Exploring the Link Between Economic Growth and GHG Emissions: Insights from BRICS+ and Beyond

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Exploring the Link Between Economic Growth and GHG Emissions: Insights from BRICS+ and Beyond

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Abstract

The transition from fossil fuels to sustainable solutions remains a significant challenge, primarily due to path dependence which affects many economies. This calls for a new approach to economic growth that fully accounts for environmental costs. Consequently, understanding the factors that influence GDP growth is essential for achieving sustainable economic development. This study contributes to the existing literature by examining how greenhouse gas emissions, renewable energy, and urbanization impact GDP growth across various economic contexts. Employing a balanced panel comprising the US, EU27 and the BRICS economies from 1990 to 2022, it is among the first ones to incorporate the expanded BRICS+ economies into the analysis. Key empirical results are the following: **First,** Greenhouse gas emissions have a unidirectional effect on GDP growth across all panels, driven by emissions-intensive sectors like manufacturing; **Second,** in BRICS+ countries, urbanization and GDP are strongly interconnected, with emissions-driven growth posing future sustainability challenges; **Third,** the Environmental Kuznets Curve hypothesis is supported, indicating that while economic growth initially leads to greater pollution, higher incomes eventually promote investment in renewable sources.

Hence, policies promoting the energy transition underscore the importance of integrating the economic growth and environmental sustainability in pursuing multidimensional well-being.

Keywords: Renewable energy, Economic growth, GHG emission, Panel data regression.
JEL Classification: E60, F64, F68, C23.

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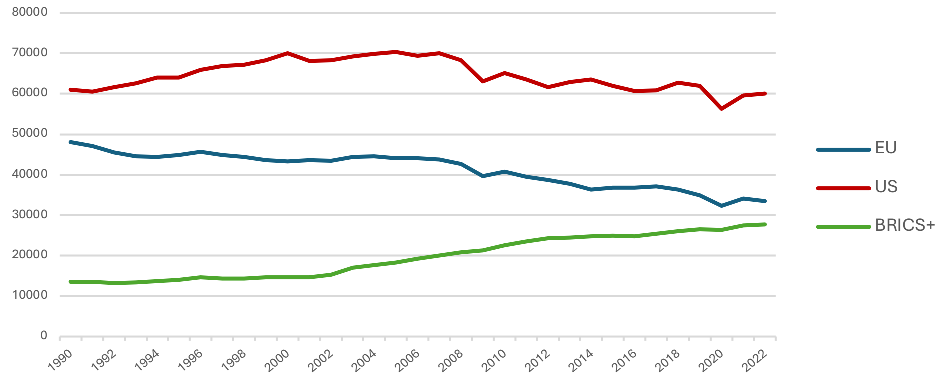
1. Introduction

In recent decades, human activity has placed unsustainable pressure on the environment. Economic growth has traditionally relied on resource-intensive, greenhouse gas (GHG)-emitting models, leading to severe environmental impacts such as climate change, resource depletion, air and water pollution. Despite growing awareness, transitioning from fossil fuels to sustainable alternatives remains challenging due to path dependence[5]. This characterizes the energy transition paths of many economies, including the United States, the European Union, and BRICS countries - the world's largest GHG emitters. Specifically, together they account for a substantial share of global emissions, with the US returning to emission levels seen in 1990, the EU experiencing a slight decline in recent years and the BRICS+ countries showing an upward trend (Figure 1)[6].

Figure 1. GHG emissions in the US, EU and BRICS+ from 1990 to 2022



Source: Author's own creation from Jones et al. (2024), Population based on various sources (2023) – with major processing by Our World In Data.

As leaders in renewable investments, the US and EU face both opportunities and challenges in transforming their economies and influencing global markets. Meanwhile, the original BRICS countries now expanded into BRICS+ continue to depend heavily on emissions-driven energy sources[7]. Greenhouse gas emissions remain substantial across BRICS+ economies, where traditional energy sources still play a central role in supporting economic activity.

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[5] Path dependency is defined as the tendency of past decisions and events to reinforce themselves, limiting future options.

[6] Among top emitters, in 2022 the United States, China and India increased their emissions compared to 2021.On the contrary, the other top emitters, namely the EU27, and the rest of BRICS economies decreased their emissions in 2022.

[7] The original BRICS countries—Brazil, Russia, India, China, and South Africa—formed a coalition to promote economic cooperation and influence global economic policies. In January 2024, Egypt, Ethiopia, Iran, and the United Arab Emirates joined the group, expanding its reach and influence. With these new members, the alliance has been rebranded as BRICS + to reflect its broader, more inclusive membership.

In this context, understanding the factors that influence GDP is crucial for achieving sustainable economic development. While traditional growth models tend to focus mainly on increasing economic output, they often fail to consider the environmental costs of growth, such as high emissions, as well as the social impact on local communities. Considering that this study aims to explore how greenhouse gas emissions, urbanization, and renewable energy influence economic growth, providing insights into how these factors can be managed to support economic and environmental sustainability. This analysis allows us to identify economic pathways that support a sustainable development minimizing environmental impacts and promoting overall well-being for both developed and developing economies. Specifically, by employing a panel regression on balanced data from the US, EU27, and BRICS+ economies from 1990 to 2022, and performing various empirical tests, we address the following questions: 1) What impact do greenhouse gas emissions have on economic growth across different economies, and what causal relationships exist between these variables? 2) Could the economic growth trajectory of emerging markets shift with the inclusion of new BRICS+ members? 3) Does the Environmental Kuznets Curve (EKC) hypothesis hold for both developing and developed economies?

Main results are following. **First,** greenhouse gas emissions have a unidirectional effect on GDP growth across all panels. This highlights the impact of emissions-intensive activities, such as manufacturing and industry, on economic growth, though it also raises concerns about sustainability. Furthermore, developed economies exhibit a more complex dynamic: while emissions maintain a unidirectional relationship with GDP growth, renewable energy demonstrates a bidirectional relationship with GDP. This suggests that as these economies expand, investments in renewable energy not only support sustainability but also drive further economic growth. **Second,** in BRICS+ countries, there is a strong bidirectional causality between urbanization and GDP illustrating how urbanization and industrialization are intertwined with growth in emerging economies. Additionally, the reliance on emissions-driven activities underscores the immediate growth priorities of BRICS+ countries but suggests future sustainability challenges. **Third,** the Environmental Kuznets Curve (EKC) hypothesis is supported. Specifically, our findings indicate that economic growth initially drives emissions higher. However, as incomes rise, countries become increasingly able to invest in cleaner technologies, facilitating a shift toward more sustainable growth. This shift not only mitigates environmental damage but also contributes to improved social well-being and fosters healthier living conditions in the long term.

Recent research explores a variety of hypotheses to explain the relationship between greenhouse gas (GHG) emissions, renewable energy use, and economic growth. Numerous studies focus on identifying the direction and causality of these relationships (Asumadu-Sarkodie & Owusu, 2016; Nguyen & Kakinaka, 2019; Bekun et al., 2019; Inglesi-Lotz & Dogan, 2018; Rehman et al., 2020). Some studies examine developing economies using panel data (Al-Mulali, 2012; Narayan & Narayan, 2010; Bekun et al., 2019; Khoshnevis Yazdi & Ghorchi Beygi, 2018; Nguyen & Kakinaka, 2019; Inglesi-Lotz & Dogan, 2018; Rehman et al., 2020), while others analyze a broader set of countries or focus specifically on developed economies (Burnett et al., 2013; Bleviss, 2021; Haider, Bashir, & ul Husnain, 2020; Popescu et al., 2022).

This paper contributes to existing literature by introducing three novel insights. This study is one of the first to analyze the expanded BRICS+ group, which now includes Egypt, Ethiopia, Iran, and the UAE. It offers a timely perspective on how these diverse economies, with their unique economic structures, energy demands, and environmental policies, influence global sustainability. By incorporating these new members, the study extends previous research focused solely on the original BRICS nations and enhances understanding of how varying sustainability policies can shape the growth trajectories of emerging markets.

Moreover, this paper is among the few to examine both carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions when assessing greenhouse gas (GHG) impacts in emerging economies. While most studies have primarily focused on CO_2 due to its prominence, nitrous oxide often neglected is equally important, given its high global warming potential and significant role in sectors like agriculture and waste management. By incorporating both CO_2 and N_2O emissions, our study provides a more comprehensive understanding of how different GHGs influence economic growth in both developed and developing economies.

Lastly, our study makes a pioneering contribution to both the growth hypothesis literature and EKC theory, exploring the intricate relationships between economic growth and gas emissions, renewable energy and urbanization.

The remaining work is organized as follows: section 2 provides the literature review. The data and methodologies employed in this work are presented in section 3. The preliminary results are shown in section 4. Section 5 presents the empirical findings of this work. Finally, section 6 provides the conclusion and policy implications.

2. Literature review

Over the past decade, a number of studies have contributed to the development of four causality hypotheses which seek to explain the relationship between economic growth with GHG emissions, urbanization and renewables. These hypotheses are: growth, conservation, feedback, and neutrality. Moreover, numerous studies have tested the Environmental Kuznet Curve theory for different economies.

The growth hypothesis suggests that GHG emissions are an essential component of economic growth, meaning that any increase in emissions can directly stimulate economic activity. Apergis (2010) highlights that nuclear energy consumption significantly reduces CO_2 emissions in both short- and long-term scenarios. Similarly, Al-Mulali (2014) observes that in Sub-Saharan Africa, energy consumption promotes both economic growth and financial development. However, the trade-off is a rise in emissions, underscoring the importance of policies aimed at improving energy efficiency to sustain economic growth while minimizing environmental degradation.

The conservation hypothesis posits a unidirectional causal relationship between economic growth and emissions, suggesting that energy conservation policies would not have a detrimental impact on economic growth. For instance, Inglesi-Lotz (2015) found that while non-renewable energy consumption increases pollution levels in Sub-Saharan Africa, renewable energy use contributes to environmental improvement by lowering emissions. These findings support the conservation hypothesis, suggesting that policies focusing on renewable energy adoption could sustain growth while enhancing environmental quality. Moreover, in developed nations, the conservation hypothesis aligns with energy efficiency strategies that aim to decouple economic growth from energy consumption, fostering sustainable development.

The feedback hypothesis presents a bidirectional relationship, whereby changes in energy consumption influence economic growth, and vice versa. Khoshnevis Yazdi and Ghorchi Beygi (2018) identified such bidirectional causality between economic growth and CO_2 emissions in African countries, suggesting that economic expansion and emissions mutually reinforce each other. Bekun et al. (2019) also support the energy-led growth aspect of this hypothesis, demonstrating that energy consumption plays a significant role in driving growth. Additionally, Wang et al. (2022) investigate the relationship between renewable energy use and economic development in OECD countries and conclude that renewable energy positively influences economic growth.

Lastly, the neutrality hypothesis states that changes in energy use have no significant impact on economic growth, asserting their independence. Research findings on this hypothesis are more limited, particularly in developing regions, where energy use often correlates strongly with economic performance. However, Nguyen and Kakinaka (2019) shed light on income-related differences in this relationship. They find that renewable energy contributes to emission reductions and growth in high-income countries. Conversely, in low-income countries, renewables may paradoxically lead to higher emissions and lower output due to infrastructure and technological constraints, highlighting the limitations of the neutrality hypothesis in regions without robust energy systems. Moreover, Sadiq et al. (2023) analysis a panel of South Asian nations and finds that economic growth does not act as a driver for changes in gas emissions.

In regard to the Environmental Kuznets Curve (EKC), a significant body of literature has examined the relationship between economic growth and greenhouse gas emissions through the lens of this hypothesis. This theory posits that environmental quality initially deteriorates during the early stages of economic development but begins to improve once income per capita surpasses a certain threshold. Specifically, Hasan et al. (2023) investigate the EKC hypothesis by analyzing the connection between industrial growth and CO_2 emissions in the BRICS. Their findings affirm the validity of the EKC hypothesis. Similarly, Umalla and Goyari (2020) explore the impact of clean energy consumption on economic growth and CO_2 emissions within the EKC framework, focusing on the BRICS nations. Their analysis reveals that while traditional energy consumption increases CO_2 emissions, clean energy consumption significantly mitigates them, further supporting the EKC hypothesis in these countries. Zeraibi, A., et al. (2022) identifies an inverse U-shaped relationship between real GDP per capita and per capita carbon dioxide emissions in a sample of 11 developing nations. Mahamood et al. (2023) findings indicate that the EKC hypothesis is more frequently supported than rejected in Chinese literature, particularly when global pollution proxies are used. Finally, Khan and Kong (2019) investigate the relationship between core energy consumption and country-specific factors through the EKC hypothesis, analyzing panel data from 29 countries (14 developed and 15 developing). Their findings, confirm the EKC hypothesis for emissions from solid and liquid fuels, gases, manufacturing, and construction sectors.

This work advances the current body of research by introducing novel insights. This study is one of the first to analyze the expanded BRICS+ economies, including the new members added in January 2024, extending previous research by assessing whether sustainability trends in the original BRICS group apply to a broader set of emerging economies. Moreover, our study is among the first ones to examine both CO_2 and nitrous oxide (N_2O) emissions, offering a more comprehensive view of how different greenhouse gases impact economic growth. Differently from Bui (2023) exploring financial variables, and Haider (2022) and Rehman (2020) focusing on sector-specific impacts within agriculture in a single country, we analyze the macroeconomic dynamics across BRICS+, the US, and the EU27 regions. Additionally, the study contributes to the literature on the growth hypothesis and Environmental Kuznets Curve (EKC) theory by exploring the complex interactions between economic growth, emissions, renewable energy, and urbanization in a unified framework. Unlike previous studies (Wang et al., 2022; Xue et al., 2022; Aslan et al., 2022; Sadiq et al., 2023; Shokoohi, 2022) which often focus on a single aspect, our research integrates these elements comprehensively, enriching the discussion on sustainability across diverse economic contexts.

3. Data and Methodology

This research adopts a multitude of econometrics techniques to empirically analyze the relationship between GDP growth with carbon dioxide emissions, nitrous oxide emissions, renewable energy and urbanization for developed countries and the BRICS+ group as of January 2024. Before running the regression, we test for stationarity[8], cointegration and granger causality between the variables.

Equations 1 and 2 are set up to perform the balanced panel data regression analysis:

$$\text{lnY}_{it} = \beta_0 + \beta_1 lnC_{it} + \beta_2 ln\text{N}_{it} + \beta_3 lnR_{it} + \beta_4 ln\text{U}_{it} + \beta_5\text{B} + \beta_6 lnC_{it} * \text{B} + \beta_7 ln\text{N}_{it} * \text{B} + \beta_8 lnR_{it} * \text{B} + \beta_9 ln\text{U}_{it} * B + \varepsilon_{\text{it}} \quad (1)$$

$$\text{lnY}_{it}^2 = \alpha + \beta_{10} lnC_{it} + \beta_{11}\text{lnN}_{it} + \beta_{12} lnU_{it} + \beta_{13}\text{lnR}_{it} + e_{\text{it}} \quad (2)$$

where i indicates the countries; t represents the time and β_j with j=1, 2…13 represents the coefficients. β_0 and α are constant terms. While ε_{it} and e_{it} are the error terms.

[8] The ADFT results are shown in Appendix A.

The dependent variable in the first equation is Y_{it}, denotes Real GDP growth and serves as a fundamental indicator of economic performance. For the second equation the dependent variable is Y_{it}^2 to tests the Environmental Kuznets Curve (EKC) hypothesis. This specification enables us to investigate the possibility of a non-linear, inverted-U relationship between GDP and environmental degradation[9]. As for independent variables, N_{it} denotes nitrous oxide emissions growth and is included due to the high global warming potential, providing a broader perspective on greenhouse gas impacts beyond *carbon dioxide* (CO_2) which is also included in our analysis as C_{it}; R_{it} refers to Renewable Energy consumptions as a percentage of final energy consumption in terms of annual growth and is employed to analyze its role in reducing emissions and promoting sustainable growth. Lastly, U_{it} represents Urbanization, in terms of % of the whole population and annual growth, this variable enables us to capture the potential intensification of emissions in highly populated areas. In addition, to analyze the impact of the new BRICS+ economies in the first equation, we introduce additional variables. Specifically, B is the dummy identifying the new BRICS+ members, while $\mathrm{C_{it}} * \mathrm{B}$, $\mathrm{N_{it}} * \mathrm{B}$, $\mathrm{U_{it}} * \mathrm{B}, \mathrm{R_{it}} * \mathrm{B}$ are interaction terms examining the effects of the regressors in relation to the new entries in the BRICS+ bloc.

The data for this analysis, sourced from the World Bank and FRED, include several key variables to comprehensively examine the relationship between economic growth and emission reduction in BRICS+ countries, the European Union 27 members, and the United States from 1991 to the 2022[10].

4. Preliminary Results

To present sections presents the Johansen test to test for cointegration. Following, it runs the Granger Causality test to establishing causal directions. After the preliminary results the study proceeds with a regression model[11].

4.1.Cointegration Test

[9] In this model, pollution initially rises with economic growth, but as GDP continues to increase, it eventually declines, suggesting that higher income levels may correlate with improvements in environmental quality.
[10] The descriptive statistics is presented in Appendix B
[11] Johansen, S.,1988, Saint Akadiri et al. 2019; Onifade et al. 2020; Alola and Kirikkaleli 2019.

The Johansen test provides a comprehensive analysis of the dynamic interactions and shared stochastic trends among the variables under consideration[12]. The null hypothesis is that there are at most r cointegrating relationships among the variables in the system[13]. The following table shows results.

Table 1. Cointegration test results.

	Test	***10%***	***5%***	***1%***	***Eigen Value***
r ≤4	25.85	7.52	9.24	12.97	0.2442
r ≤3	212.36	17.85	19.96	24.6	0.211
r ≤2	443.31	32	34.91	41.07	0.1776
r ≤1	723.24	49.65	53.12	60.16	0.1461
r ≤0	1053.86	71.86	76.07	84.45	0.02165

Source: Authors' Calculations.

Since we reject the null hypothesis for all values up to r=4, this test suggests that there are 5 cointegrating relationships among the variables at the 10%, 5% and 1% significance level implying they share a long-term relationship. Any short-term deviation among them is likely to be corrected over time, especially with faster adjustments in renewable energy usage.

4.2.Granger Causality Test

While examining the casual relationship between variables, we employ Granger Causality test. This test operates by estimating two autoregressive models: one in which Y is regressed only on its own lagged values, and another in which Y is regressed on both its own lagged values and lagged values of X. If including past values of X significantly enhances the prediction of Y, then X is said to Granger-cause Y. Therefore, our null hypothesis will be X does not Granger-cause Y. The following table summarizes results of the multivariate causality first for the Panel, then for developed economies and the BRICS+ group.

Table 2: Granger Causality tests.

Null Hypothesis	**F-Statistics**	**P-value**
		Panel
Carbon Emissions ≠> GDP	2.1007	0.0484
Nitrous Emissions ≠> GDP	5.0889	0.002
Renewable Energy ≠> GDP	1.5892	0.1902
Urbanization ≠> GDP	4.4618	0.004
GDP ≠> Carbon Emissions	0.8388	0.4726
GDP ≠> Nitrous Emissions	1.7563	0.1538
GDP ≠> Renewable Energy	0.8152	0.4855

[12] The test operates within a Vector Autoregressive (VAR) model framework, systematically assessing the rank of the cointegration matrix through trace and maximum eigenvalue statistics to determine the number of distinct long-term relationships.
[13] r can range from 0 (no cointegration) to k−1, with k being the number of variables.

GDP ≠> Urbanization	6.4398	0.0002
		Developed Economies
Carbon Emissions ≠> GDP	0.0598	0.0481
Nitrous Emissions ≠> GDP	2.1958	0.0471
Renewable Energy ≠> GDP	1.3659	0.0118
Urbanization ≠> GDP	3.054	0.0117
GDP ≠> Carbon Emissions	1.6228	0.1825
GDP ≠> Nitrous Emissions	0.9028	0.4392
GDP ≠> Renewable Energy	1.2142	0.0174
GDP ≠> Urbanization	2.3795	0.0093
		BRICS+
Carbon Emissions ≠> GDP	6.0258	5.3e-04
Nitrous Emissions ≠> GDP	5.5556	0.0010
Renewable Energy ≠> GDP	0.7451	0.826
Urbanization ≠> GDP	1.4225	0.0264
GDP ≠> Carbon Emissions	1.5558	0.2004
GDP ≠> Nitrous Emissions	0.4131	0.7437
GDP ≠> Renewable Energy	0.4969	0.6847
GDP ≠> Urbanization	7.3075	9.8e-05

Note: for a p-value < 0.05 we reject the null hypothesis that is: X does not Granger Cause Y
Source: Authors' Calculations.

In the overall **panel**, there is evidence that carbon and nitrous emissions as well as urbanization Granger cause GDP, with p-values of 0.0484, 0.002 and 0.004, respectively. Additionally, GDP Granger causes urbanization (p = 0.0002), indicating a bidirectional relationship where economic growth can also drive further urbanization.

The positive link between emissions and GDP growth suggests that economic activities associated with higher emissions, perhaps industrial processes, are contributing to growth. However, this could signal environmental concerns, as it implies that economies might be relying on emission-heavy activities. Moreover, the bidirectional causality between GDP and urbanization may be attributed to mutually reinforcing dynamics. Higher GDP growth frequently results in increased urbanization as economic expansion creates employment opportunities, attracts people to cities and enables investment in urban infrastructure. Urbanization, in turn, stimulates further GDP growth through higher productivity, larger labor markets and economies of scale[14].

In **developed economies**, there is a unidirectional causality between emissions and GDP, with a significance at 5% for both GHG emissions. The reason lies in the fact that developed economies have likely achieved a degree of decoupling, where economic growth becomes less

[14] The birectional causality does not entails problems in the regression models as urbanization is not a key variable in our analysis.

reliant on increasing emissions due to efficiency gains and cleaner technologies. Instead, renewable energy and urbanization have a bidirectional causality with GDP. This shows how as economic growth boosts urban development by enabling infrastructure investments, urbanization drives further GDP growth through productivity gains and economies of scale. Similarly, higher GDP levels support investments in renewable infrastructure, which in turn promotes sustainable economic growth by reducing energy costs and fostering innovation.

Lastly, for **BRICS+** countries, carbon and nitrous emissions both Granger cause GDP, with p-values of 5.3e-04 and 0.010, respectively. This causality implies that emissions-intensive activities are currently drivers of economic growth in these economies. Additionally, the bidirectionality with urbanization and GDP indicates that economic growth is a catalyst for urban expansion in these countries and vice versa (Jiang, W., & Yu, Q., 2023)[15].

5. Regression Results

This section studies how dangerous greenhouse gas emissions, renewable energy and urbanization can affect economic growth, for BRICS+ countries, the 27 members of the European Union and United States. The aim is to catch the long-run effects of greenhouse gas emissions on economic growth employing a dataset from 1990 to 2022.

Table 3 presents the results of the 4 balanced panel regression models with fixed effects. Specifically, the first model analyses the entire panel. The second model by applies the GDP^2 to tests the EKC theory on both developed and developing economies. The third models uses the panel data for developed economies, namely the 27 members of the European Union and the US. Lastly, model 4 employs only BRICS+ economies to study the impact of emissions on emerging economies.

Table *3* - Results of the Regression Analysis

	Model I	***Model II***	***Model III***	***Model IV***
	Panel		***Developed***	***BRICS+***
	GDP	GDP^2	***GDP***	***GDP***
Constant	3.145***	19.952***	3.145***	1.898***
	(0.149)	(1.498)	(0.150)	(0.314)
New	1.247***			
	(0.349)			

[15] Our results are in line with Ortega-Ruiz, G., et. Al., 2022; Acheampong, A. O., 2018; Jiang, W., & Yu, Q., 2023.

CO2*New	0.151***			
	(0.044)			
N2O*New	0.0070*			
	(0.055)			
Renewable Energy*New	0.006			
	(0.015)			
Urbanization*New	2.955***			
	(0.434)			
Carbon Dioxide	0.142***	-0.810***	0.143***	0.293***
	(0.019)	(0.184)	(0.019)	-0.04
Nitrous Oxide	0.109***	-0.434**	0.095***	0.179***
	(0.021)	(0.203)	(0.021)	-0.05
Renewable Energy	0.012**	0.036*	0.007*	0.018*
	(0.006)	(0.06)	(0.005)	-0.014
Urbanization	1.284***	-2.049	1.145*	1.671***
	(0.355)	(9.335)	(0.607)	-0.249
Observations	1,184	1,184	896	288
R2	0.837	0.718	0.710	0.783
Adjusted R2	0.828	0.716	0.706	0.774
Residual Std. Error	3.542 (df = 1169)	51.518 (df = 1179)	3.579 (df = 891)	3.556 (df =283)
F Statistic	25.961*** (df = 14; 1169)	7.310*** (df = 3; 1179)	27.583*** (df = 4; 891)	43.905*** (df = 4; 283)

*Note: the table reports the regressions analysis results with significance level at *p<0.1; **p<0.05; ***p<0.01*
Source: Authors' Calculations.

Our analysis yields several key insights regarding the impact of greenhouse gas emissions, renewable energy and urbanization on economic growth.
The dummy variable captures the additional growth effect associated with BRICS+ countries compared to the overall panel. The coefficient is positive and highly significant, suggesting that new entries of BRICS+ economies entails a higher GDP growth. The higher value likely due to rapid industrialization, urbanization, and growing energy demands in these emerging markets.

The Carbon Dioxide and BRICS+ new entries interaction term[16] is positive and significant. This result suggests that BRICS+ countries' economic growth is closely tied to carbon-intensive industries, reflecting a reliance on fossil fuels. This dependency may raise future environmental concerns and sustainability challenges for these economies. Interestingly, the interaction with N_2O and BRICS+ new entries is positive but weakly significant. This

[16]The Carbon Dioxide and BRICS+ new entries interaction term tests whether the effect of CO_2 emissions on GDP growth differs in BRICS+ economies compared to the rest of the panel.

difference may stem from the fact that N_2O emissions are typically associated with specific sectors, such as agriculture and waste management, rather than the broader industrial and energy sectors that predominantly drive economic growth in the new BRICS+ entries.

Let's now analyze the common regressors in the models. The positive and highly significant coefficients for both GHG emissions in both the full panel (Model I) and developed economies (Model III) indicate a strong link between carbon and nitrous emissions and GDP growth, emphasizing the ever-growing dependency on gas emissions for all types of economies. The coefficient for both GHG emissions in BRICS+ economies (Model IV) is even larger, reflecting a common reliance on industrial, emissions-heavy activities. This relationship highlights that as these economies undergo growth and industrialization, they increasingly face sustainability challenges intensified by ongoing urbanization and expansion. In Model II, the dependent variable is GDP^2, which allows for testing the EKC hypothesis. The negative coefficients for CO_2 and N_2O suggest that while economic growth initially leads to higher pollution levels, rising income eventually prompts greater investment in cleaner technologies, which in turn reduces pollution. The shift from fossil fuels usage to renewable energies mitigates environmental damage but also contributes to improve social well-being and fosters healthier living conditions in the long term.

The impact of renewable energy on GDP is small but significant in both the panel (Model I) and developed economies (Model III). In Model IV, renewable energies show weak significance, indicating a modest contribution to growth in BRICS+ economies. This result suggests that, for developing economies, the renewable energy sector has matured to a level that not only addresses domestic energy needs but also promotes technological advancement and energy self-sufficiency. Lastly, the variable urbanization is positive and significant across all models, suggesting that urbanization is a significant contributor to GDP. The impact of urbanization on GDP is much stronger in BRICS+ economies, showing that urban growth is especially beneficial in these rapidly urbanizing regions. In contrast, for developed economies, the focus may have shifted from expansion to optimizing existing urban areas, improving infrastructure efficiency, and enhancing livability. The strong impact of urbanization on GDP in BRICS+ economies reflect the transformative economic impact of urban migration and the concentration of economic activities in cities. Urban centers foster innovation, boost productivity, and attract foreign investments, which all boost GDP.

6. Conclusions and Policy Implications

Over the past few decades, the global economy has faced a deepening environmental crisis, driven mainly by unsustainable, greenhouse gas-emitting growth patterns. Due to path dependency, transitioning from fossil fuels to sustainable solutions remains challenging in many economies, including the United States, the European Union, and the BRICS+ countries. This requires a new approach to economic growth considering environmental costs associated with high emissions in pursuing social well-being. In this context, it is essential to understand how factors affect GDP in achieving sustainable economics. To this end, this study contributes to knowledge by delving into how GHG emissions, renewable energy, and urbanization affect GDP growth across diverse economic settings by employing balanced panel data for the US, EU27, and BRICS+ countries from 1990 to 2022.

The results show significant relationships between greenhouse gas emissions, renewable energy, urbanization and economic growth. Carbon dioxide and nitrous oxide emissions have a unidirectional effect on GDP growth across all panels, highlighting the role of emissions-intensive activities, such as manufacturing, in driving economic expansion. Moreover, there is a strong bidirectional causality between urbanization and GDP in BRICS+ countries, illustrating how urbanization and industrialization are intertwined with growth in emerging economies. Lastly, the EKC hypothesis holds for our panels. This implies that economic growth initially leads to higher levels of pollution, but over time rising incomes support investment in cleaner technologies that ultimately reduce emissions.

This paper offers several key policy recommendations aimed at fostering both economic growth and environmental sustainability. First, policymakers should prioritize industrial strategies that accelerate the transition to low-carbon emissions, particularly in manufacturing and heavy industries. By adopting cleaner and more efficient production methods, nations can drive economic growth while simultaneously lowering their carbon footprints, paving the way for sustainable development. This dual approach not only drives environmental sustainability but also delivers long-term social benefits, such as improved public health and well-being.

Second, for countries that have yet to introduce carbon taxes, particularly those within the BRICS+ group, adopting this market-based mechanism could be an effective strategy. By directly pricing carbon-intensive activities, businesses and consumers would be incentivize to reduce emissions. This system would empower countries to meet global emissions reduction targets while stimulating the growth of green sectors and fostering economic resilience. Furthermore, extending carbon taxes globally would establish a fair and unified framework, ensuring that all economies contribute to emissions reductions while promoting sustainable growth.

Finally, urbanization and industrialization continue to propel economic growth, especially within BRICS+ economies. Therefore, it is essential to include sustainability within their development models. Policies focused on energy-efficient infrastructure, green building practices and sustainable urban planning are pivotal in reducing the environmental impacts of urban expansion. These initiatives not only promote growth but also ensure that it remains within ecological limits, enhancing the quality of life and resilience of communities. By adopting these strategies, economies can create a balanced, sustainable development model that supports both environmental sustainability and socio-economic prosperity.

Along this line of research, other features could be included in the analysis. Specifically, incorporating green investments would be particularly valuable, given their potential to reduce greenhouse gas emissions and impact economic growth. Additionally, accounting for external investments and considering a broader range of greenhouse gases could provide a more comprehensive perspective on the relationship between economic growth and emissions. Furthermore, employing quarterly data or adopting a dynamic model could yield deeper insights. We leave these extensions for future research.

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Appendix A - ADFT

The first step of any econometric exercise is to explore whether a given series is stationary or not. For this purpose, our study applies the technique developed by Levin et al. (2002, hereafter LLC).

For the LLC panel unit root test, consider the following panel ADF process:

$$\Delta y_{i,t} = \rho_i y_{i,t-1} + \Sigma \rho_{i,j} y_{i,t-j} + \varepsilon_{i,t}$$

Levin (2002) assumes that the persistence parameters are common across cross-sections $\rho_i = \rho$. The First Differences is indicated with Δ. j stands fir the optimal lag chosen by AIC and SBC. The null hypothesis of a unit root tested over the alternative hypothesis of no unit root, that is, H_o: $\rho_i = 0$ for all i and H_1 : $\rho_i < 0$

For all tests, null hypothesis of a unit root is tested over alternative hypothesis of no unit root. Table A depict the unit root tests results. The results show that all the variables $GDP, GDP^2, CO_2\ , N_2O\ ,\ R, and\ U$ are stationary in its first difference.

Appendix A - Levin-Lin-Chu Unit-Root Test

	Statistics	***p-value***
$\boldsymbol{GDP}$	-12.492	0
$\boldsymbol{GDP^2}$	-11.452	0
$\boldsymbol{CO_2}$	-23.264	0
$\boldsymbol{N_2O}$	-23.93	0
$\boldsymbol{R}$	-20.859	0
$\boldsymbol{U}$	-15.921	0

Appendix B - Descriptive Statistics

Table B reports the descriptive statistics for the whole data Panel, for Developed Economies and BRICS+ bloc across five variables GDP, CO_2, N_2O , Renewable Energy and Urbanization:

Appendix B - Descriptive Statistics

		Mean	Median	S.D.	Kurtosis	Skewness
Panel	***GDP***	3.049	3.072	4.032	3.063	-0.516
	Urbanization	0.396	0.271	0.613	6.864	2.277
	CO_2	-0.682	-0.475	6.415	5.273	-0.497
	N_2O	-0.192	0.168	5.532	6.423	-1.116
	Renewable Energy	5.382	2.038	20.869	154.829	9.860
		Mean	***Median***	***S.D.***	***Kurtosis***	***Skewness***
Developed Economies	***GDP***	2.644	2.804	3.786	4.330	-0.604
	Urbanization	0.223	0.215	0.337	1.956	0.883
	CO_2	-1.448	-1.145	6.439	5.307	-0.422
	N_2O	-0.849	-0.274	5.743	6.588	-1.165
	Renewable Energy	6.750	3.637	22.248	154.722	10.270
		Mean	***Median***	***S.D.***	***Kurtosis***	***Skewness***
BRICS+	***GDP***	4.309	4.472	4.495	1.504	-0.679
	Urbanization	0.934	0.798	0.902	0.594	1.083
	CO_2	1.700	1.699	5.731	8.231	-0.746
	N_2O	1.850	2.129	4.218	1.531	-0.075
	Renewable Energy	1.126	-0.279	15.084	23.093	3.964

Note: the table reports the descriptive statistics for the whole panel, the developed economies and BRICS+ countries.
Source: Authors' Calculations.

Panel-wide trends show a positive GDP, Urbanization and Renewable Energy while the mean for both GHG emissions is negative. Notably, skewness and kurtosis values for Renewable Energy are extremely high in all groups, suggesting heavy-tailed distributions, likely due to large differences in renewable energy adoption across countries.

For **Developed Economies**, while the mean values for GDP and Urbanization and GHG emissions are lower than the one shown for the whole Panel. Renewable Energy mean is higher, suggesting renewable energy integration in more industrialized nations. Transitioning to renewables can reduce dependency on imported fuels, lower emissions, and promote energy security.

Lastly, **BRICS+** display a higher GDP and positive averages for both GHG emissions, indicating potentially more carbon-intensive industries and energy generation. Their Renewable Energy mean is lower, which could reflect less developed infrastructure for sustainable energy. Additionally, high urbanization in BRICS+ suggests rapid development, which, without planning, can lead to issues like overcrowding, pollution, and strained infrastructure.