigm shift, seeking to harmonize industrial productivity with sustainability. It advocates for the development and adoption of eco-friendly technologies, the utilization of renewable energy sources, and efficient resource management to foster economic growth while minimizing environmental impact. Implementing this new industrial revolution requires the adoption of green growth policies that not only stimulate economic growth and development but also ensure that natural assets continue to provide the resources and environmental services crucial for our well-being (OECD, 2014). Therefore, the aim of this study is to empirically estimate the relationship between industrial value added and production-based CO2 emissions for OECD countries, because these countries typically have advanced industrial sectors that are major contributors to CO2 emissions.

## Literature Review

As the process of industrialization evidently affected the environment and threatened sustainable development and green growth in the global framework, there was a large and diverse body of literature which assesses the link between economic growth and environmental pollution. This relationship is regarded as one of the most significant empirical connections in environmental economics. Numerous studies have explored the interplay between various development indicators and environmental metrics, employing diverse methodologies and focusing on different regions. Many of these studies examine the Environmental Kuznets Curve (EKC) hypothesis, which posits that during a country's development, environmental quality initially worsens with rising per-capita income up to a certain point, after which it improves as income continues to increase. This relationship between economic growth and environmental degradation is graphically represented as an "inverted U-shaped" curve. The phenomenon was first noted by Kuznets (1955), who proposed an inverted U-shaped relationship between economic growth and income inequality.

The critical validation of the Environmental Kuznets Curve (EKC) hypothesis was provided by Grossman and Krueger (1991). Their analysis of the relationship between various environmental indicators and a country's per capita income revealed a similar inverted U-shaped correlation between economic growth and environmental degradation.

Following the influential paper by Grossman and Krueger (1991), many researchers have tested the Environmental Kuznets curve hypothesis using different model specifications, time span, explanatory variables in various countries or regions. One of these studies prepared by Dasgupta et al. (1995), developed environmental policy and performance indices for a group of 31 countries. Employing cross-country regressions, they find a very strong and continuous association between these indices and per capita income. Further study analysis made by Hettige et al. (1998) uses panel data for the period of 1975-1994 to investigate the relationship between industrial pollution and economic development within the Kuznets curve framework. They find that manufacturing share follows a Kuznets-type curve.

Dinda and Coondo (2006) examine the nature of causality between per capita CO2 emission and per capita GDP using unit root tests, cointegration and error correction model for a cross country annual panel data set covering 88 countries for the period of 1960-1990. They show the existence of a cointegrating vector between the variables of interest. The same year, Yörük and Zaim (2006) investigate the relationship between environmental efficiency and income by constructing an environmental efficiency index for OECD countries and establishing an environmental Kuznets curve. Their results support the evidence of a positive relationship.

On the other hand, Bacon and Bhattacharya (2007) analysed many countries' CO2 emissions for 1994-2004. They conclude that emissions per capita are positively but only moderately correlated with GDP per capita. Their findings fail to support the existence of Kuznets Curve phenomenon.

Investigating the relationship between industrial value-added and CO2 emissions for developing and developed countries, Çelik and Deniz (2009) concluded that both developing and developed countries have higher levels of CO2 emissions as their industry value-added increases. However, the coefficient's magnitude for developed countries is notably lower compared to that of developing countries. This suggests that the rate of causing air pollution in developed countries is presumably lower than in developing countries. Their empirical analysis further indicates that developed countries tend to exercise relatively more caution in terms of environmental protection compared to developing countries.

Alam and Kabir (2013) observed that economic growth contributes to environmental sustainability by reducing carbon emissions. Similarly, Shahbaz et al. (2013) identified economic growth as the main driver of CO2 emissions and suggested reducing emissions even at the cost of economic growth by investing in environmentally friendly technologies. Chang and Hao (2017) confirmed a positive interaction between environmental performance and economic growth in both OECD and non-OECD countries. However, they noted that increased output and consumption come with environmental costs, including higher consumption of non-renewable resources and increased pollution. Ardakani and Seyedaliakbar (2019) and Xie and Liu (2019) supported this view, asserting that economic growth below a certain threshold can lead to higher carbon emissions, while growth beyond this point improves the environmental quality. Wang et al. (2019) found that investment and economic growth together enhance the environmental quality, advocating for emission reduction policies that focus on efficient energy use, clean technology investments, and improved labor standards to control emissions.

The impact of economic growth on environmental degradation was also analyzed in relation to the development level of countries. De Angelis et al. (2019) determined that developing countries have high pollution rates, while developed countries are the main contributors to CO2 emissions, though their emissions are decreasing.

In response to environmental degradation, developed nations such as the US and Western European countries have implemented policies falling under the "scale effect" to reduce carbon emissions. This is primarily achieved through investments in technological innovation, addressing capital consumption, and enforcing policies aimed at simultaneously enhancing economic growth and environmental protection (Paramati et al., 2017). In Eastern Europe, however, CO2 emissions continue to rise unabated, as the nation's focus is oriented towards promoting tourism for the purpose of employment generation, income, and economic development, without due consideration for environmental consequences (Paramati et al., 2017).

Many scholars' further analyses show that excessive energy consumption negatively impacts green growth, whereas the utilization of renewable energy enhances it. This underscores that while high energy consumption poses challenges to green growth, the prevalence of renewable energy in the energy mix, fosters positive contributions to both green growth and environmental sustainability. Examining the factors that influence green growth across 123 developing and developed countries recorded in the OECD database from 2000 to 2017, Aye and Edoja (2017) discovered that economic growth negatively impacts carbon emissions in the developing nations. The study's outcomes indicate that robust economic development fosters sustainable growth and economic prosperity, aligning with the notion that countries with a high GDP per capita possess sufficient resources to support initiatives for green growth. This underscores the importance of adopting economic development policies geared towards increasing GDP, as it emerges as a crucial determinant for achieving both green growth and sustainability objectives. In a similar vein, Tawiah et al. (2021) conducted an analysis focused on achieving environmental sustainability alongside economic growth and development by 2030. They utilized data from 123 developed and developing nations to investigate the determinants of green growth. Their findings revealed variations in the impact of these determinants between developed and developing countries. This suggests that nations at different stages of development will need tailored strategies to attain the Sustainable Development Goals by 2030. Moreover, in the study undertaken by Waheed et al. (2019), an exhaustive examination was conducted concerning the correlation between economic growth, intertwined with energy consumption, and carbon emissions, both at the individual country level and across regions and multiple countries. Specifically, they scrutinized 24 studies focusing on single countries and 21 multi-country articles investigating the link between economic growth and carbon emissions from 2007 to 2019. The results of this survey revealed that the majority of studies supported a unidirectional relationship from economic growth to carbon emissions.

In a separate review, Mardani et al. (2019) examined 175 articles focusing on the correlation between economic growth and CO2 emissions from 1995 to 2017. Their observation of a bidirectional relationship between economic growth and CO2 emissions led to the acknowledgment that economic growth might also face adverse effects in the process but with limited level of statistical significance to confirm it. They proposed the reduction of carbon emissions by implementing constraints on economic growth. Over the years, numerous scholars have pointed out diverse factors influencing environmental degradation, including economic growth, globalization, renewable energy consumption, fossil fuel use, financial development, energy utilization, and foreign direct investment (Adebayo and Odugbesan 2021a; Bekun et al., 2021a; Kihombo et al., 2021).

Particularly noteworthy is the extensive discourse surrounding the swift development of renewable energy and its impact on environmental quality and economic growth (Bekun et al., 2021b; Adebayo and Kirikkaleli, 2021; Tawiah et al. 2021; Udemba et al., 2020).

Regarding climate change, the utilization of renewable energy sources is believed to significantly contribute to environmental sustainability by mitigating the levels of greenhouse gas emissions (Solarin et al., 2017; Kirikkaleli and Adebayo, 2020; Yuping et al., 2021). Consequently, by endorsing the use of sustainable energy, nations can enhance environmental sustainability and contribute to the establishment of a globally sustainable and cleaner environment.

Aiming to determine the contribution of innovation and financial development to Green growth in BRICS-T countries, Arzova and Şahin, (2023) conducted panel data analysis spanning from 2001 to 2019. The empirical findings reveal that the growth of national income and foreign direct investments positively contribute to green growth while personnel expenditure negatively impacted the green growth.

## Methodology and Data

The methodology of this study consists of panel regression analysis that investigate the relationship between industrial production and production-based CO2 emissions, with a focus on understanding their implications for green growth. The methodology encompasses three distinct regression techniques: pooled, fixed effects, and random effects models. Initially, pooled ordinary least squares (OLS) regression is utilized to estimate the general association between industrial production and CO2 emissions across OECD countries, assuming a common regression coefficient and intercept. Subsequently, fixed effects regression is employed to account for time-invariant unobserved heterogeneity at the country level by incorporating country-specific intercepts, thus controlling for potential confounding factors that remain constant over time. Additionally, random effects regression is applied to address both time-invariant and time-varying unobserved heterogeneity across countries, treating country-specific effects as random variables with a specific distribution. The general form of the panel regression equation can be expressed as follows:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \alpha_i + \varepsilon_{it}$$

Where $Y_{it}$ represents the dependent variable (production-based CO2 emissions) for country *i* at time *t*. $X_{it}$ is the independent variable of interest (industry value added index) for country *i* at time *t*. $\alpha_i$ represent the country-specific fixed effects. $\beta_1$ is the coefficient of interest, representing the marginal effects of $X_{it}$ on $Y_{it}$. $\varepsilon_{it}$ is the error term, representing unobserved factors affecting the dependent variable. Also, socio-economic, and policy-related indicators are included in the model, as control variables. These control variables encompass factors such as: environmental tax to capture the policy framework imposed by the governments; renewable energy supply (% of total energy supply), development of environment related technologies, real GDP index, inflation and population aiming to account for potential confounding factors that may influence the relationship between industrial activity and environmental outcomes. By incorporating these control variables, the analysis seeks to provide a more comprehensive understanding of the dynamics between industrial development, environmental sustainability, and economic green growth within the context of OECD countries. Thus, the specified regression model is of the following form:

$$CO2EMS_{it} = \beta_0 + \beta_1 IND_{it} + \beta_2 RGDP_{it} + \beta_3 INF_{it} + \beta_4 ENVTAX_{it} + \beta_5 RENENERG + \beta_6 ENVTECH_{it} + \beta_7 POP_{it} + \alpha_i + \varepsilon_{it}$$

The dependent variable production-based CO2 emission is used as a proxy of green growth, as it is so classified by the OECD database of green growth indicators. It is under the environmental and resource productivity indicators that indicate whether economic growth is becoming greener (OECD, 2023). By using production-based CO2 emissions as a proxy for green growth, the analysis becomes directly relevant to policy discussions and evaluations in the context of environmental sustainability. Advocating investment in research, development and deployment of clean and green infrastructure is of particular importance for countries, for this reason as potential determinants to green growth are considered the development of environment related technologies and renewable energy supply.

**The data**

The study utilizes annual data spanning the period from 1990 to 2021, sourced from the OECD's Green Growth Indicators Database. This dataset encompasses information pertaining to 38 member countries of the Organisation for Economic Co-operation and Development (OECD). Table 1 provides descriptions of variables used in the regression analysis which definitions are based on the database documentation of OECD green growth indicators.

*Table no. 1 - Variables' description*

| Variables | Indicator | Proxy indicator |
|---|---|---|
| **IND** | Percentage of total value added contributed by the industry sector. This includes value added from mining, manufacturing, construction, and utilities such as electricity, water, and gas. | Economic development |
| **RGDP** | Real GDP, index 2000=100 | |
| **INF** | GDP deflator. The GDP deflator is expressed as an index 2015=100 | |

| | | |
|---|---|---|
| **CO2EMS** | Production-based CO2 emissions are expressed as an index with values in 2000 normalised to equal 100. | Environmental and resource productivity |
| **ENVTAX** | Environmentally related tax revenue, % total tax revenue | Environmental policy |
| **RENENERG** | Percentage of total energy provided by renewable sources. This includes energy from hydroelectric, geothermal, solar (both thermal and photovoltaic), wind, and marine (tide, wave, ocean) sources, along with combustible renewables like solid and liquid biomass, biogas, and renewable municipal waste. | Environmental and resource productivity |
| **ENVTECH** | Environment related technologies, % all technologies | Technology and Innovation |
| **POP** | Population growth rate | Population |

*Source:* Author's calculations

Table 2 provides descriptive statistics of used variables in the regression model summarizing key statistics such as mean, standard deviation and the minimum and maximum values. This helps to have a clear picture on the characteristics, average trends and variability of the data used in the regression models. For instance, it can be observed a relatively low standard deviation in population growth rate, that indicates similar population growth rates across countries, conversely a high standard deviation in real GDP index, production-based CO2 emissions, implies that they varied considerably across countries. Based on the number of observations it can be clearly noticed that the panel is unbalanced, merely it was used the moving average method (with factor 2) to fill in those missing observations.

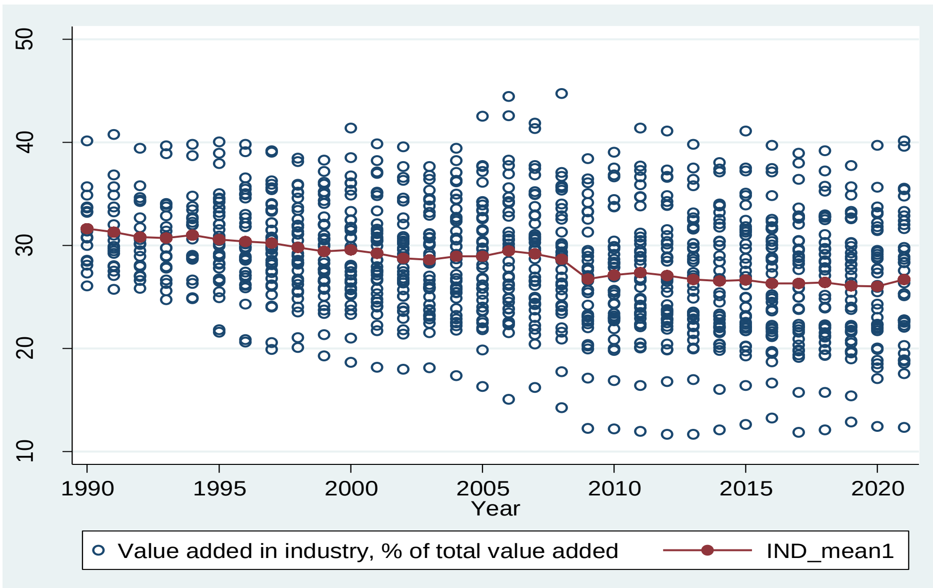
*Table no. 2 - Descriptive Statistics*

| **Variable** | **Observations** | **Mean** | **St.Deviation** | **Min** | **Max** |
|---|---|---|---|---|---|
| IND | 1101 | 28.30867 | 5.666455 | 11.64 | 44.77 |
| RGDP | 1209 | 117.5357 | 34.65298 | 50.26 | 279.53 |
| INF | 1204 | 80.35531 | 25.67203 | 0.07 | 235.62 |
| CO2EMS | 1216 | 101.9925 | 23.62515 | 48.61 | 335.42 |
| ENVTAX | 1105 | 1.248908 | 3.5731 | 0.254 | 3.2811 |
| RENENERG | 1216 | 16.13017 | 16.33436 | 0.28 | 89.75 |
| ENVTECH | 1139 | 9.871624 | 5.078904 | 0 | 50 |
| POP | 1216 | -0.436 | 0.8804 | -3.5805 | 1.0926 |

*Source:* Author's calculations

Figure 1 below displays the mean of value added in industry (% of total value added) over years of OECD countries. Each point in the graph represents the average of value added in industry across OECD countries in the panel for each year. In this case one can observe a slightly decreasing trend in the means of value added in industry, over years.

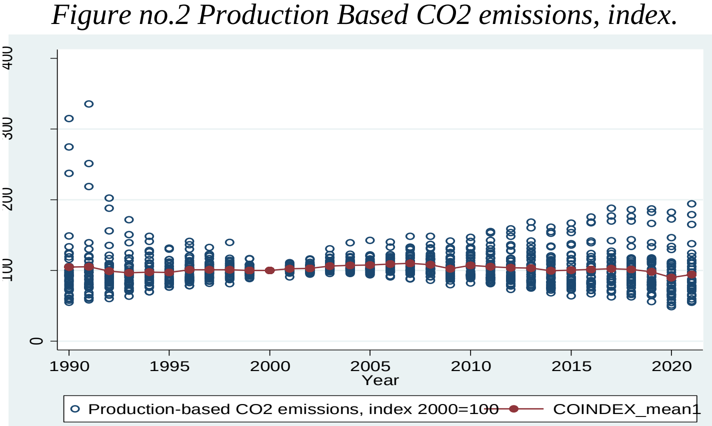
*Figure no. 1 Value added in industry (% of total value added) of OECD countries.*




*Source:* Author's calculations

Figure 2 presents the mean of production-based $CO_2$ emissions for detecting any heterogeneity across years, thus one can conclude that the means of this variable do not deviate significantly from the overall trend; however, a decline in the last few years can be observed.

*Figure no.2 Production Based $CO_2$ emissions, index.*




*Source:* Author's calculations

**Empirical Findings**

The regression results reveal that industry value added is associated with a significant increase in production-based $CO_2$ emissions and this relationship is statistically significant under the three regression techniques i.e. Pooled OLS, Random and Fixed effects (these results are in line with the findings of Çelik and Deniz, 2009). While Pooled OLS suggests no significant relationship between environmental tax and $CO_2$ emissions, both Fixed Effects and Random Effects models show a significant negative relationship. This indicates that higher environmental taxes are associated with lower $CO_2$ emissions when accounting for individual-specific effects. Both Pooled OLS and Random effects models indicate a significant negative association between environmental technology and $CO_2$ emissions. However, this relationship is not statistically significant under Fixed Effects, suggesting potential individual-specific effects influencing the relationship. Under Fixed and Random Effects, there is a highly significant negative relationship between renewable energy and $CO_2$ emissions, indicating that higher usage of renewable energy sources is associated with lower $CO_2$ emissions (see also, Solarin et al., 2017; Kirikkaleli and Adebayo, 2021). As highlighted by Shahbaz et al. (2021), investments in renewable energy sources are often considered less carbon-intensive than traditional energy. The creative initiatives for renewable energy serve as a steady foundation for the states' sustainable development (Suchikova and Nestorenko, 2017). As a result, an increased usage of renewable energy in OECD countries leads to a decrease in the reliance on fossil fuels for electricity generation. Consequently, there is a corresponding reduction in $CO_2$ emissions associated with electricity production. This relationship is reinforced by the fact that renewable energy technologies continue to advance.

All estimation methods show a significant positive association between real GDP and $CO_2$ emissions. This suggests that higher economic output, as measured by real GDP, is associated with increased $CO_2$ emissions. So, as real GDP increases, so does industrial production, transportation, and consumption of goods and services. These activities often rely heavily on fossil fuels, such as coal, oil, and natural gas, which are significant sources of $CO_2$ emissions when burned for energy. The variables, such as inflation and population growth rate, are omitted from the models as they both were statistically insignificant in the three regression models.

*Table no.3 - Panel regression results*

| **Variables** | **Pooled OLS** | **Fixed Effects** | **Random Effects** |
|---|---|---|---|
| IND | 0.3986706*** (0.000) | 0.170224*** (0.000) | 0.7754663*** (0.000) |
| ENVTAX | 0.0459637 (0.197) | -0.5447734*** (0.000) | -0.4370186*** (0.000) |
| ENVTECH | -0.3295364*** (0.003) | -0.0487609 (0.150) | -0.3672552*** (0.000) |
| RENENERG | -0.0971403 (0.146) | -1.960016*** (0.000) | -0.2785409** (0.019) |
| RGDP | 0.2702647 (0.000) | 0.3889488*** (0.000) | 0.3206542*** (0.000) |
| Constant | 24.99324 (0.000) | 61.592 (0.124) | 24.99324 (0.010) |
| R squared | 0.212 | - | - |
| Hausman test | - | chi2(5) =38.63 Prob>chi2 = 0.000 | - |
| Heteroscedasticity Test | - | Chi2(38)=2.982 Prob>chi2 = 0.159 | - |
| Serial correlation Wooldridge test | - | Prob>F = 0.301 | - |

*Source:* Author's calculations

*Note*:*** indicates statistical significance at the 1% level and ** indicates statistical significance at the 5% level.

The Hausman test is used to determine whether the fixed effects model or the random effects model is more appropriate for the regression analysis. The null hypothesis (H0) of the Hausman test is that the preferred model is the random effects model. The alternative hypothesis (H1) is that the fixed effects model is preferred. In this case, the p-value for the Hausman test is reported as 0.000, which is less than any conventional significance level (such as 0.05 or 0.01). Therefore, we reject the null hypothesis at any reasonable significance level, and we favour the fixed effects model for this regression analysis. This implies that there are individual-specific effects (or unobserved heterogeneity) present in the data that are better captured by the fixed effects model.

Diagnostic tests were performed for the fixed random model and based on the results of heteroskedasticity-robust standard errors, known as Huber/White test, we cannot reject the null hypothesis of homoscedasticity. Thus, the results are efficient and unbiased. Moreover, the Wooldridge test for autocorrelation in panel data was performed and the results imply no first order autocorrelation, which means that the errors are independent of each other over time (see results at Table 3). Consequently, the estimated coefficients are likely to be unbiased and efficient, and the standard errors and hypothesis tests can be considered as valid.

## Conclusions

The aim of this study was to estimate the relationship between industrial activity and green growth. The production-based CO2 emissions index was used as a proxy variable of green growth. It is a key environmental indicator, and as such, tracking changes in CO2 emissions can provide insight into the environmental sustainability of economic activities. Green growth, as defined by sustainable development goals, seeks to promote economic growth while ensuring environmental sustainability. Since CO2 emissions are closely linked to environmental degradation, a reduction in CO2 emissions signifies progress towards green growth objectives. The results suggest a positive relationship between value added in industry and production-based CO2 emissions. The results also imply that policy interventions such as environmental taxes and investments in environmental technology could potentially mitigate CO2 emissions. The significance and direction of the coefficients vary across estimation methods, emphasizing the importance of considering individual-specific effects. The positive association between real GDP and CO2 emissions highlights the challenge of decoupling economic growth from environmental impacts, suggesting the need for sustainable development strategies. However, further analysis and consideration of additional variables and model specifications may be necessary for a comprehensive understanding of the factors influencing CO2 emissions.

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