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Examining the Environmental Phillips Curve Hypothesis in the Ten Most Polluting Emerging Economies: Economic Dynamics and Sustainability

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Abstract: In the context of the Environmental Phillips Curve hypothesis, this study investigates the impact of unemployment on environmental quality in ten emerging economies with the highest carbon emissions, as identified in the International Monetary Fund's 2015 World Economic Outlook. The primary aim of this study is to estimate the effects of income, natural gas usage, renewable energy usage, unemployment, and population size on carbon dioxide emissions in the selected countries. The study utilizes panel data from 1990 to 2019 and employs an Autoregressive Distributed Lag model (ARDL) to evaluate the short- and long-run relationships between these variables. Findings obtained using the Pooled Mean Group (PMG) estimator indicate that both income and population size have a significant positive impact on air pollution levels, whereas natural gas consumption and the use of renewable energy correlate with a decrease in emissions. The results support a negative correlation between unemployment and environmental degradation, aligning with the EPC. The error correction term suggests that the process returns to equilibrium in about 2.8 years. The findings are validated through robustness tests utilizing the Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) estimators. This study offers important insights for environmental policymaking in these emerging economies, emphasizing the importance of sustainable development strategies and green energy adoption.

Keywords: Environmental Phillips Curve; renewable energy; natural gas; unemployment; population; emerging economies

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1. Introduction

Economies produce and consume more to accomplish their target income goals. In the wake of the Industrial Revolution, the rise in industrialization has been observed to correlate with an increase in environmental pollution, contributing to climate change and the emergence of pandemics. These developments have underscored the inadequacy of mere economic growth in enhancing societal welfare. As a result, economic literature has begun exploring the interactions between the environment, natural resources, and income following the rapid industrial expansion.

After the 1980s, the increase in globalization, alongside the rise in production and consumption, has heightened concerns regarding the environmental future within the growth literature. An extensive collection of research explores the connection between environmental pollution and economic activities, particularly highlighting the Environmental Kuznets Curve (EKC) hypothesis. This hypothesis verifies the presence of a reversed U-shaped association between environmental pollution and economic growth [1]. Environmental pollution escalates concurrently with economic growth during the initial phase of income generation. During the subsequent phase of generating income, that is, after the turning point, as income continues to increase, air damage decreases due to structural changes.

Since the 20th century, identifying the factors contributing to greenhouse gas emissions (GHG), which propel climate change and global warming, has become crucial for policymakers and researchers. There is an increasing trend in global GHG for sectors such as energy, transportation, etc. ([2], pp. XII–XIII and pp. 6–8). Understanding these factors has led to the development of various policies aimed at addressing environmental pollution. Efforts have been made to reduce pollution while ensuring that growth and development proceed in an environmentally sustainable manner. These measures are evaluated within the framework of the sustainable development vision, efficient use of resources, awareness of environmental and climate issues, and the green economy. On the other hand, energy is needed to prolong sustainable economic growth and development. However, as a result of the energy consumption, carbon emissions occur.

Carbon dioxide (CO_2) is the source of gas that has the highest share in GHG. Moreover, economic activities such as industrialization, transportation, and energy generation are the most effective factors in the increase in emissions. Therefore, the relationships between economic activities and CO_2 emissions should be analyzed deeply and comprehensively. In this context, the Environmental Phillips Curve (EPC) hypothesis is employed to scrutinize the association between unemployment and environmental conditions.

The concept of an EPC is a refined adaptation of the original Phillips Curve (PC), which is an economic theory suggesting a decline in unemployment rates as inflation rates increase within an economy [3]. The PC implies a reciprocal relationship between inflation and unemployment rates, as indicated by the correlation between the two economic factors. On the other hand, as mentioned earlier, the EPC concept investigates the trade-off between unemployment and environmental quality. In this sense, the Environmental Pressure Curve (EPC) emerges from concerns over the disconnect between environmental degradation and economic growth. The drive to increase production has led economies to exploit greater quantities of human, physical, and natural resources, thereby leaving a significant environmental footprint through pollution. Global socio-economic systems rely extensively on materials and energy for sectors such as agriculture, livestock, manufacturing, and other human activities, all of which contribute to the emission of GHG and waste. Consequently, the need to decouple economic growth from its resource consumption and environmental impacts has become a central policy focus in response to the severe consequences of climate change. The failure to achieve this decoupling may necessitate a slowdown in economic growth to mitigate pollution, potentially leading to negative implications for employment levels. The objective of dissociating environmental pressures from resource-intensive economic activities is to foster sustainable economic development, ensuring that future generations' needs are met without compromising the ability of the economy to expand and mitigate its own environmental consequences.

When applied to environmental economics, the EPC might be understood as highlighting a compromise between environmental quality and unemployment. Essentially, this curve could suggest that efforts to improve environmental quality might lead to higher levels of unemployment or slower economic growth. Conversely, rapid income growth might come at the expense of environmental degradation.

The EPC is not a standard concept in economics and might not be universally recognized or studied under this specific term. However, the underlying idea that a trade-off between air quality and economic performance is a topic of significant discussion in environmental economics. This debate involves analyzing how economic activities impact the environment and examining the costs and benefits of implementing environmental regulations and policies.

Economists and policymakers often deal with these trade-offs when designing environmental regulations, aiming to strike a balance where economic growth is achieved without compromising environmental sustainability. The discussion also extends into how technological innovation can shift this curve, potentially reducing the trade-off by enabling economic growth with less environmental impact. In this sense, while unemployment decelerates economic growth, it concurrently reduces energy consumption and environmental pressure. Consequently, a reduction in environmental pollution is anticipated. In summary, while the term EPC is not standard, the concept it alludes to is critical in the discourse on sustainable development, indicating the complex interrelations between economic policies, environmental health, and societal well-being.

This study examines not only the impacts of natural gas usage, green energy consumption, and total population but also investigates how income and unemployment impact carbon emissions during the period from 1990 to 2019. The primary goal of this study is to examine the effects of income, natural gas use, renewable energy use, unemployment, and the total population on CO_2 emissions for the ten economies that emit the most CO_2 emissions among 23 emerging economies with high social and economic potential. Furthermore, the selection of the dataset timeframe from 1990 to 2019 can be explained as follows: A survey of existing literature reveals that the 1990s is commonly chosen as the starting point in similar studies. On the other hand, the decision to end the dataset in 2019 is based on the fact that the global COVID-19 pandemic has significantly impacted parameters such as energy use, air quality, income, and unemployment, which are critical to this study. Therefore, these reasons have guided the restriction of the study's dataset to the years between 1990 and 2019. The primary aspect that distinguishes this study from other academic studies on the subject is the use of a unique dataset that has not been utilized in previous research, according to the literature review conducted. Additionally, the fact that these countries are classified as emerging economies and are among the most polluting countries further enhances the significance of this study.

This study is significant in addressing several research gaps and contributing to the existing literature. Firstly, the countries selected for analysis play a crucial role in providing a comprehensive view of global carbon emissions. According to the IMF's World Economic Outlook 2015 [4], 23 countries were identified as emerging economies. Included in these, Bangladesh (+683%), Chile (+208%), China (+373%), India (+336%), Indonesia (+344%), Malaysia (+377%), Pakistan (+212%), the Philippines (+253%), Thailand (+209%), and Türkiye (+185%) exhibited the highest increases in CO_2 emissions in 2019 compared to 1990. Additionally, while the global annual average growth rate of CO_2 emissions between 1990 and 2019 was 1.72%, the average for these economies was significantly higher at 5.31% [5]. Thus, these countries contribute substantially to global environmental degradation due to their rapid increase in CO_2 emissions. Consequently, any progress in environmental or energy policies within these economies would be vital for improving global environmental quality.

Moreover, these countries are also characterized by high income levels. While the global average GDP growth rate for the 1990–2019 period was 3.01%, these economies experienced an average growth rate of 7.48% [6], making them key drivers of global economic growth. As a result, they act as catalysts for global economic expansion. Besides, as far as we know, no previous studies have examined this particular group of countries with respect to the connection among CO_2 emissions and other relevant variables mentioned earlier. Additionally, this study evaluates the authenticity of the EPC, which posits a counteractive connection between unemployment and environmental degradation. The inclusion of various variables along with a specific set of countries distinguishes this research. Finally, the analysis relies on data from the period prior to the COVID-19 pandemic, and robustness experiments have been carried out to affirm the reliability of the results.

The following section presents a comprehensive overview of the relevant literature. A detailed review of the data and econometric techniques utilized in the study follows. Following this, the empirical findings and insights are detailed. The study wraps up with a concise summary of the key findings and suggestions for policy implications.

2. Literature Review

A significant number of academic inquiries have been undertaken to explore the correlation between unemployment and other factors subsequent to the seminal publication by Phillips (1958) [7]. In most of these studies, an inverse association between changes in nominal wages and the level of unemployment has been identified. Moreover, the association between inflation and unemployment rates was brought to the forefront of academic discourse by Samuelson and Solow (1960) [8]. Consequently, PC has initiated a debate regarding the possible relationship of compromise between unemployment and the inflation rate. The analysis indicates a negative correlation between unemployment levels and inflation rate, suggesting that a decrease in unemployment rates is associated with an increase in inflation rates.

Conversely, the relationship between economic prosperity and air quality has long been a subject of concern in the field of economics. In a more precise manner, a substantial body of research has been dedicated to investigating the phenomenon known as the EKC hypothesis, which was first presented by Grossman and Krueger (1991) [1], grounded on the Kuznets Curve (KC) hypothesis by Kuznets (1955) [9] regarding the economic progress and income disparity. This theoretical construct proposes a curvilinear association between economic growth and ecological conditions, whereby a negative correlation is initially observed, followed by a positive one, ultimately resulting in an inverted U-shaped pattern. Nonetheless, the principal critique of the EKC hypothesis pertains to its inadequate explication of the precise mechanisms that may facilitate the conversion of augmented income into enhanced environmental conditions [10–17]. Actually, it is essential for policymakers to conduct an investigation into the impact of specific macroeconomic indicators, such as the unemployment rate, on environmental quality.

For these reasons, the EPC framework contributes to this nexus by incorporating the ecological ramifications of economic growth, including escalated pollution levels, deforestation, and resource depletion, in order to comprehend the existing trade-offs between economic growth and environmental degradation, as well as their impacts on the overall welfare of the population. The EPC hypothesis is a novel extension of the conventional PC, taking into account the influence of environmental degradation on the nexus between unemployment, economic growth, and environmental damage [18].

According to the present literature, it is revealed that investigations have been carried out on the subject of environmental preferences and unemployment. Overall, the research conducted has demonstrated that under certain circumstances, there exists a pivotal point at which economic progress begins to adversely affect the natural environment, ultimately resulting in a decline in general welfare. Nevertheless, there is a lack of scholarly works that scrutinize the correlation between unemployment and environmental degradation. Empirical investigations utilizing the EPC have ascertained the presence of a dialectical link between ecological damage and income, whereby a boost in income is associated with an associated rise in environmental damage, ultimately resulting in a diminution of the overall quality of life. Eventually, the academic literature carried out on EPC can be presented as follows.

Kashem and Rahman (2020) [19] conducted one of the initial investigations into the EPC Hypothesis. The research presents the novel notion of the EPC Hypothesis as positing an inverse correlation between environmental degradation and unemployment. The study employs the aforementioned concept to examine a sample of 30 countries spanning a period of 26 years. The findings indicate that the EPC holds true for the majority of developed countries. The findings of the study specify that the mitigation of pollution may entail a trade-off with respect to employment, thereby necessitating the pursuit of alternative technologies ensuring less pollution and conducive to employment. Moreover, the results highlight that the effective management of pollution can lead to a rise in the gross domestic product of an economy without any concurrent increase in the rate of unemployment. Additionally, it is posited that economic downturns may have the unintended consequence of reducing pollution levels due to the high levels of unemployment that often accompany such crises. The research makes key contributions by introducing a new idea in environmental economics, being the first study of its kind, showing evidence of the EPC hypothesis in selected countries, and confirming the results with reliability tests such as cross-sectional and Housman tests.

Rayhan et al. (2020) [20] targets to observe the legitimacy of EKC and EPC hypotheses in the context of Bangladesh. The research employs annual data spanning from 1987 to 2016. A diverse range of econometric methodologies benefited in the study, encompassing both conventional and structural break unit root tests, Autoregressive Distributed Lag (ARDL) Error Correction model, and Toda–Yamamoto Causality test. The research outcomes indicate that the EPC maintains relevance over a long duration, while the EKC holds validity over a shorter duration within the context of Bangladesh. The consumption of nonrenewable energy sources has been observed to have deleterious effects on the environment, whereas the influence of trade on the same is deemed negligible. Moreover, it is worth noting that the Toda–Yamamoto causality test reveals the presence of one-way causality from energy usage, unemployment, and income towards environmental damage. The research also suggests integrating eco-friendly manufacturing techniques that prioritize both employment and environmental considerations, along with the implementation of renewable energy sources.

The study conducted by Anser et al. (2021) [21] aims to evaluate the empirical support for the EPC hypothesis within the BRICST countries (Brazil, Russia, India, China, South Africa, Türkiye). With panel data from 1992 to 2016, they assess the hypothesis while accounting for cross-sectional dependence. Their findings support the EPC Hypothesis, suggesting a trade-off between unemployment rates and air damage in these countries. The study further suggests expanding the incorporation of clean energy into the energy mix to enhance environmental standards and supports the achievement of sustainable development goals.

The study conducted by Bhowmik et al. (2021) [22] investigates the link between unemployment and environmental destruction, employing the EPC hypothesis as a theory-based framework. The study aims to examine the acceptability of the EPC hypothesis in the context of the United States of America (USA). Furthermore, the study aims to examine how uncertainties in monetary policy, fiscal policy, and trade policy affect CO_2 emissions. The utilization of the Dynamic ARDL model has facilitated the examination of the data, ultimately disclosing that the EPC hypothesis is not upheld in the short term, yet it is in the long term. Furthermore, it is noteworthy that both monetary policy uncertainty and fiscal policy uncertainty exert substantial influence on the emission of CO_2, whereas trade policy uncertainty does not engender any discernible modification in the level of air quality.

Tanveer et al. (2022) [23] focus on evaluating the contribution of environmental benchmarks—specifically CO_2, methane (CH_4), and ecological footprint—on various economic factors in Pakistan over the period from 1975 to 2014. To address their research goals, the study utilizes the ARDL approach. The research has established a durable correlation between variables, thereby validating the EPC hypothesis specific to Pakistan. The identified negative relationship between unemployment rates and environmental metrics in Pakistan indicates that higher employment levels correspond with increased degradation of the environment within the overall country. This indicates a positive relationship between employment and environmental degradation. Research uncovers a positive correlation between energy consumption and the levels of GHG, along with the ecological footprint. Moreover, it is stated that foreign direct investments have exhibited a noteworthy negative association with CO_2 and the ecological footprint. Additionally, CH_4 has demonstrated a positive correlation with foreign direct investment. The empirical evidence suggests a positive correlation between economic growth and the levels of CO_2, CH_4, and ecological footprint. This implies the association of an increase in environmental damage with a boost in income. The phenomenon of globalization has had a favorable impact on the escalation of CO_2 emissions and the ecological footprint. However, it has been observed that globalization can be conducive to the reduction of methane emissions, thereby contributing to the attainment of environmental sustainability in Pakistan over an extended period. The study recommends that the Pakistani government undertake measures to foster employment-friendly production, cultivate favorable relations with foreign countries to attract greater foreign direct investment, and establish cooperative partnerships with other countries to address environmental concerns.

The study undertaken by Ng et al. (2023) [24] analyzes the challenge of environmental sustainability that OECD countries are confronted with, while simultaneously striving to maintain economic growth and ensuring that employment is not compromised. The study employs the ecological footprint as an indicator of environmental degradation and examines the validity of the EKC and EPC hypotheses across 36 OECD member countries from 1995 to 2015. The results reveal that the EKC hypothesis is disproven, whereas the EPC hypothesis is supported. This suggests a balance must be struck between unemployment and environmental degradation in OECD economies. Nevertheless, the introduction of new technological advancements, especially in green energy, offers the potential to promote sustainable growth and improve air quality. The research recommends that OECD economies should prioritize the development of innovative eco-friendly technologies and the promotion of sustainable energy inputs.

Tariq et al. (2022) [25] analyze the interplay between unemployment, population growth, economic growth, and both clean and pollutant energy consumption, along with their impact on ecological footprints in South Asian countries from 1991 to 2019. By employing panel and country-specific estimations through the PMG and ARDL methods, the study substantiates the favorable impacts of Gross Domestic Product (GDP), pollutant energy use, and population growth on environmental degradation. Contrarily, the study establishes that unemployment and the use of sources of renewable energy reduce environmental degradation. The study supports the EPC hypothesis regarding significance of the accumulation of human capital within the economic progress of the countries analyzed. The results indicate that South Asian countries ought to enhance their utilization of clean energy sources to moderate ecological corruption and maintain their economies with rising employment rates, while reevaluating urban policies to tackle the role of population growth in environmental deterioration.

Shastri et al. (2023) [26] aim to investigate whether the EPC exists in the Indian context while incorporating a gender-based analysis into the inquiry. The findings of the study indicate that a correlation exists between air quality and male unemployment, while no such correlation is observed between environmental quality and female employment. Furthermore, a reciprocal causal nexus is found between female unemployment and environmental deterioration, implying that enhancing ecological conditions can decrease female unemployment. The research posits that policy initiatives ought to concentrate on establishing a virtuous cycle that interlinks the enhancement of environmental quality and the augmentation of women's economic participation, given that both objectives are mutually complementary and mutually reinforcing. The inclusion of women in natural resource management can yield significant benefits, particularly in terms of promoting environmentally sustainable practices.

More recently, Haciimamoglu (2023a) [27] examines the correlation between unemployment and environmental pollution within the framework of the EPC hypothesis. This study evaluates the appropriateness of the EPC hypothesis in relation to the MIKTA countries (Mexico, Indonesia, South Korea, Türkiye, Australia), while considering the EKC hypothesis. The research reveals a correlation between environmental damage and unemployment in MIKTA countries, thereby substantiating the credibility of the EPC hypothesis for MIKTA countries in both the short and long term. Besides, the study outlines two distinct approaches for interpreting the aforementioned correlation: Economic growth and the preferences approaches. Additionally, the study ascertains the justification of the EKC hypothesis in the MIKTA countries, which implies that the magnitude of environmental degradation resulting from economic pursuits is inclined to diminish over a protracted period. In the scope of using unemployment as a mechanism for reducing air pollution in MIKTA countries, the study cautions against utilizing unemployment as a policy instrument to mitigate environmental pollution and advocates for the adoption of more sustainable and eco-friendly policies instead. Moreover, the study advocates the adoption of sustainable and more environmentally friendly policies in sectors that cause intense environmental pollution while suggesting the implementation of policies to promote employment in industries that generate lower levels of environmental pollution.

The study by Haciimamoglu (2023b) [28] proposes to evaluate the validation of the EPC hypothesis within the Next-11 (N-11) (Bangladesh, Egypt, Indonesia, Iran, South Korea, Mexico, Nigeria, Pakistan, Philippines, Türkiye, Vietnam) countries. The study covers the period spanning from 1991 to 2018. The study employs the ecological footprint as a metric for gauging air pollution. The LM test was utilized to determine the long-term association, while the Dynamic Common Correlated Effects (DCCE) and Augmented Mean Group (AMG) estimators were employed to estimate the coefficient. The empirical analysis yielded evidence validating the EPC hypothesis in the N-11 countries.

A recent study, Kinnunen et al. (2024) [29], analyzes EPC for Finland using an ARDL model and explores that an increase in income and urbanization stimulates GHG in the long run. However, renewable energy usage diminishes them. In the short run, the results for urbanization are not strong. Their FMOLS, DOLS, and CCR results also confirm their findings. Our study's results are compatible with this study but for a different set of countries.

A summary of the abovementioned studies about the EPC is given in Table 1 as in the following.

Table 1. Literature summary.

Author(s)	Period	Sample	Methods Used	Focus of Study	Key Findings
[19]	1990–2016	30 industrialized countries	Random and Fixed Effect Panel models	The existence of EPC in the selected countries	In industrial countries, there is a negative relationship between pollution and the unemployment rate.
[20]	1987–2016	Bangladesh	A-ARDL model, ARDL ECT model, Toda–Yammamoto Causality test	The existence of EPC and EKC in Bangladesh	The EPC holds true in the long run, while the EKC is valid in the short run.
[21]	1992–2016	BRICST countries	PMG ARDL model	The validity of EPC for the BRICST countries	The usage of renewable energy resources increases environmental quality and employment level in the selected economies.
[22]	1985–2018	USA	D-ARDL model	The validity of EPC in the USA	While the EPC is not valid in the short run, it is valid in the long run.
[23]	1975–2014	Pakistan	ARDL model	The validity of EPC in Pakistan	There is a negative relationship between unemployment rate and carbon emissions in the long-run.
[24]	1995–2015	36 OECD countries	The Second-Generation Panel Unit Root and Cointegration tests	The existence of EPC and EKC in the selected OECD countries	EKC hypothesis is not valid in 36 OECD countries. On the other hand, there is a negative relationship between unemployment rate and ecological footprint. Therefore, EPC hypothesis is valid for the selected countries.
[25]	1991–2019	South Asian countries	PMG ARDL model	The validity of EPC in the South Asian countries	While there is a positive impact of economic growth, non-renewable energy consumption and population on environmental pollution, renewable energy consumption and unemployment rate reduce the pollution. This means that the EPC hypothesis is valid for the South Asian countries.
[26]	1990–2019	India	ARDL model, FMOLS estimator, DOLS estimator	The presence of EPC in India	The EPC hypothesis is valid for the male unemployment whilst the hypothesis is not valid that of female.
[27]	1991–2018	MIKTA countries	Durbin–Hausman Cointegration test, CS-ARDL model	Testing the validity of EPC hypothesis in MIKTA countries	The EPC hypothesis is valid in MIKTA countries both in the short and long run.
[28]	1991–2018	N-11 countries	AMG estimator	Testing the EPC hypothesis in N-11 countries	The EPC hypothesis is valid in N-11 countries.
[29]	1990–2022	Finland	ARDL model, FMOLS, DOLS, and CCR techniques	Evaluating the EPC hypothesis in Finland	The EPC hypothesis is valid in Finland.

3. Data, Methodology, and Findings

3.1. Data

This study examines the impact of income levels, clean energy usage, natural gas consumption, and total population on CO_2 emissions in the ten emerging economies with the highest levels of air pollution (Bangladesh, Chile, China, India, Indonesia, Malaysia, Pakistan, Philippines, Thailand, and Türkiye), as highlighted in the IMF's 2015 World Economic Outlook [4]. Additionally, this study tests whether the EPC hypothesis holds by including the unemployment variable in the analysis. To conduct this investigation, panel data from 1990 to 2019 for these ten emerging economies are examined.

The choice of the dataset period, spanning from 1990 to 2019, is justified by several factors. A review of previous studies shows that the 1990s are frequently selected as a starting point for similar research. The end year, 2019, was chosen to exclude the impacts of the COVID-19 pandemic on variables such as energy usage, air quality, income, and unemployment, which are key components of this analysis. The exclusion of the pandemic period ensures consistency in the analysis and avoids potential distortions caused by the extraordinary and unprecedented dynamics introduced during the pandemic, which could alter the typical relationships between the variables studied.

Similar approaches have been adopted in prior research when addressing pre-pandemic conditions. For instance, Sahin (2018) [30] and Naimoglu (2022) [31] emphasize the importance of establishing relationships under stable economic and environmental conditions. The methodology in this study is designed to focus on the long-term and short-term dynamics of income, clean energy usage, natural gas consumption, and total population on CO_2 emissions under "normal" economic cycles, allowing for generalizable insights.

While this study provides robust findings based on pre-pandemic data, it acknowledges the potential knowledge gap caused by excluding the pandemic period. Future studies could address this by extending the dataset to include post-pandemic years or by integrating complementary analyses to specifically evaluate the pandemic's impact. Farooq et al. (2024) [32], for example, provide insights into how disruptive events can be analyzed using a cross-sectional version of the ARDL model, which may serve as a foundation for exploring post-pandemic trends. Additionally, emerging literature focusing on COVID-19's impact on air quality, energy usage, and socioeconomic variables offers valuable perspectives for bridging pre- and post-pandemic analyses, which remain critical avenues for subsequent research.

The primary analytical method used in this research is the ARDL model. This method is particularly effective for investigating relationships between variables, both in the short term and long term, especially when the data exhibits mixed stationarity. One may refer to Sahin (2018) [30], Naimoglu (2022) [31], and its references for the details of the ARDL model. For an application of the cross-sectional version of this model, one might look at Farooq et al. (2024) [32].

The descriptive statistics concerning the variables are outlined in Table 2. As indicated in the table, the mean values for all variables are positive. CO_2 emissions have the lowest average, while population shows the highest. Additionally, economic growth exhibits the least volatility, whereas natural gas usage displays the most variability.

The reason behind the use of natural gas data is that the share of this resource is approximately 36% of global fossil fuel use in 2019. In addition, natural gas is the least polluting resource among fossil fuels. Therefore, the effect of this resource on CO_2 emissions is desired to be analyzed in this study. On the other hand, given that these economies are typically energy importers, the adoption of clean energy plays a crucial role in improving air quality and ensuring sustainable energy sources. Furthermore, these economies have almost half of the world's population, with a 49% share in 2019. Therefore, the population factor is added to the models as an independent variable in this study. On the other hand, since the EPC has not been previously explored for this group of countries in the literature, incorporating the unemployment variable will introduce a new perspective and depth to the research. Therefore, the findings can give significant ideas about these countries.

Table 2. Summary information on the variables.

	Description Source	Unit	Source	Mean	Std. Dev.	Max.	Min.
CO_2	Log (Carbon dioxide emissions per capita)	Mt	[6]	0.206	0.430	0.869	−1.000
UNMP	Log (Number of unemployed)	Number	[7]	2.080	0.701	−3.745	−6.444
GDP	Log (GDP per capita)	Constant 2015 USD	[7]	3.454	0.402	4.143	2.709
REC	Log (Total renewable energy usage per capita)	Koe	[6]	1.332	0.688	2.407	−0.584
POP	Log (Total population)	Number	[7]	8.099	0.594	9.149	7.123
NTR	Log (Natural gas usage per capita)	Koe	[6]	2.011	0.715	3.143	−1.209

Note: The observation length (T) is 30 and the unit (N) is 10 for all series. NxT is 300.

3.2. Unit Root Test

Assessing the degree of integration or stationarity of variables is the first step in exploring both the short- and long-term associations among the variables. Specifically, the Im et al. (2003) [33] (IPS) test will be employed, which builds upon the traditional Dickey-Fuller (DF) method. The IPS test allows individual stationarity tests to be conducted separately for each series within the panel, enhancing the accuracy of the results across different variables. In addition, the Augmented Dickey-Fuller (ADF) statistics will be calculated by averaging the results across groups. This approach is particularly valuable for generating more reliable results in cases with small sample sizes, ensuring the robustness of the stationarity findings before proceeding with further econometric analysis.

3.3. Estimators

In this section, a dynamic panel model will be used to account for the heterogeneous characteristics of the data. To achieve this, a variety of estimation techniques and modeling frameworks will be applied. Specifically, this study will use the Mean Group (MG), Pooled Mean Group (PMG), and Dynamic Fixed Effects (DFE) models, as established by Pesaran and Shin (1995) [34] and later refined by Pesaran et al. (1999) [35]. These models are designed to effectively capture the variations and complexities among the cross-sectional units within the panel data. Moreover, the methodology introduced by Loayza and Ranciere (2006) [36] will be utilized to structure and estimate the model, ensuring that the analysis encompasses both the short-term fluctuations and long-term equilibrium associations between the variables effectively. This combination of models will provide a comprehensive analysis, offering insights into both the commonalities and heterogeneities within the panel data, while also addressing potential endogeneity and other econometric concerns.

$$\Delta(y_i)_t = \sum_{j=1}^{p-1} \gamma_j^i \Delta(y_i)_{t-j} + \sum_{j=0}^{q-1} \delta_j^i \Delta(X_i)_{t-j} + \varphi^i \left[(y_i)_{t-1} - \left\{\beta_0^i + \beta_1^i (X_i)_{t-1}\right\}\right] \varepsilon_{it} \ldots \quad (1)$$

Equation (1) incorporates "i" to represent the cross-sectional unit, "t" as the time dimension, and "y" as the dependent variable, while "X" denotes the explanatory or independent variables. The coefficients "γ" and "δ" indicate the explanatory variables' short-term impacts on the dependent variable, whereas "β" represents the long-term coefficient, which describes the equilibrium relationship that emerges between the variables over a more extended timeframe. Additionally, "φ" signifies the rate at which adjustment occurs, indicating the acceleration of the system's returns to long-term equilibrium after a short-term shock. The terms within the square brackets are indicative of the long-term growth regression, which accounts for the sustainable effects of the variables.

In the broader academic literature, various econometric methods—such as the ones proposed by Johansen (1995) [37] and Phillips and Hansen (1990) [38]—necessitate that all variables within the model be integrated at the same order of stationarity, usually I(1), in order to accurately estimate long-term coefficients. These methods, known as cointegration techniques, assume that the variables follow similar statistical properties in terms of stationarity for consistent and valid results. However, for the PMG and MG approaches introduced by Pesaran and Shin (1995) [34], this strict condition of identical integration orders is not necessary. These methods are flexible and operate even if the variables show varying integration degrees, either I(0) (stationary) or I(1) (non-stationary). This makes them particularly efficient and useful for datasets with relatively small unit (N) and time (T) dimensions, allowing the inclusion of both stationary and non-stationary variables.

These methods provide a significant advantage by enabling the estimation of both short- and long-term coefficients simultaneously. This is in contrast to traditional approaches like the Engle and Granger (1987) [39] test, which, although effective for cointegration, can encounter issues such as endogeneity, in which explanatory variables exhibit correlation with the error terms. The simultaneous estimation of short- and long-term dynamics facilitates a more integrated understanding of the variables' relationships.

In this study, the PMG approach is utilized to estimate both short-term and long-term coefficients. One of the key features of the PMG estimator is its premise of homogeneous long-run parameters, indicating that the long-term effects of explanatory variables are presumed to be uniform for each cross-sectional unit. The PMG method allows for variability in short-term coefficients, suggesting that the immediate effects of the variables may vary across units. Moreover, PMG delivers an estimate of how quickly equilibrium is restored in the long run. For the ECT to be valid, it must fall between -1 and 0, and it must be statistically significant. These conditions ensure the efficiency, consistency, and validity of the model, confirming the presence of sustained links between the variables.

It is also important to note that the PMG method assumes all explanatory variables to be exogenous, as consistency in the estimates requires that the variables be uncorrelated with the error terms. Given that the N and T dimensions in this study are appropriate for a dynamic model, the PMG method is chosen to avoid issues related to heterogeneity and bias, providing a robust framework for the analysis.

In addition to the PMG approach, the study also employs the MG estimator, formulated by Pesaran and Shin (1995) [34]. Unlike PMG, the MG method involves conducting separate regressions for each cross-sectional unit, which results in unweighted averages of the estimated coefficients across the units. The key distinction is that the MG method allows for heterogeneity in the long-term coefficients, meaning that both short-term and long-term coefficients can vary across different units. This approach is suitable when the assumption of homogeneity in the long-term coefficients may not hold, providing a more flexible estimation method that reflects the diversity of the units in the panel dataset. Just like the PMG method, the N and T dimensions in this study support the reliability and consistency of the MG method, ensuring that the results obtained are robust and dependable.

Finally, the study applies the DFE (Dynamic Fixed Effects) estimator. Unlike the MG and PMG approaches, the DFE method assumes that the coefficients for both short-term and long-term effects are consistent across all panel units, meaning that the impact of the explanatory variables is uniform throughout the dataset. One potential drawback of the DFE approach is the risk of endogeneity between the residuals and the dependent variable's lag, which may lead to simultaneous equation bias. To address this issue and ensure the validity of the results, the Hausman Test, as recommended by Baltagi et al. (2000) [40], will be conducted to check for the presence and degree of endogeneity within the model. This test helps identify whether the DFE method is appropriate for the data or if alternative methods should be considered to mitigate bias and enhance the reliability of the findings.

4. Empirical Findings and Discussion

4.1. Unit Root Test Results

In this section, stationarity tests are carried out for each variable under analysis. The primary method chosen for this purpose is the IPS test. Additionally, the Maddala and Wu (1999) (MW) [41] stationarity test is employed to evaluate the integration levels of the variables.

A unit root test was applied to all variables within the study, and the outcomes are summarized in Table 3. The findings indicate that the population variable is stationary at its level, but the other variables attain stationarity only after being differenced. In other words, all variables, apart from the population variable, achieve stationarity at their first difference. As a result, the variables exhibit differing orders of integration, with some exhibiting stationarity at I(0) and others at I(1).

Table 3. Unit root test results.

	Level		First Difference	
	IPS	**MW**	**IPS**	**MW**
CO_2	0.298	18.617	−7.240 ***	91.202 ***
GDP	5.303	8.851	−4.936 ***	65.099 ***
NTR	−1.145	28.951	−5.706 ***	71.094 ***
REC	1.142	21.639	−8.814 ***	111.430 ***
UNMP	0.427	21.527	−8.696 ***	109.374 ***
POP	−3.436 ***	50.086 ***	−1.894 **	43.378 ***

Note: The symbols *** and ** denote significance levels of 1% and 5% respectively.

4.2. Estimations

The following section presents the parameters estimated utilizing PMG, MG, and DFE methods. Following this, FMOLS and DOLS estimators are applied to the data to assess the robustness of the results. Additionally, the Hausman test was performed to choose the most appropriate model among PMG-MG and MG-DFE. The results are summarized in Table 4.

Table 4 presents the results from the PMG, MG, and DFE estimators, highlighting the relationships between the variables and CO_2 emissions over the short and long term. The Hausman test results confirmed the PMG estimator as the most appropriate for long-term analysis due to its superior efficiency compared to MG and DFE. Therefore, the discussion focuses on the PMG findings while emphasizing the significant results for better alignment with real-world dynamics.

In the long term, economic growth (GDP) is positively and significantly associated with CO_2 emissions, with a coefficient of 0.851, indicating that a 1% increase in GDP leads to a 0.85% rise in emissions. This finding reflects the early stages of the EKC hypothesis, where economic expansion drives higher emissions due to increased energy demand and industrial activity, particularly in emerging economies. Similarly, population growth demonstrates a significant positive impact on emissions, as a 1% rise in population corresponds to a 0.51% increase in CO_2 emissions. This result is consistent with the challenges faced by densely populated countries, where urbanization and higher resource consumption exacerbate environmental degradation.

Table 4. PMG, MG, and DFE results.

	PMG	MG	DFE
Long Term			
GDP	0.851 ***	0.959 ***	0.982 ***
	(−0.108)	(−0.199)	(−0.161)
NTR	−0.040 ***	−0.147	−0.079 ***
	(−0.015)	(−0.312)	(−0.030)
REC	−0.113 ***	−0.009	−0.159 *
	(−0.036)	(−0.064)	(−0.092)
UNMP	−0.099 ***	0.077	0.004
	(−0.022)	(−0.298)	(−0.065)
POP	0.512 **	−0.938	−0.106
	(−0.198)	(−1.753)	(−0.337)
ECT	−0.357 ***	−0.707 ***	−0.191 ***
	(−0.036)	(−0.064)	(−0.033)
Short Term			
ΔGDP	0.596 **	−0.255	0.619 ***
	(−0.24)	(−0.498)	(−0.154)
ΔNTR	−0.124	−0.087	−0.004
	(−0.172)	(−0.080)	(−0.025)
ΔREC	−0.015	−0.010	−0.024
	(−0.037)	(−0.419)	(−0.026)
ΔUNMP	0.163	0.069	−0.004
	(−0.206)	(−0.108)	(−0.025)
ΔPOP	3.771	−7.090	−2.103
	(−3.902)	(−9.444)	(−2.699)
C	−2.617 ***	2.653	−0.352
	(−0.575)	(−8.188)	(−0.536)

Note: The symbols ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively. The numbers in parentheses represent the standard errors for the estimated coefficients.

Conversely, renewable energy consumption plays a critical role in mitigating emissions. The long-term coefficient of −0.113 indicates that a 1% increase in renewable energy usage reduces CO_2 emissions by 0.11%. This result underscores the importance of transitioning to cleaner energy sources to address climate change. Additionally, natural gas consumption has a modest but significant negative effect on emissions, with a coefficient of −0.040, reflecting its role as a transitional fuel that is cleaner than coal and oil but not entirely emission-free. The unemployment rate also shows an inverse relationship with emissions; a 1% increase in unemployment results in a 0.10% decrease in CO_2 emissions, likely due to reduced industrial and economic activity during periods of higher unemployment. The error correction term (ECT) coefficient of −0.357, significant at the 1% level, indicates that approximately 36% of any deviation from the long-run equilibrium is corrected in each period, suggesting that the system stabilizes within roughly 2.8 years.

In the short term, the impact of economic growth on emissions remains significant, with a coefficient of 0.596, reaffirming that industrial and energy-intensive activities temporarily increase emissions as economies grow. Population growth shows the largest short-term impact on emissions, but the relationship lacks statistical significance, potentially due to the delayed effects of population increases on energy demand and infrastructure. Renewable energy consumption, while associated with a slight reduction in emissions, also lacks statistical significance in the short term, reflecting the longer time horizon required for clean energy investments to yield substantial environmental benefits. Similarly, natural gas consumption does not exhibit a significant short-term impact on emissions, further emphasizing the need for sustained efforts to transition to cleaner energy systems.

The findings from the PMG model reveal crucial insights into the factors influencing CO_2 emissions. The significant long-term results for GDP, renewable energy consumption, population growth, and natural gas usage align well with global trends and policy priorities. Developing economies experiencing rapid economic growth and population expansion face significant emissions challenges, necessitating comprehensive strategies to transition to renewable energy and leverage cleaner alternatives such as natural gas. While short-term results indicate limited immediate impacts of policy interventions, the findings underscore the importance of sustained efforts and long-term strategies to reduce emissions. Investments in renewable energy infrastructure, energy efficiency measures, and population management must be prioritized to achieve meaningful progress in environmental sustainability.

To validate the reliability of the PMG results, robustness checks were performed using the FMOLS and DOLS estimators. The DOLS estimator is particularly important for managing efficiency across various stability levels of the variables and addressing endogeneity concerns. It is effective, especially for panel data with limited observations and time periods. Alongside DOLS, the FMOLS estimator, as per Pedroni's (2001) [42] criteria, is used for robustness checks and is well suited for heterogeneous cointegrated panels. FMOLS is advantageous because it offers unbiased and efficient results, addressing potential endogeneity issues and allowing for heterogeneous residuals in the long run. The insights from the FMOLS estimation corroborate theoretical expectations, adding further credibility. Thus, the outcomes from FMOLS and DOLS are compared to those from PMG, with the complete results outlined in Table 5.

Table 5. Robustness test results (FMOLS and DOLS).

	FMOLS		**DOLS**	
	Coef.	**Std. Err.**	**Coef.**	**Std. Err.**
GDP	0.917 ***	0.008	0.774 ***	0.059
NTR	−0.157 ***	0.017	−0.039 ***	0.012
REC	−0.061 ***	0.016	−0.085 ***	0.030
UNMP	−0.004	0.008	−0.006	0.028

Note: The symbol *** denotes significance level of 1%.

As presented in Table 5, the direction and magnitude of the variables in the FMOLS results align with those found using the PMG method. According to the FMOLS analysis, economic growth is the most significant contributor to environmental degradation, whereas natural gas usage has the most pronounced effect on reducing it. CO_2 emissions decrease following an increase in renewable energy usage. Conversely, a growing population is associated with higher CO_2 emissions, while a negative correlation exists between unemployment and CO_2 emissions. The coefficients highlight the following detailed relationships: A 1% increase in economic growth leads to a 0.92% rise in CO_2 emissions, reflecting the strong positive correlation between economic activity and emissions due to higher energy use and industrial production. Similarly, population growth of 1% results in approximately a 0.52% increase in emissions, underscoring the population's effect on consumption of energy and its related environmental effects. On the other hand, a 1% increase in natural gas consumption correlates with a 0.16% decrease in CO_2 emissions. This indicates that natural gas, as a cleaner alternative to other fossil fuels, contributes modestly to reducing overall emissions. Similarly, renewable energy usage shows a positive environmental impact, with a 1% rise leading to a 0.06% reduction in emissions, further demonstrating the critical role of renewables in addressing climate challenges. Lastly, unemployment levels reveal a slight inverse relationship with emissions: a 1% increase in unemployment is associated with a minimal 0.004% decrease in CO_2 emissions. This small reduction suggests that reduced economic activity during higher unemployment periods may lead to slightly lower energy demand and emissions output.

In contrast, the results from the DOLS method suggest that economic growth has the highest substantial impact on increasing environmental degradation, while renewable energy use has the most notable effect in mitigating it. Additionally, DOLS results indicate that increased natural gas consumption leads to lower CO_2 emissions, while a rising population results in higher CO_2 emissions. In line with the FMOLS results, the DOLS findings also indicate a negative association between unemployment and CO_2 emissions. The coefficient specifications emphasize the subsequent points: A 1% increase in economic growth leads to an estimated 0.77% increase in CO_2 emissions. This positive relationship is because of the increased energy demand and production activities. Similarly, a 1% rise in population contributes to approximately a 0.50% increase in emissions, emphasizing the significant role of population growth in driving energy consumption and its associated environmental impacts. In contrast, renewable energy usage shows a beneficial effect on emissions, with a 1% increase leading to an approximate 0.09% reduction in CO_2 emissions. This underscores the importance of expanding renewable energy sources to mitigate environmental damage. A comparable trend is seen with natural gas consumption, where a 1% increase correlates with a modest 0.04% decrease in emissions, reflecting the relatively cleaner nature of natural gas compared to other fossil fuels. Lastly, unemployment reveals a slight inverse relationship with emissions, as a 1% increase in unemployment pertains to a minimal 0.01% reduction in CO_2 emissions. This minor decrease suggests that reduced economic activity during higher unemployment periods can slightly lower energy consumption and emissions output, though the effect is minimal. Figure 1 is a graphical summary of the findings as in the following.

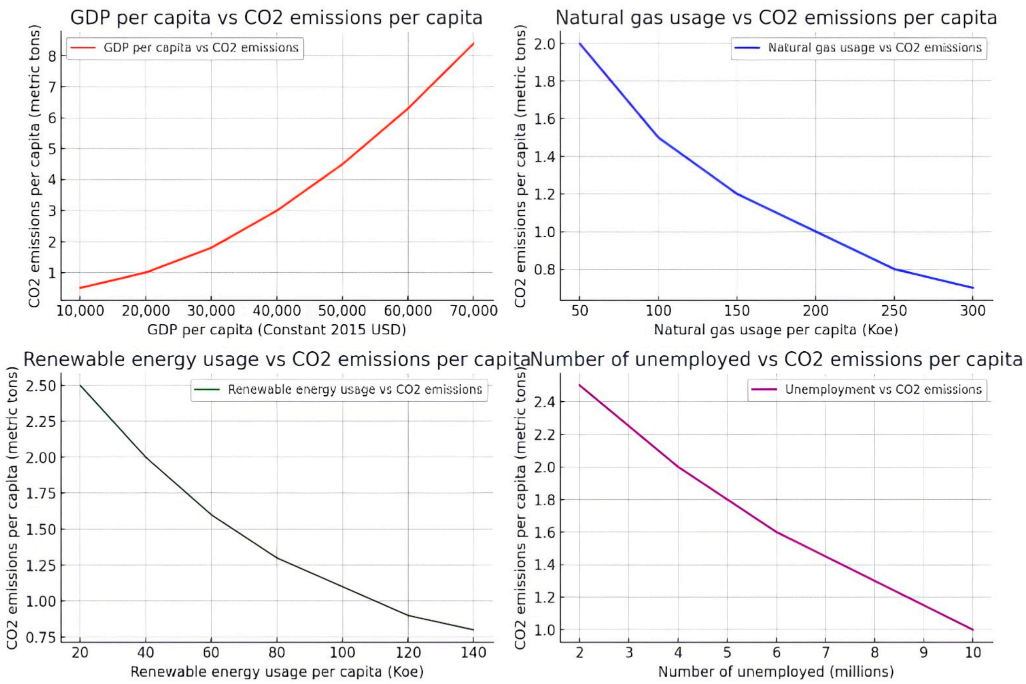

Figure 1. Summary of findings. Source: Created by authors.

As a result, the EPC hypothesis is valid for the countries investigated in this study. When compared with the literature, the findings of this study are consistent with many studies. For instance, the evidence of a negative correlation between unemployment and environmental degradation is consistent with studies [19–29]. In addition, the outcome that natural gas and renewable energy use are effective in reducing carbon emissions is similar to that of [23].

5. Conclusions and Policy Implications

5.1. Conclusions

This study aims to evaluate the credibility of the EPC and to investigate the repercussions of income, natural gas consumption, clean energy consumption, unemployment, and population size on carbon emissions in the ten emerging economies with the highest levels of carbon emissions. Specifically, the research investigates whether unemployment has a positive impact on air quality improvement in these economies. Leveraging data from 1990 to 2019 and employing the panel ARDL method, the study applies the PMG, MG, and DFE models, supplemented by robustness checks with DOLS and FMOLS estimators. This timeframe is significant as it includes years leading up to the COVID-19 pandemic, giving rise to major shifts in global economic and environmental conditions, making the analysis of pre-pandemic trends crucial. Notably, in 2019, these ten economies were responsible for approximately 42% of global CO_2 emissions, highlighting the importance of focusing on them for this case study.

Initially, this study evaluates the stationarity of variables using the IPS and MW tests. Subsequently, the PMG, MG, and DFE methodologies are employed to assess the effects of explanatory variables on the dependent variable. The Hausman test determines the most appropriate model, with results favoring PMG for interpretation. To strengthen the resilience of the PMG findings, FMOLS and DOLS estimators are applied. The results from PMG, FMOLS, and DOLS estimations consistently align in both the magnitude and direction of the effects, hence strengthening the robustness of the findings. The empirical analysis demonstrates a positive correlation between economic and population growth and higher CO_2 emissions, whereas natural gas and renewable energy usage are linked to reductions in CO_2 emissions. The study reveals a negative correlation between unemployment and environmental degradation, which lends substantiation to an EPC's existence within the scope of the examined economies. Moreover, natural gas and renewable energy use are effective in reducing carbon emissions, while economic and population growth exacerbate environmental issues.

5.2. Policy Implications

Based on these findings, several policy recommendations can be made for the top carbon-emitting emerging economies. The analysis enhances the understanding of carbon emission dynamics in these economies and fills important gaps in the literature. Policymakers should prioritize sustainable development strategies that balance environmental concerns with economic growth. Effective measures could include legislation promoting sustainable business practices, energy-efficient technologies, and green energy consumption. For instance, Bangladesh should focus on expanding decentralized solar power systems and adopting energy-efficient technologies in its textile sector, while China must prioritize renewable energy infrastructure, carbon capture technologies, and stricter emission regulations to decarbonize its energy-intensive industries.

Reducing carbon emissions requires improving conservation and resource efficiency. Policymakers should promote effective resource use across various sectors, encourage recycling, support circular economy principles, and foster environmentally friendly production methods. For example, the Philippines should enhance waste management regulations and adopt circular economy principles, while Indonesia should implement sustainable land-use policies to combat emissions from deforestation and forest degradation. Strong environmental governance and strict regulations are essential for controlling carbon emissions. Comprehensive regulations should be developed to enforce emission limits, promote sustainable land use, and support responsible waste management, accompanied by implementation strategies and monitoring systems. Malaysia, for example, must enforce sustainable agricultural practices in palm oil production and expand public transportation infrastructure to address urban emissions.

Investment in renewable energy infrastructure is crucial. Policymakers should create incentives for private investments in clean energy projects, such as feed-in tariffs and tax breaks, to transition away from carbon-intensive energy sources. Chile could lead by prioritizing renewable energy integration in its mining sector, and Türkiye could expand solar and wind projects while offering incentives to phase out coal. Moreover, given that climate change is a global challenge, international cooperation is vital. Emerging economies should actively engage in global climate agreements and pursue collaborative efforts, including knowledge sharing, technology transfer, and international financial mechanisms, to accelerate the transition to a low-carbon economy.

Our study underscores the priority of shifting toward greener energy sources and highlights the role of clean energy in minimizing ecological harm. Policymakers should focus on transitioning to sustainable energy sources by establishing regulatory frameworks, offering financial incentives, and supporting research and development in renewable energy technologies. For instance, India should invest in wind and solar energy while promoting energy-efficient practices in construction and transportation. Similarly, Pakistan should develop solar and wind projects and improve energy efficiency in agriculture and industry. Additionally, since population growth correlates with increased carbon emissions and environmental degradation, sustainable urban planning, accessible family planning services, and the promotion of sustainable consumption habits are necessary to mitigate these impacts.

By addressing the compound associations among economic growth, renewable energy use, fossil fuel reliance, population growth, and environmental quality, policymakers can make informed decisions to balance ecological sustainability with economic development. The insights gained from this study can guide policymakers in managing these dynamics effectively. For example, Thailand could adopt electric vehicles and enhance energy efficiency in manufacturing and tourism, while policies in Indonesia and the Philippines could support climate-resilient renewable energy projects.

Besides, future research should consider investigating post-pandemic data to provide deeper insights into how these dynamics have evolved in response to the COVID-19 pandemic and refine policy recommendations accordingly. On the other hand, the study focuses on specific explanatory variables such as income, natural gas consumption, renewable energy usage, unemployment, and population size. However, other potentially significant factors such as industrial structure, technological progress, etc., can be added to the model in future studies. Carbon dioxide (CO_2) emissions are used as a proxy for environmental degradation. While CO_2 emissions are a critical indicator, other dimensions of environmental quality, such as water and soil pollution or biodiversity loss, are not considered, potentially providing an incomplete perspective on environmental sustainability. Broader environmental indicators, such as the ecological footprint, could be employed in future research to offer a more comprehensive assessment. Additionally, the analysis does not explicitly account for global external shocks, such as oil price fluctuations, geopolitical tensions, or major climate agreements, which could significantly influence carbon emission dynamics and the effectiveness of renewable energy adoption. Addressing these factors in future studies would enhance the robustness of the findings.

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