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Investigating The Environmental Kuznets Curve: A Dynamic Panel Data Analysis Of Economic Growth, Energy Consumption, Urbanization And Tourism's Impact On Environmental Degradation In Selected Developed And Developing Countries

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ABSTRACT:
The growing concern over global carbon emissions and their impact on climate change has made it crucial to understand the economic and environmental drivers of emissions across different economies. This study aims to explore the long-run and short-run relationships between carbon emissions and key determinants such as income, energy consumption, urbanization, and tourism in a panel of eight selected developed and developing countries from 1990 to 2020. The research applies dynamic panel estimation techniques including Mean Group, Pooled Mean Group, and Dynamic Fixed Effects models to assess these relationships. Rooted in the Environmental Kuznets Curve (EKC) theory, which posits an inverted U-shaped relationship between income and environmental degradation, this study examines whether carbon emissions increase with economic growth up to a certain point and then decrease as economies adopt cleaner technologies. The sample includes data from both developed and developing countries, allowing for a comprehensive analysis of heterogeneous effects across different stages of development. The results indicate a long-run causal relationship between carbon emissions and its explanatory variables, as evidenced by the significant error correction terms across all models tested. Income, energy consumption and urbanization were found to significantly increase carbon emissions in the long run, while tourism (measured by the number of tourist arrivals) has a significant negative impact on carbon emission. The study's empirical results further confirm the EKC hypothesis, revealing an inverted U-shaped relationship between income and carbon emissions. These findings highlight the urgent need for policy measures that foster sustainable urbanization and energy efficiency to mitigate the long-term environmental consequences of economic growth.
The negative effect of tourism on emissions suggests that promoting environmentally sustainable tourism could be an effective strategy to balance economic growth with environmental protection.
KEYWORDS: *Carbon Emissions, Environmental Kuznets Curve, Economic Growth, Dynamic Panel Data Analysis*

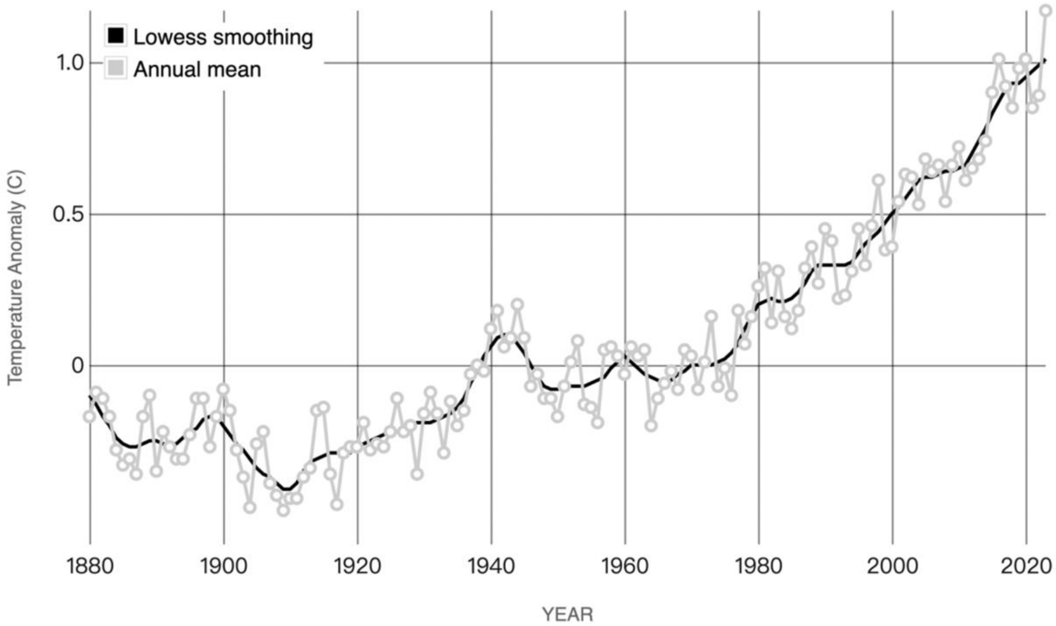
1. INTRODUCTION

Climate change, a significant anthropogenic alteration in temperature and weather patterns since the 19th century, poses a major threat to human health, international security, and biodiversity (United Nations, 2024; World Economic Forum, 2024; The Lancet Respiratory Medicine, 2023). Primarily driven by the combustion of fossil fuels, this phenomenon has fundamentally disrupted the Earth's climate system, primarily through the emission of greenhouse gases including carbon dioxide (CO_2) and methane. Global warming, a main manifestation of climate change, is influencing global temperatures and weather patterns, leading to numerous adverse environmental and societal impacts. These impacts include increased frequency and intensity of heatwaves, droughts, and floods, rising sea levels, ocean acidification, and ecosystem disruptions (Molotoks et al., 2021). The greenhouse effect, a natural mechanism for warming the planet's surface, has been exacerbated by human activities. As greenhouse gas concentrations in the atmosphere rise, they trap more heat, causing global warming and its associated implications for weather patterns, ocean circulation, and ecosystems globally.
Due to the Earth's systemic nature, changes in one area can ripple across the globe. Climate change poses a significant threat to the planet, leading to severe droughts, water scarcity, famine, rising sea levels, devastating storms, melting polar ice, flooding, biodiversity loss, and, ultimately, global food shortages

(Molotoks et al., 2021). The greenhouse effect, caused by the buildup of CO_2 and other greenhouse gases in the atmosphere, is driving global warming, accounting for nearly three-quarters of climate-warming pollution (Gibbens, 2024).

Recent data highlights the urgency in addressing climate change. Global temperatures have consistently ranked among the warmest on record for the past decade, as illustrated in Figure 1 (Nasa, 2023). The Paris Agreement seeks to cap global warming at below 2 degrees Celsius above pre-industrial levels, with an ideal target of 1.5 degrees Celsius. However, achieving this goal requires immediate and substantial action. Exceeding the 1.5 degrees Celsius threshold would result in more frequent and severe climate impacts, such as severe droughts, heatwaves, and extreme precipitation (IPCC, 2023). To prevent such outcomes, global greenhouse gas emissions need to be reduced by 43% by 2030, with a peak in emissions occurring in 2025.

Figure 1 Global Land-Ocean Temperature Index



source: climate.nasa.gov

The achievement of Sustainable Development Goal 13, "Climate Action," which calls for reducing and responding to climate change for the benefit of humanity and the Earth (United Nations, 2024), necessitates radical reductions in greenhouse gas emissions. This requires a global effort to understand and address the causes of greenhouse gas emissions, while also adopting sustainable practices that balance environmental protection with economic development.

As a measure quantifying direct and indirect greenhouse gas emissions, the carbon footprint has become a central concept in navigating and addressing climate change. Currently accounting for 61% of humanity's environmental impact and growing rapidly, the carbon footprint has increased elevenfold since 1961 (Global Footprint Network, 2021). Reducing the carbon footprint is crucial for mitigating climate change as it directly addresses the largest and fastest-growing driver of the issue (Global Footprint Network, 2018). Research consistently demonstrates that reducing emissions is crucial for bettering environmental quality, which is critical for mitigating climate change and achieving sustainable development goals (Raihan & Tuspekova, 2022). To meet global climate targets, it is imperative to understand the economic and environmental factors driving emissions, particularly in contexts where economic priorities often compete with sustainability goals. Addressing the carbon footprint of both individuals and industries through sustainable practices, energy efficiency, and responsible consumption can play a significant role in achieving these climate targets.

Furthermore, the Environmental Kuznets Curve (EKC) hypothesis, while widely studied, lacks analysis on the combined effect of income, energy consumption, urbanization, as well as tourism on CO_2 emissions in both developed and developing nations. Tourism's impact on emissions is particularly understudied, especially in countries where it drives economic growth. Research suggests a mixed relationship between tourism and carbon emissions, with some studies indicating a worsening environmental impact (Adedoyin et al., 2021; Zhang & Liu, 2019), while others show a potential for emissions reduction with renewable energy and technology (Voumik et al., 2023; Sun et al., 2021). In Latin America, a U-shaped relationship is observed, where tourism initially reduces emissions but reaching a threshold, after which emission levels will start increasing as tourism revenues grow (Ochoa-Moreno, 2022). These contradictory findings highlight the complex and context-specific nature of tourism's impact on the environment.

Recent systematic reviews have examined the EKC hypothesis and its evolution using literature between 1991 and 2023, focusing on the environmental degradation associated with energy use (Guo & Shahbaz, 2024). The majority of research uses carbon emissions as a proxy for environmental degradation, with recent studies emphasizing the distinction between renewable and non-renewable energy use. While EKC remains a useful model, future research should delve into sectoral and regional analyses to develop a deeper insight into the energy-emissions relationship.

This study seeks to provide a detailed analysis of the factors driving environmental degradation across different economic contexts. By examining the relationship between economic growth, energy use, urbanization, tourism, and carbon emissions in both developed (US, UK, Japan, Singapore, South Korea) and developing countries (China, India, Malaysia), this research aims to shed light on how these processes impact environmental sustainability at different levels of economic development. These nations, being key drivers of global economic and environmental trends, offer valuable insights into how policy measures and economic changes can influence emissions patterns worldwide.

2. BRIEF REVIEW OF LITERATURES

2.1 Theoretical Literature

This nonlinear relationship between per-capita income and income inequality, which Kuznets first proposed, became renamed in the 1990s in environmental economics as the Environmental Kuznets Curve (EKC) (Kuznets, 1995). This hypothesis has become one of the main theoretical tools to analyse the relationship between energy use, economic growth and the environment (Hasan et al., 2023). It is developed by Grossman and Krueger, who suggest an upside-down U between economic development and environmental degradation (Grossman & Krueger, 1995). This U-shaped connection has three possible avenues of explanation, referred to by Grossman and Krueger as scale, composition and technical effects (Grossman & Krueger, 1991). That is, the EKC suggests that while the negative environmental impact of the scale effect dominates during the early stages of economic growth, it is eventually outweighed by the positive effects of composition and technique changes, which tend to reduce emission levels (Dinda, 2004).

In terms of scale effects, increasing production demands greater input, which leads to the depletion of more natural resources during manufacturing. Higher output also results in the generation of more waste and emissions, contributing to environmental degradation. Thus, economic growth exhibits a scale effect that negatively impacts environmental quality (Tenaw & Beyene, 2021). However, regarding composition effects, economic growth can also have a beneficial impact on the environment. As incomes rise, the economic structure gradually shifts towards cleaner, less-polluting industries. While environmental degradation may initially increase during the transition from rural to urban and from agricultural to industrial activities, it tends to decline as economies shift towards service sectors and knowledge-based, technology-intensive industries (Dinda, 2004). In terms of technological effects, wealthier nations can allocate more resources to research and development, which accelerates technological progress (KOMEN et al., 1997). This facilitates the replacement of outdated, polluting technologies with cleaner and more efficient innovations, thereby enhancing environmental quality.

Despite being widely applied, the EKC hypothesis remains contentious, particularly when comparing its application to developed and developing nations, and has several notable limitations (Dinda, 2004). In developed countries, technological advancements and stringent environmental policies have enabled economic growth that contributes to reducing emissions. However, the EKC assumes that economic growth will inherently lead to environmental improvements, which oversimplifies the ongoing emissions challenges these nations continue to face. On the other hand, developing countries, which are in the earlier stages of industrialization, primarily experience scale effects, where pollution increases in tandem with economic growth. Without external assistance, such as green technology transfers or deliberate environmental policy actions, these nations may not achieve the environmental improvements forecasted by the EKC.

This study bridges this gap by analyzing both developed and developing economies, assessing whether the EKC accurately captures the environmental and economic dynamics within different contexts, and investigating the potential need for modifications to its application in developing nations. Furthermore, this research delves into the specific factors that influence the turning point of the EKC, exploring whether income level alone is a sufficient predictor or if other variables, such as institutional quality, governance effectiveness, and access to clean technologies, play a more significant role.

2.2 Empirical Literature

2.2.1 Economic Growth and Carbon Emissions

The relationship between economic growth and carbon emissions has been extensively examined within the EKC hypothesis. Studies on high-emitting countries have found a strong positive relationship between GDP per capita and CO_2 emissions, supporting the EKC hypothesis (Shahbaz et al., 2024). Similarly, in the EU-27, an inverted U-shaped relationship between economic growth and carbon emissions is observed, with CO_2 emissions dropping considerably, especially in Germany (Mohammed et al., 2024). These findings support the EKC hypothesis, suggesting that economic growth can eventually lead to environmental improvements.

Research has also examined the effects of globalization, economic growth, and industrialization on carbon emissions across 64 nations (Patel & Shahbaz, 2023). The findings support the EKC hypothesis for upper- and lower-middle-income countries, while revealing a U-shaped relationship for low-income countries, where growth continues to drive up emissions. The study also argues for targeted policy support for renewable energy in low-income countries to disentangle growth from environmental degradation. In a related study, researchers investigated how to reconcile economic growth and carbon emissions in ASEAN and GCC countries (Naz et al., 2024). They discovered that while strong ASEAN economic growth was linked to bigger ecological footprints, the GCC economies were more successful in reducing emissions through renewable energy use. These studies highlight the need for local solutions to balance growth with environmental responsibility, challenging the universality of the EKC.

Research on China suggests a more nuanced relationship between economic growth and environmental impact (Tian et al., 2024). It appears from their research that China is not subject to the EKC paradox, as the rise of economic growth and energy use has generated higher emissions, renewable energy and tourism have made significant contributions to China's environmental objectives.

Developing nations often experience a rise in carbon emissions alongside economic expansion, especially in their initial growth phases. This correlation is often driven by the dependence on fossil fuels to fuel industrial expansion, build infrastructure, and meet growing consumption needs. As these economies strive to improve living standards and catch up with developed nations, their energy needs escalate, and often, the cheapest and easiest to obtain energy sources are coal, oil, and natural gas. However, the connection between economic growth and carbon emissions is not a simple liner one. With increasing economic maturity, a transition towards environmental enhancement might be observed, which is often described by the Environmental Kuznets Curve (EKC) hypothesis. Energy use, urban growth, and tourism are among the key factors influencing this dynamic. Grasping these intricate relationships is essential for crafting impactful policies to combat climate change and foster sustainable development.

2.2.2 Energy Consumption and Carbon Emissions

This relationship is well-established in the literature. Numerous studies have demonstrated a strong positive correlation between these two variables, highlighting the significant role of fossil fuels in driving climate change. Numerous studies have demonstrated a strong relationship between energy consumption and carbon dioxide emissions (Dunyo et al., 2024; Choudhury et al., 2023). These studies emphasize the significant role of fossil fuels in environmental degradation and advocate for a transition to cleaner energy sources. Notably, developed nations, particularly those with a strong focus on clean energy technologies, have achieved significant reductions in per capita CO_2 emissions (Zhang et al., 2024).

In the context of Malaysia, a study has evaluated the environmental impacts of sectoral growth, identifying agriculture, industry, and finance as major contributors to carbon emissions (Ehigiamusoe et al., 2024). The study emphasizes the urgent need for sustainable practices and the adoption of cleaner energy sources to balance economic growth with environmental protection. Research on BRICS nations has highlighted the necessity of shifting away from fossil fuels towards renewable energy sources to ensure sustainable economic development (Hasan et al. 2023). This shift is crucial for mitigating climate change and achieving long-term environmental sustainability.

Finally, research on Japan's energy consumption has demonstrated the significant role of renewable energy sources, such as photovoltaic (PV) power, in reducing CO_2 emissions (Aruga et al., 2024). The increasing adoption of renewable energy technologies in Japan has contributed to a significant reduction in greenhouse gas emissions, showcasing the potential for such technologies to drive a sustainable energy future.

Overall, the vast body of research dedicated to energy consumption and its impact on carbon emissions underscores the pressing need for a worldwide transition to cleaner energy. Broad implementation of sustainable practices is crucial to mitigating climate change and securing a more sustainable future. This global energy transformation will be greatly aided by ongoing innovation in renewable energy production, energy storage, and carbon capture and sequestration. Also, future studies should delve into the complex interplay between energy systems, economic progress, and climate change, while also developing groundbreaking policy solutions to expedite the shift towards a low-carbon world.

2.2.3 Urbanization and Carbon Emissions

Studies have consistently demonstrated the significant environmental consequences of urbanization, particularly concerning carbon emissions. In Malaysia, urbanization has been identified as a key driver of rising CO_2 emissions, with a focus on the rapid expansion of urban centers and the associated increase in energy demand for transportation and residential use (Ridzuan et al., 2020). This trend is echoed in research examining the world's 15 largest natural gas supply economies, which highlighted the negative impact of urbanization on carbon emissions, emphasizing the urgent need for innovative policies that address energy efficiency, promote sustainable urban planning, and encourage a shift towards cleaner energy sources (Shah et al., 2023). The authors specifically pointed to the lock-in effect of infrastructure development favoring fossil fuel consumption, making policy changes crucial.

Additional research in the PIIGS countries has shown that urbanization puts significant stress on environmental quality, leading to increased emissions (Balsalobre-Lorente et al., 2022). In contrast, studies in BRICS countries have found a more complex relationship between urbanization and carbon emissions, with energy consumption emerging as a stronger driver (Balsalobre-Lorente et al., 2022).

At the international level, research has demonstrated that urbanization can amplify the positive relationship between economic growth and carbon emissions, particularly in high-income economies (Wang et al., 2022). However, in lower-income countries, urbanization can worsen emissions, reinforcing the pollution haven argument (Muhammad et al., 2020).

While urbanization indisputably contributes to economic growth and development, its environmental consequences, particularly the increase in carbon emissions, cannot be ignored. Studies have shown that urbanization leads to increased energy consumption across various sectors, including residential, commercial, and transportation. This increased energy demand, often met by fossil fuels, translates directly into higher carbon footprints. Furthermore, urbanization typically leads to increased transportation emissions due to greater commuting distances and reliance on private vehicles. Waste generation, another byproduct of urban living, also contributes to emissions, particularly if waste management practices are inefficient and rely on landfill disposal. However, it is crucial to recognize that the impact of urbanization on carbon emissions is not uniform. It varies significantly across different regions and countries, depending on a complex interplay of factors. These factors include the level of urban planning and management, the quality of infrastructure development (including public transportation and energy grids), the dominant energy consumption patterns, technological advancements, and existing environmental regulations. Understanding these nuances is critical for developing effective and targeted policies to mitigate the environmental impact of urbanization while still harnessing its potential for economic and social progress. Future research should focus on exploring the specific mechanisms through which urbanization affects emissions in diverse contexts, taking into account the dynamic interplay of these moderating factors.

2.2.4 Tourism and Carbon Emissions

Numerous studies point to tourism's contribution to CO_2 emissions, especially in highly developed countries and regions. Study concluded that tourism accounted for a significant proportion of carbon emissions in the European Union (EU), especially in areas of high economic complexity (Adedoyin et al., 2021). This emphasizes that global travel helps to fuel economic growth but also causes environmental degradation, particularly in times of crisis such as Brexit. In a similar vein, a study analysed Northeastern and Southeast Asian areas, concluding that tourism, along with energy consumption, deteriorates the environment (Zhang & Liu, 2019). Further evidence for tourism's negative environmental effects comes from other studies. Tourism receipts were found to increase energy use leading to higher carbon emissions in Himachal Pradesh in India (Manisha et al., 2023). In this research, we discovered an upside-down EKC relationship, in which tourism first fosters economic development, then leads to environmental damage. Similarly, a research analyses of different regions, including East Asia & Pacific and the EU, also confirmed that tourism-related emissions are a significant source of CO_2 (Zaman et al., 2016). The study confirms the EKC hypothesis, but only at the higher income scale, where the ecological burden of tourism might outweigh its economic upside in developing countries.

In addition to the aforementioned results, there are some studies demonstrating that tourism can have a positive effect on the environment, especially in conjunction with renewable energy and ecotourism projects. A study concluded that in the Arab Peninsula, tourism is effective in reducing CO_2 emissions when combined with renewable energy use (Voumik et al., 2023). Their work casts the EKC hypothesis into doubt here, and proves that environmental degradation is not a condition of tourism-driven economic growth. It also shows that tourism can potentially contribute positively to sustainability. Similarly, studies have shown that the combination of tourism and ecological innovation can lead to positive environmental outcomes, including reduced carbon emissions and a smaller environmental footprint (Sun et al., 2021). This finding supports the EKC hypothesis across all levels of economic development. Additionally, research in China (Razzaq et al., 2020) has demonstrated that tourism development, particularly when coupled with technological advancements, can serve as a significant source of mitigation, especially in regions with higher emissions. These findings suggest that the environmental impact of tourism is not inherently negative and can be mitigated through careful planning and the adoption of sustainable technologies.

In contrast, research on 20 Latin American countries has revealed a more complex relationship between tourism and carbon emissions (Ochoa-Moreno et al., 2022) . The study suggests that while initial tourism growth may lead to reduced emissions, further growth can eventually lead to increased emissions, challenging the traditional EKC framework. This finding highlights the importance of sustainable tourism practices to ensure that the environmental benefits of tourism are not outweighed by negative impacts.

While tourism can contribute to economic growth and development, it can also have significant environmental impacts. Numerous studies have shown that tourism can lead to increased carbon emissions, particularly in developed countries and regions. Factors such as air travel, accommodation, and transportation contribute to the tourism industry's carbon footprint. However, the impact of tourism on emissions can vary depending on factors like the type of tourism, the development stage of economy, and the implementation of sustainable practices. Moving forward, research should prioritize a more granular analysis of the tourism sector, differentiating between various types of tourism (e.g., mass tourism vs. ecotourism) and their respective environmental impacts. Furthermore, investigating the efficacy of specific policy interventions, such as carbon pricing for air travel or incentives for eco-friendly accommodations, is crucial for developing effective strategies to mitigate the carbon footprint of tourism. A deeper understanding of the complex interplay between tourism, economic growth, and environmental sustainability is essential for fostering a responsible and thriving tourism sector that minimizes its negative impact on the planet.

3. RESEARCH METHODOLOGY

3.1 Data

The present paper applies a quantitative research approach to analyse panel data of eight countries, categorised into developed and developing economies. The selected countries include China, India, Malaysia, the US, the United Kingdom, Japan, Singapore, and South Korea covering the period from 1990 to 2020. The research aims to investigate the long-term and short-term relationships of economic development, urbanization, energy consumption, tourism, and CO_2 emissions, with an emphasis on testing the EKC hypothesis. Secondary data, encompassing the variables listed in Table 1, were sourced from the World Bank's World Development Indicators (WDI).

Table 1 Summary Details of Variables

Variable	Descriptor	Data Source
Carbon Emissions	CO_2 emissions (metric tons per capita)	WDI, World Bank
Economic Development	GDP per capita	WDI, World Bank

Energy Consumption	Energy use (kg of oil equivalent per capita)	WDI, World Bank
Urbanization	Urban population	WDI, World Bank
Tourism	Number of tourist arrivals	WDI, World Bank

3.2 METHODOLOGY

This study employs three primary econometric techniques to assess the short-run and long-run dynamics among the variables: the Mean Group (MG) estimator, the Pooled Mean Group (PMG) estimator, and the Dynamic Fixed Effects (DFE) model (Pesaran et al., 1995; Pesaran et al., 1999). Additionally, logarithmic transformations are implemented to address issues of heteroscedasticity and to enhance the interpretation of the results, particularly when estimating elasticities (Wooldrigde, 2010; Greene, 2019). In dynamic panel models, the inclusion of lagged dependent variable allows the model to account for temporal dependencies, where past levels of CO_2 emissions may influence current levels (Arellano & Honoré, 2001). This approach not only reflects the gradual nature of environmental and economic processes but also helps mitigate potential endogeneity issues. Here, the lagged CO_2 emissions term (i.e., $\ln CO_{2it-1}$) captures the persistence of emissions over time, recognizing that environmental impacts from economic activities do not dissipate instantly and often exhibit inertia.

For macro panel datasets (where T>N), traditional estimation techniques, such as fixed effects, instrumental variables, or the Generalized Method of Moments (GMM), may lead to biased or inconsistent parameter estimates due to heterogeneous panel characteristics that violate the pooling assumption (Rasiah et al., 2018). The PMG estimation technique addresses this issue by allowing short-run coefficients and error variances to differ across cross-sectional units, while assuming long-run homogeneity in slope coefficients (Pesaran et al., 1999). To enhance robustness and validate the results, the MG and DFE models are applied for comparative purposes.

The general equation for the model is as follows:

$$\begin{aligned} \ln CO_{2it} = {} & \beta_0 + \beta_1 \ln CO_{2it-1} + \beta_2 \ln GDP_{it} + \beta_3 \ln GDP_{it}^2 + \beta_4 \ln UPOP_{it} + \beta_5 \ln ENERGY_{it} \\ & + \beta_6 \ln TOURISM_{it} + \varepsilon_{it} \end{aligned}$$

Where:

$\ln CO_{2it}$: the natural logarithm of CO_2 emissions for country i at time t, representing the dependent variable; $\ln CO_{2it-1}$: the lagged natural logarithm of CO_2 emissions, which helps to capture the dynamic nature of the model by accounting for past emissions influencing current emissions; $\ln GDP_{it}$: the natural logarithm of GDP per capita, reflecting economic development levels; $\ln GDP_{it}^2$: the square of log GDP, included to test for the EKC hypothesis; $\ln UPOP_{it}$: the natural logarithm of urban population, representing urbanization; $\ln ENERGY_{it}$: the natural logarithm of energy consumption; $\ln TOURISM_{it}$: the natural logarithm of number of tourist arrivals; ε_{it}: the error term.

4. RESULTS AND DISCUSSION

4.1 Descriptive Analysis

Before conducting the empirical analysis of the determinants of CO_2 emissions, it is crucial to present the summary statistics for all variables, as depicted in Table 2.

Table 2 Descriptive Statistics for Key Variables of the CO_2 Emission Model

Variable		Mean	Std. Dev.	Minimum	Maximum	Observations
LCO2	overall	1.861	0.827	-0.435	3.019	248
	between		0.837	0.071	2.883	
	within		0.259	1.090	2.489	
LGDPPC	overall	28.015	1.527	24.985	30.634	248
	between		1.553	25.898	30.312	
	within		0.459	26.559	29.214	
LGDPSQ	overall	787.167	85.178	624.238	938.415	248
	between		86.673	670.946	918.842	
	within		25.603	703.807	857.728	
LUPOP	overall	18.071	1.537	14.930	20.580	248
	between		1.625	15.297	20.103	
	within		0.205	17.442	18.549	
LENERGY	overall	7.884	0.871	5.861	8.994	204

	between		0.907	6.097	8.930	
	within		0.203	7.292	8.513	
LTOURISM	overall	16.750	1.241	14.569	19.026	207
	between		1.199	15.446	18.547	
	within		0.527	15.470	18.133	

The results suggest that a significant portion of the variability in the data is explained by the between-country variance. For instance, CO_2 emissions exhibit an overall variance of 0.684 (i.e., 0.827 squared), with only 0.067 (i.e., 0.259 squared) attributed to within-country variance, meaning just 6.7% of the variation occurs within individual countries. Similarly, the within-country variance for GDP per capita accounts for merely 21.1% (0.459 squared = 0.211) of the overall variation. Additionally, urbanization (UPOP) shows a within-country variance of 0.042 (0.205 squared), energy consumption (ENERGY) has a value of 0.041 (0.203 squared), and number of tourist arrivals (TOURISM) reflects 0.278 (0.527 squared) of the within-country variance. These results indicate that between-country differences largely explain the variation in the dataset.

4.2 MG, PMG and DFE Estimation

The estimation techniques used in this study include the Mean Group (MG), Pooled Mean Group (PMG), and Dynamic Fixed Effects (DFE) estimators. Table 3 presents the estimation results for both long-run and short-run coefficients, along with the error correction terms.

The MG estimator is the least restrictive of the three, allowing full heterogeneity across all parameters, meaning that both short- and long-run coefficients vary across countries. While this approach captures country-specific dynamics, it may result in less efficient estimates due to high parameter variability (Pesaran et al., 1995). In contrast, the PMG estimator serves as a compromise between the MG and DFE approaches. It allows for country-specific variation in intercepts, short-run coefficients, and error variances, while imposing homogeneity on long-run slope coefficients, assuming that the long-term relationships among variables are consistent across countries (Pesaran et al., 1999). The DFE estimator is the most restrictive, allowing only the intercepts to vary by country, while assuming homogeneity across all other parameters.

The Hausman test results (Table 3) indicate that the PMG estimator is the most suitable, as it demonstrates both consistency and efficiency. Specifically, with a p-value greater than 0.05, the null hypothesis of long-run homogeneity cannot be rejected, affirming the PMG model as the optimal choice. Consequently, the analysis and discussion focus on the PMG results, which provide a balanced perspective by capturing short-term heterogeneity while maintaining a consistent long-term relationship among the variables.

Table 3 Estimation Results for the Determinants of CO_2 Emissions

	Mean Group (MG)	**Pooled Mean Group (PMG)**	**Dynamic Fixed Effects (DFE)**
Long-run coefficients			
LGDPPC	5.755 (13.762)	2.396*** (0.541)	- 1.374 (2.847)
LGDPSQ	- 0.074 (0.251)	- 0.045*** (0.009)	0.027 (0.050)
LUPOP	0.103 (0.910)	0.469*** (0.139)	- 0.155 (0.954)
LENERGY	0.782 (0.545)	1.209*** (0.030)	0.845** (0.390)
LTOURISM	- 0.140 (0.089)	- 0.032** (0.014)	0.085 (0.183)
Error correction coefficient	- 0.830*** (0.181)	-0.417** (0.187)	- 0.075 (0.050)
Short-run coefficients			
ΔLGDPPC	- 48.445** (20.289)	-70.821* (39.015)	- 3.33* (1.849)
ΔLGDPSQ	0.832** (0.344)	1.234* (0.670)	0.076** (0.034)

ΔLUPOP	2.064** (0.910)	2.010 (1.777)	0.318 (0.417)
ΔLENERGY	0.057 (0.269)	0.229 (0.234)	0.206*** (0.057)
ΔLTOURISM	0.028 (0.046)	0.025 (0.036)	- 0.015 (0.022)
Hausman test	0.1015		

1 - The numbers in parentheses are standard errors.
2 – The asterisks ***, ** and * indicate the rejection of null hypothesis at 1%, 5% and 10% of significance levels, respectively.

Based on the PMG estimation technique, a long-run causal relationship exists between the explanatory variables and CO_2 emissions, as indicated by the significant error correction terms. The magnitude of the disequilibrium correction coefficient is 0.417, suggesting that approximately 42% of the adjustment towards long-run equilibrium occurs in each period.
The PMG estimation technique, recognized as the most efficient method, reveals a robust positive long-term relationship between GDP and CO_2 emissions, aligning with previous research (Shahbaz et al., 2024; Mohammed et al., 2024; Naz et al., 2024; Tian et al., 2024). This finding highlights the significant impact of economic development on environmental degradation. Consistent with the EKC hypothesis, the results show a significant negative relationship between GDP squared (LGDPSQ) and CO2 emissions. This supports the notion of an inverted U-shaped curve, as suggested by previous research (Ramayah et al., 2019). Furthermore, our study supports the established positive long-term relationship between energy consumption and carbon emissions, consistent with prior research (Zhang et al., 2024; Ehigiamusoe et al., 2024; Hasan et al., 2023; Aruga et al., 2024; Balsalobre-Lorente et al., 2022). This reinforces the notion that increasing energy demand, particularly from fossil fuel sources, is a major driver of carbon emissions. Additionally, our analysis indicates that urbanization has a significant positive impact on carbon emissions, in line with existing literature (Ridzuan et al., 2020; Shah et al., 2023; Balsalobre-Lorente, 2022; Wang et al., 2022; Muhammad et al., 2020). This suggests that rapid urbanization, often accompanied by increased industrialization and transportation, can exacerbate environmental pressures. However, our findings regarding tourism diverge from the general consensus (Voumik et al., 2023; Sun et al., 2021; Razzaq et al., 2020), revealing a significant negative relationship between tourism and carbon emissions. This counterintuitive result suggests that the impact of tourism on carbon emissions may be more complex than previously thought, and further research is needed to explore the underlying mechanisms.

5. CONCLUSION

This study investigates the causal relationship between key economic factors—GDP, urbanization, energy consumption, and tourism—and carbon emissions across eight diverse economies over the period 1990-2020. By employing the Mean Group (MG), Pooled Mean Group (PMG), and Dynamic Fixed Effects (DFE) estimation techniques, the study explores both short-term and long-term relationships between these variables. The findings indicate a long-run equilibrium relationship between per capita carbon emissions and a range of economic factors, including per capita GDP, GDP squared, energy consumption, and tourism. These results provide a nuanced understanding of the distinct economic drivers of carbon emissions at various stages of economic development.
The most efficient model was identified as PMG estimate with the help of the Hausman test. We observed using the PMG model that per capita GDP and energy use are both highly and positively related to carbon emissions over the long-term, with higher levels of economic output and energy consumption leading to higher levels of per capita carbon emissions. But the main break from much of the literature was seen in the case of tourism. What we find is that tourism has a statistically significant but negative emissions effect in this research. This observation stands in contrast to a lot of previous research linking more tourism with worsening environmental damage. This rare outcome is indicative of the emissions-reduction power of tourism combined with sustainable methods, renewable energy and climate policies.
As for the short-run dynamics, the estimated error-correction terms for all three models (MG, PMG, and DFE) were negative and statistically significant, which indicates the robustness of the findings. These negative error-correction words mean that if any variable moves out of the long-run equilibrium, it is then

fixed in time and returned to a steady-state equilibrium every time. This result is crucial, since it means that the chosen nations can restore a level of equilibrium to their environmental performance by using flexible economic policy even if initiative shocks or policy shifts initially disturb this level of equilibrium. These results have implications especially for policymakers in these eight countries who should be mindful of the two-way relation between GDP growth and energy use on carbon emissions. Economic development and energy consumption are still fundamental drivers of growth but they are major carbon sources, so they need a middle way between growth and environmental accountability. Crucially, we found that tourism, if managed well, can actually contribute to reductions in emissions. Governments should enact policies that promote sustainable tourism to trade-off economic gain with environmental protection, particularly in countries where tourism is a significant driver of national income.

Energy efficiency is one of the most urgent routes to sustainability. The incentives that policymakers are called upon to encourage investments in energy-efficiency and emissions-reducing technologies should be targeted. These investments can not only make a longer-term investment in operating expenses for companies and homeowners, but also be good for the environment. Government budgets are encouraged to put more resources into clean, renewable and sustainable energy research and development in biofuels, hydropower and so forth. They are less polluting than fossil fuels, good alternatives to traditional energy technologies, and may be a better strategy to tackle global warming than carbon taxes. Carbon taxes might be a short-term solution to emissions, but they would stunt growth and don't cover the need for clean energy sources. So a balanced solution of fiscal policy and incentives for renewable investment is more likely to produce more sustainable long-term results.

This study points to the need for governments to coordinate in their efforts to attain shared environmental sustainability targets for the benefit of society. As climate change threatens human and environmental health at an ever-serious rate, global coordination of sustainable development policies is a must. States must understand that economic growth and environmental protection are not a two-way street but need new kinds of policies and cross-cutting partnership to coexist.

Last but not least, this paper is fully aware that its conclusions are only a start, not a finish line. The next studies could expand on these findings by considering the influence of other economic and environmental factors and other methods of econometric estimation. Further research might include sectoral analysis to understand more about the ways in which various industries have impacted the environment across economic systems. Furthermore, incorporating new factors including technological development, green finance and regulatory regimes into the future studies could enable a more detailed picture of how these nations can work towards financial and economic restructuring focused on ambitious carbon reduction targets. It is our wish that this study will add to the growing literature on sustainable development and can also help other researchers and policymakers in their search for solutions to reduce climate change.

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