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Research Article

Panel Examination of the impact of economic growth on Carbon Emissions—Case of 15 emerging and advanced economies

Joseph-Tuakolon Tokpah, Mehdi Seraj*, Huseyin Ozdeser

Department of Economics, Near East University, Nicosia, North Cyprus
E-mail: mehdi.seraj@neu.edu.tr

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Abstract: In today's world, there are numerous urgent global challenges that require our attention, prominent among those issues is the need to address climate change. Due to this, governments around the world have united in support of initiatives such as the Sustainable Development Goals, which seek to achieve a harmonious balance between development and the protection of the environment. The pivotal roles that environmental conservation measures, technical progress, and contemporary industrial strategies play are essential for the economic expansion of developing and industrialized countries in lowering CO_2 emissions. Therefore, this study suggests that expanding green growth through the consumption of renewable energy is an effective strategy to mitigate CO_2 emissions and achieve sustainable development, thus improving the contribution to environmental quality. Consequently, this research explores the long-term relationship between per capita CO_2 emissions and economic development in 15 industrialized and developing countries with data spanning from 1991 to 2019. The present study employs PMG-ARDL estimation technique to rigorously examine the research objectives. The result shows that in the long run, both FDI and quadratic GDP significantly and negatively influence carbon emissions in industrialized nations. However, the other elements have a substantial positive and negative impact on climate change. The result also showed that increasing FDI reduces carbon emissions in industrialized countries. However, the opposite is true for emerging ones. Additionally, the findings of this article indicate that there is a considerable positive correlation between the use of fossil fuels and the progression of climate change in both developed and developing nations. Therefore, the findings of this research provide credence and legitimacy to the notion of the Kuznets curve when viewed and compared in the context of both emerging and developed economies.

***Keywords*:** carbon emission; Environmental Kuznets curve; economic growth; fossil fuel consumption; foreign direct investment

1. Introduction

The history of the industrial revolution has taught us that excess fossil fuel energy is one of the primary drivers of carbon emissions into our environment. As a result, the link between economic expansion and carbon emissions has sparked much debate among academics. As a result, the most pressing concern facing the world today is sustainable development, which involves protecting the environment without jeopardizing the pursuit of economic progress (Costa-Campi et al., 2017; Landrigan et al., 2018). The natural environment has been shown to suffer from different types of industrialization in developed and developing nations; nonetheless, despite the damage that economic growth has caused. Environmental pollution is a significant consequence of human health problems, with one in every ten fatalities linked to poor air quality (World Bank, 2016; By 2060, 6–9 million

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people will have died prematurely). On the other hand, countries with low and moderate income levels account for roughly 92% of pollution-related fatalities (IPCC, 2018). If CO2 emissions continue to rise at their current rate, the world will soon face increasingly severe environmental concerns (Landrigan et al., 2018). Gyamfi et al. (2021) and Tsadiras et al. (2021) proposed the EKC hypothesis to investigate the link between economic activity and environmental degradation. Their study found that increasing renewable energy sources in the seven countries evaluated could reduce pollution emissions, as energy is inextricably tied to economic growth. However, increased CO2 emissions degrade environmental quality and contribute to global warming. Shah et al. (2022) study on Pakistan's socioeconomic impact of environmental deterioration revealed a U-shaped relationship between ecological footprint and real GDP, and an inverted U-shaped relationship between CO_2 emissions and GDP. The study also revealed a negative correlation between power use and environmental deterioration, suggesting a need for energy conservation and the transition to renewable energy sources such as solar and wind for a sustainable future. Furthermore, Bilgili et al. (2016) studied the effect of renewable energy use on CO_2 emissions using a panel data set of 17 OECD nations from 1977 to 2010. Their results validate the EKC hypothesis and show that GDP per capita and GDP per capita squared positively and negatively affect emissions. However, Wang et al., 2020; & Weldemeskel et al. (2020) provide that environmental regulations have tightened in recent years. Furthermore, it has been shown that the north-south trade of pollutants causes carbon leakage (Santos et al., 2019; Fan et al., 2019). Therefore, the amount of carbon dioxide emissions established economies generate has been drastically exaggerated. This implies that developed economies' contributions to reducing carbon emissions have been significantly overblown. Environmental degradation has caused a rise in concern about climate change and global warming due to natural factors such as insufficient allocations for land degradation neutrality, movement of continents, volcanic activity, solar radiation, ocean currents, and human actions Abbas et al. (2022). This has led to many ecological issues, making it a popular topic of debate in emerging and developed economies Zhao et al. (2019). According to scholars, the fundamental reasons for climate change include increasing human activity due to industrialization, global population growth, and the need to adapt to these changes Ozturk I et al. (2016) and Alkhathlan et al. (2015). Moreover, they argue that industrialization has resulted in a rise in carbon emissions, even though it is beneficial to the economy since it produces more goods and services, improves people's lives, and makes the world a better place. The study by Huang et al. (2023) used the Cointegrated Structural Autoregressive Distributed Lag (CS-ARDL) model to look at how industrial value-added and fossil fuel consumption affected carbon emissions in the G-20 countries from 1990 to 2020. The analysis carried out showed a favorable correlation between the use of fossil fuels and the emissions of carbon dioxide emissions. However, their research supported and confirmed the concept of the environmental Kuznets curve (EKC) in the G-20 economies. The researcher focused on China, the United States, India, Russia, and Japan, since they use the most energy and release carbon dioxide into the environment. For example, China's industrial operations accounted for 30.34% of total carbon emissions in 2022, with the USA responsible for 13.43% of the world's carbon emissions, India accounting for 6.3%, Russia for 4.7% and Japan for 3.03%. The conservation of the environment in emerging economies is an important issue that should be integrated into a comprehensive strategy for long-term economic growth. In emerging nations, preventing the overexploitation of natural resources and environmental damage has become more challenging, leading to an estimated 265 million people living in poverty between 1985 and 2000 and almost half of the world's population living in extreme poverty by the turn of the century. Examining these environmental degradation predispositions may help us appreciate the full scale of the situation and compare the problems generated by nature. Developing countries have transitioned from an agricultural-based economy to an industrialized one, but are often seen as pollution havens due to their loose environmental regulations and lack of access to financial resources. Therefore, it is crucial to determine whether improvements in environmental quality can be achieved after substantial economic expansion. To the authors' knowledge, this evaluation is the first to consider this nexus in a comparative sense for both developed and developing countries, including other controlled variables such as oil price, FDI, and fossil fuel consumption in the analysis. Our study focuses on comparing the panel of these countries for two reasons. First, regarding the categories of countries chosen by this investigation, the researcher selected 15 nations from each panel with high income, economic structure and c02 emissions per capita. Secondly, the inclusion of oil prices is based on the fact that crude oil is the world's most traded commodity and the most prominent in the nonrenewable energy market. Therefore, it is essential to determine and compare the degree of contribution of growth led by the energy consumption of developing nations, as they are heavily endowed with crude oil and therefore supply these advanced nations. Thus, we will investigate the relationship between a country's GDP, the fossil fuels it consumes, and the direct foreign investment it receives. Therefore, this research adds to the existing literature and recommendations, necessitating the need to maintain future energy security and achieve the environmental policy objectives of providing a secure environment. In the following subheadings, you will find the following. This first section covers many territories. In Section 2, we conduct an in-depth examination of the relevant literature. An economic framework and data sources are discussed in Section

3. There are results and conclusions in Unit 4 based on the study. Finally, Section 5 concludes with a discussion of choices, policy implications, and potential future paths.

2. Review of related literature

Environmental sustainability is a primary concern for researchers and governments. Research in Europe and Asia reveals links between economic growth and healthy ecosystems. However, due to GDP and other factors, environmental sustainability is weakened. Azam et al. (2022) suggest that different sectors of the economy should adopt green resources to preserve the environment. Mikayilov et al. (2018) found that economic growth negatively influences emissions using ARDL, DOLS, and FMOLS techniques. Their findings suggest that the EKC hypothesis is incorrect, as long-term economic growth positively influences emissions. Zhang et al. (2023) studied the factors that influence carbon emissions of the 15 largest natural gas producers between 2000 and 2019. They found an inverted U-shaped Kuznets curve in some economies, resulting in environmental degradation due to urbanization. The study also found an inverse relationship between technology and natural gas supplies, which affects carbon dioxide emissions and ecosystem sustainability. Urbanization and technological progress also contribute to the quality of the environment. The study proposes measures to achieve environmental sustainability. In addition, Farooq et al. (2021) examined Pakistan's environmental Kuznets curve (EKC) between 1972 and 2018, examining the impact of FDI, financial development, and urbanization on ecological footprint. The results show a statistically significant and positive correlation between urbanization, FDI, foreign development, and long-term environmental degradation. Similarly, only FDI contributes to the worsening of environmental deterioration over a limited period. Furthermore, the authors found a link between economic development and Pakistan's environmental quality that follows the reverse pattern. This finding further confirms the existence of the Kuznets (EKC) environmental curve.

Also, Radulescu et al. (2022) found that carbon dioxide emissions, renewable energy use, and Pakistan's GDP per capita positively impacted economic growth. However, the total economic development is severely affected by energy use, nuclear energy, and total electricity use. Their conclusion led to observations of Pakistan's economic development on various energy sources, including carbon emissions, clean energy, nuclear energy, and fossil fuels. Furthermore, between 1990 and 2018, Jahanger et al. (2023) evaluated the connection between electricity consumption, renewable energy, the use of natural resources and environmental degradation in the BRICS economies. Moment quantum regression was used, and the results show a link between electricity and damage to the environment. This shows how important electricity is to increase the environmental impact. Zhu et al. (2016) examined the impact of economic development and foreign direct investment (FDI) on the number of carbon emissions generated in various countries, including Indonesia, Malaysia, the Philippines, Singapore, and Thailand. Depending on the quantile, the effect of independent factors on carbon emissions may vary dramatically, as shown by the actual findings of a panel model using quantile regression. In particular, direct investment from foreign countries negatively impacts the number of CO_2 released into the atmosphere. Furthermore, using a quantile regression, Esmaeili et al. (2023) assessed the effects of FDI, economic complexity, and the use of renewable energy on CO2 emissions in the N-11 nations from 1995 to 2019. The results of their assessment show that the environmental Kuznetz curve is true across N-11 with different levels of economic complexity and thus argue that FDI is a major contributor to the environmental footprint. Similarly, Pata et al. (2022) study examines the impact of financial development on renewable energy use in the US between 1980 and 2019. The research, using the Fourier quantile causality test with wavelet transformations, found that financial development significantly positively influenced the use of renewable energy over time. In newly industrialized nations, Zhang et al. (2021) analyze the effect of OFDI, human prosperity, and other public sector macrofactors on carbon footprint, and argue that improving human well-being, increasing urbanization, and reducing emissions all contribute to lowering China's carbon footprint. On the other hand, countries with high levels of emissions can lower their emissions through solid economic expansion and population increases. Then Bamisile et al. (2021) found that economic growth positively affects total carbon emissions in Africa. As a result, GDP increases in Africa, leading to increased carbon emissions. Their study proposes that a renewable energy-based strategy for power production is needed to achieve net zero emissions from the electricity sector, with BEVs and hydrogen generation being key, like the findings of Zhang et al. (2022), which highlight the importance of biomass and hydroelectric energy in sustainable development, while labor force participation is beneficial for GG. However, they argue that capital development can hinder long-term expansion. A recent study by Samour et al. (2020) found that oil prices positively affect current account balances, GDP growth, and 15 other economic indicators, leading to increased investment and the use of nonrenewable energy in oil-exporting economies. Furthermore, the consumption of energy increases carbon dioxide emissions. Then Muhammad et al. (2020) found that population density and the use of energy derived from fossil fuels positively influence carbon emissions. This contrasts with the increase in carbon emissions, as the effects of fossil fuels, foreign direct investment, and total export have been very positive because these factors have contributed to economic expansion. Shah et al. (2021) A study of the correlation between economic growth and environmental degradation was conducted in some countries of West Asia and North Africa between 1980 and 2017. To measure long-term associations, they used IFE and D-CCE, which proved that the U-shaped inverted hypothesis was not valid for carbon emissions, but that the ecological footprint hypothesis was valid. Energy intensity and financial development are considered environmentally friendly indicators. Empirical research by Ahmad et al. (2022) found a negative correlation between greenhouse gas emissions and FDI in green and renewable technologies. Their results showed that FDI reduces carbon emissions by 0.11% in the short term and 0.14% in the long term. It can also reduce CO_2 emissions by 14% by increasing energy use and population. In addition, CO_2 emissions have been reduced in the long term due to economic expansion, financial development, and greater openness to international commerce. Likhachev et al. (2022). According to the findings of their study, there is a correlation between economic growth and environmental degradation, which provides credence to the EKC framework. However, Wen et al. (2021) conducted an analysis of the relationship between information and communication technology (ICT), renewable energy, and CO_2 emissions in the MINT countries from 1990 to 2018. They utilized quantile regression to examine the dynamic effects. The findings indicate that factors such as FD, GDP, and POP exhibit a positive association with CO_2 emissions, while ICT and renewable energy demonstrate a negative association with CO2 emissions. Then Ozdeser et al. (2021) assessed the effect of financial growth on Nigeria's energy consumption between 1960 and 2019. The ARDL bound testing method was used to establish if there was a long-term link between the variables. The data indicated a short-term connection but no long-term relationship. Financial development has a significant and negative effect on FFEC when domestic credit supplied by the financial sector (DCPF) variable is employed, but when the market capitalization of listed domestic firms (MCAP) variable is used, the effect is insignificant. On the contrary, GDP has a negative correlation with FFEC but a positive correlation with REEC. A study published in 2020 by Mita Bhattacharya, John N. Inekwe, and Perry Sadorsky found a correlation between improvements in total factor productivity (TFP), the use of clean energy, and urbanization. According to the research findings, an increase in the industry's value would result in a decreased likelihood of membership in a club with low carbon intensity. Even in nations with sound macroeconomic policies, the population of low-carbon countries may have to undergo structural changes to increase their use of renewable energy. Countries with a lot of money are more concerned about environmental advantages and more devoted to ecological management when it comes to green technology innovation Yangfan Li et al. (2022). To manage fossil fuel use and reduce CO_2 emissions, McDowall et al. (2018) studied the role of growing high-tech energy companies. Input-output modeling found that the expansion of the solar industry reduced global CO_2 emissions by 7%. In addition, they dispute the Environmental Kuznets Curve (EKC) idea by demonstrating that the slope coefficient of TFP was more relevant in the long term than over the short term. This suggests that the EKC does not adequately explain the connection between the variables. In the same vein, research conducted by Anwar et al. (2022) used quantile regression analysis to examine the varied effects of technological innovation, institutional quality, per capita income, trade openness, and population on CO_2 emissions. The data used in their study pertain to the E7 countries and covers the period from 1996 to 2018. The empirical findings substantiate the significant impact of technical innovation and institutional quality on the reduction of CO_2 emissions. Furthermore, the results of their study indicate that the prevailing trends of economic expansion in the E7 nations are characterized by a lack of environmental sustainability. Then Jiang et al. (2023) conducted a study using a panel quantile regression model to analyze the long-term impact of policy uncertainty and institutional quality on green growth in countries of E-7 between 1996 and 2019. Empirical findings suggest that economic policy has a detrimental effect on green growth in the E-7 countries. However, the quality of institutions and the use of renewable energy sources are factors that contribute positively to green growth in these countries. The study suggests that governments in these countries can improve environmental quality by prioritizing political stability and implementing reliable macroeconomic policies. Additionally, it is recommended to adopt flexible policies that can effectively address unforeseen economic challenges. Similarly, the energy economy and emissions levels of the G-7 nations were also analyzed by Cai et al. (2018). They investigated causation by doing an ARDL bounds test with structural breaks using bootstrap ARDL samples. Their study reports that economic development was also connected to carbon emissions in Germany and Japan. Energy use in Germany is inversely correlated with carbon dioxide emissions. However, the use of clean energy in the United States is merely inversely related to carbon dioxide emissions. From 1979 through 2019, a panel of researchers led by Haneklaus et al. (2022) examined the link between pure energy consumption and GDP in G7 nations, as well as openness to international commerce and urbanization. They concluded that the G7 economies are reducing carbon emissions by increasing their use of renewable energy and urbanization. Several studies show that research and innovation may help reduce China's CO_2 emissions, including those of Liang et al. (2019) and Razzaq et al. (2020). This contrasts with previous studies showing that increasing aggregate demand increases CO_2 emissions. Wang and Zhu (2020), for example, found that green innovation reduced CO_2 emissions in the G-7 nations. Furthermore, according to their study, economic growth and environmental deterioration are closely linked in BRICS countries. Baig et al. (2021). They argue that sustainable economic development and management of energy demands and crises are possible with green technology to safeguard natural resources and limit the increase in population in the future. Khan et al. (2022) studied the factors that influence carbon emissions in developing economies during a green recovery. They found that reducing energy poverty in developing nations should be a priority to achieve SDG7 and reduce CO_2 emissions. Meanwhile, urbanization is closely associated with economic development; it has led to the migration of employees from rural areas to urban centers, including industrial sectors. Thus, urbanization contributes to environmental stress (Wang et al., 2016c; Parveen & Ahmad, 2020). A recent study has examined the global link between urbanization and carbon emissions. Rehman et al. (2019) studied how international migration affected human growth and remittances in SAARC nations from 2000 to 2014. The research found that migration, commerce, population, political openness, and corruption play a role in the flow of remittances, which has been a significant factor in recent economic expansion. Financial systems can contribute to economic growth through management of deficit balance payments (BOPs), which positively affects the economy by mitigating local and national unemployment rates. Rehman et al. (2019) found that many low-income nations rely mainly on BOP for their BOP.

3. Data and methodology

3.1 *Data and variables*

This research examined data on CO_2 emissions and GDP per capita from 15 industrialized and developing countries from 1991 to 2019 to determine whether economic growth and CO_2 emissions are related. Data used were on advanced and emerging countries from 1991 to 2019 from World Data Indicators and Statistical Review of World Energy. The panel of developed nations covered under this investigation are: United states, Japan, Russia, Australia, Germany, South Korea, Denmark, Sweden, United Kingdom, Spain, Italy, France, Belgium, Netherlands, and Poland. However, the panel of developing countries is as follows: China, India, Iran, Saudi-Arabia, Brazil, Pakistan, Philippines, Iraq, South Africa, Indonesia, Turkey, Malaysia, Argentina, Bangladesh, and Thailand. These countries were selected based on their contribution to carbon emissions, economic growth, and data availability. The proxy used to measure our variables can be explained in the table below.

Table 1. List of variables employed

Variables	Proxy	Source
C02	Metric tones per capita	WDI
GDP	Per capita GDP	WDI
FDI	Foreign direct investment as a percentage of GDP	WDI
FEC	Fossil fuel consumption (% of total)	Statistical Review of world energy
WOP	World oil price (constant USD)	Statistical Review of world energy

Author's Compilation

From Table 1, Co2 will be used as our dependent variable. Our primary variable of interest is the reaction of economic growth to carbon emissions in advanced and emerging nations in the long run. FEC, FDI, and WOP will be the control variables of our analysis. All of the above variables were extracted on various pieces of literature and our theoretical framework that help to explain the impact of carbon emission. However, the author of this investigation model carbon emission as a function of GDP, GDP^2 FEC, FDI, and WOP.

Thus, the economic model of this framework can be described as follows:

$$C02= f(GDP, FEC, FDI, WOP) \quad (1)$$

Where CO2 emissions are measured as CO2 emissions in metric tons per capita, GDP is employed to represent the per capita gross domestic product, FDI represents the net inflow of foreign direct investment, and FEC was used in this study to account for fossil fuel consumption. Furthermore, the WOP represents the price of oil in the world. The data utilized in this research include yearly data for the years 1991 through 2019, resulting in 435 observations per variable for knowledge of every economy.

3.2 *Methodology and theoretical framework*

In this paper, the ARDL PMG technique developed by Pesaran et al. (1999) is used to analyze the short- and long-term relationship between carbon emissions and economic growth. In this process, samples are collected and averaged. The PMG estimator used the ARDL model's cointegration version, allowing cross-sectional changes in slope, short-term coefficients, and cointegration components. Short-term coefficients and error variances can also be variable flexibly between the heterogeneous groups of this model. However, the long-term coefficients should be the same as or identical. A simple average of a single coefficient unit gives a reliable estimate of the average of the short-term coefficient. The method is useful in examining the likely long-term correlation regardless of whether I (1) and I (0) and both I (1) are mutually integrated. Furthermore, this method provides consistent and effective estimations of endogenous and external variables, incorporating lag time, eliminating concerns related to endogeneity. The ARDL (p, q) model, which includes the long-term connection between variables, is as follows, according to Pesaran et al. (1999).

$$\boldsymbol{Y_t = y_{oi} + \sum_{i=1}^{p} \beta_i Y_{t-1} + \sum_{i=0}^{q} \beta_1 X_{t-1} + \mu_{it}} \tag{2}$$

Where Y t is the vector and the variables in X t may be a pure mix of I(0) and I(1) or co-integrated; I and _1 are the slope coefficients; y is a constant; i=1 p,q are the optimal lag orders; and _it is the vector of the error terms—an unobservable zero mean white noise vector process (serially uncorrelated or independent). However, the alphabet "p" is associated with the lag value of the dependent variable. On the contrary, the lag value of the regressors is represented by the alphabet "q," as seen in the equation above. This is because an exogenous variable's current and lagged values in the model are used to calculate that the regressor variable has lagged values. In terms of our variables, we can specify both short- and long-run form of our equations as follows:

$$\begin{aligned} C02_t = \beta_0 &+ \sum_{i=1}^{p-1} \beta_1 C02_{t-i} \\ &+ \sum_{i=0}^{q-1} \beta_2 GDP_{t-i} \\ &+ \sum_{i=0}^{q-1} \beta_3 GDPSQ_{t-1} + \sum_{i=0}^{q-1} \beta_4 FEC_{t-1} + \sum_{i=0}^{q-1} \beta_5 FDI_{t-1} + \sum_{i=0}^{q-1} \beta_6 WOP_{t-1} + \mu_i \end{aligned} \tag{3}$$

However, the re-parameterized form of EQ2 can be specified as follows:

$$\begin{aligned} \Delta C0_{2it} = \alpha_i + \delta_i C0_{2i,t-1} + \beta_{1i} GDP_{it} + \beta_{2i} GDPSQ_{it} + \beta_{3i} FEC_{it} + \beta_{4i} FDI_{it} + \beta_{5i} WOP_{it} \\ + \sum_{j=1}^{p-1} \varphi_{ij} \Delta C02_{i,t-j} + \sum_{j=0}^{q-1} \Omega_{ij} \Delta GDP_{i,t-j} + \sum_{j-0}^{q-1} \Omega_{2ij} \Delta GDPSQ_{i,t-j} \\ + \sum_{j=0}^{q-1} \Omega_{3ij} \Delta FEC_{i,t-j} + \sum_{j=0}^{q-1} \Omega_{4ij} \Delta FDI_{i,t-j} + \sum_{j=0}^{q-1} \Omega_{5it} \Delta WOP_{i,t-j} + ECT_{it-j} + \varepsilon_{it} \end{aligned} \tag{4}$$

EQ2 and EQ3 belong to long- and short-term estimations. However, the dependent variable; $C02_t$ represents carbon dioxide emissions per capita for the panel unit i at t. Subscripts (i, t, and j) represent the panel units, t represents specific time effects, and j represents the variable lag order. α_i represents a specific individual intercept for a panel unit. p and q represent the lag version of the individual regression and the regressor variables. λ_{it} represents the long-term coefficient of a delayed regression. However, β_{1i} to β_{6i} represents the slope coefficient in the long-term δ_{it} represents the short-run coefficient of the regressors. Ω_{1i} to Ω_{5i} are representative of the individual short-run coefficients. ECT_{it-j} represents the velocity of adjustment in which distortion is corrected in the next year. ε_{it} represents the random disturbance error term, and Δ represents the difference operator of the short run.

3.3 *Theoretical framework*

The EKC hypothesis proposed by Simon Kuznets (1995) suggests that pollution and other forms of degradation are severe in the early stages of economic development and less severe in the later stages. The main idea underlying EKC is that the pace of industrialization in a country leads to an increase in pollution levels, which, in turn, causes an increase in the number of resources extracted and the amount of money generated. People's awareness of environmental issues and willingness and ability to pay for cleaner energy sources begin to develop with their steadily increasing incomes. After a specific interval, pollutant emissions to begin a downward trend. In this manner, the inverted U-shape comes into existence**.** In general, a rising economy is associated with an increase in pollution. However, several factors, such as the shift to environmentally friendly technology and technical progress aimed primarily at reducing pollution, might mitigate the effect of the correlations between the two variables. Future loosening of these ties may be constrained by uncertainty about the feasibility of infinite replacement or technological advancement. When a country's economic development reaches a peak, environmental degradation also increases until that point, at which point further economic expansion causes environmental degradation to decline **(**Grossman & Kruger, 1955; Shafik, 1994; Stern, Common & Babbier, 1996). According to Qin et al. (2021), China is one of the biggest carbon dioxide emitters, demonstrating the increasing dependence in fossil fuels on countries of low-income to high-income countries, which contributes to environmental deterioration worldwide. Therefore, countries must use RE sources that do not release greenhouse gases to achieve rapid economic development. According to Dietz et al. (2012), nations will experience minimal environmental stress and improvements in economic development if they switch from utilizing fossil fuels to renewable energy.

4. Empirical analysis

Table 2. Panel A. Descriptive statistics for developed countries

	C02	**GDP**	**GDP^2**	**FEC**	**FDI**	**WOP**
Mean	9.459551	1.684366	7.684253	77.79094	3.737220	50.05082
median	8.889441	1.680457	3.183876	82.86953	1.879701	43.73417
maximum	20.471139	10.67745	114.0080	98.52626	86.47915	111.6697
minimun	3.538009	-7.344794	1.3305	24.97644	-3771240	12.71566
Std.Dev	3.713621	2.204162	12.33889	17.45681	8.293306	32.11770
skewness	1.237483	-0.234743	3.942001	-1.304354	4.175434	0.604073
kurtosis	4.064067	5.842260	24.94985	3.860164	34.1476	2.071860
Observations	435	435	435	435	435	435

Panel B. Descriptive statistics for developing countries

	C02	**GDP**	**GDP^2**	**FEC**	**FDI**	**WOP**
Mean	4.415773	49.80295	2.916977	78.87186	1.674730	50.05082
Median	3.194702	13.60075	3.282258	82.03147	1.285454	43.73417
Maximum	17.69171	4224.008	49.48028	99.99678	8.760474	111.6697
Minimum	0.102558	0.000105	-64.99237	44.28031	-4.541592	12.71566
Std. Dev	3.946309	253.3962	6.433455	16.57358	1.718047	32.11770
Skewness	1.182229	12.89162	-2.171659	-0.238178	0.697987	0.604073
Kurtosis	3.796637	191.5949	41.68732	1.583434	5.232964	2.071860
Observations	435	435	435	435	435	435

Author's Compilation

The table discussed in this paper comprises the features and characteristics of the researcher's variables for both panels of countries. **In panel A**, the mean is assigned to the mean, which determines the average of the data in the series. It reveals that GDP^2 has the highest value while FDI reports the minimal value. The standard deviation, a measure of dispersion, and thus calculates how far individual observations are away from their sample average, reveals that WOP has the highest standard deviation. Finally, the degree to which a distribution is peaked may be scaled using kurtosis, or a leptokurtic distribution, which refers to a relatively high peak distribution. WOP is strictly platykurtic, meaning its value is 2.071860, indicating a flat curve for the variable discussed. Skewness is an essential indicator of skewed distribution, as it tends to fall on the same side of the mode as the mode itself, indicating asymmetry.

Panel **B** summary data reveal that the mean values for carbon emission, GDP and its quadratic form, fossil fuel consumption, foreign direct investment, and global oil price are (4.415773), (49.80295), (2.916977), (78.87186), (1.674730) and (50.05082). GDP has the maximum distribution value, whereas GDP^2 has the lowest. GDP has a higher standard deviation than WOP, FEC, GDP^2, carbon emission, and FDI. GDP^2 and FEC are negative and skew on the left, while the other variables are positive and skew on the right. Lastly, all series' kurtosis reports are leptokurtic, indicating a peaked curve with increasing values.

Table 3. Unit root

Variables	**Developed economies**				**Emerging Economies**			
	ADF		PP		ADF		PP	
	Level	1st Diff	Level	1st Diff	Level	1st Diff	Level	1st Diff
C02	0.9537	0.0000	0.7711	0.0000	0.8050	0.0000	0.5747	0.0000

GDP	0.0000	------	0.0000	-------	0.0000	-------	0.0000	------
GDP^2	0.0000	------	0.0000	-------	0.0000	-------	0.0000	------
FEC	0.9947	0.0000	0.2669	0.0000	0.0000	-------	0.0000	------
FDI	0.0000	------	0.0000	-------	0.0012	-------	0.0002	------
WOP	0.9123	0.0000	0.9539	0.0000	0.9123	0.0000	0.9539	0.0000

Author's Compilation

The researcher performed the unit root test to determine which series variables should be integrated according to their appearance for both panels of countries. The panel of developed nations in the table above shows the result of the ADF and Phillip-Perron tests that determine whether or not the model's variables are stationary. C02, FEC, and WOP are not stationary at levels. However, FDI and GDP prove stationarity at a level for all conventional significance levels. The square of GDP was also tested and proved to be stationary at all conventional levels, as reported by both ADF and PP.

For the panel of developing economies, the ADF and PP results show that carbon emissions and WOP are not stationary at a level but just after the first difference. This confirms that these two variables are stationary in the first order. However, the remaining variables, GDP, GDP^2, FEC, and FDI, according to the findings of ADF and PP, report stationarity at levels and further implies that these variables are all integrated in the first order. Therefore, because the variables are integrated into the mix of I(0) and I(1), the researcher uses the ARDL model for further estimation.

Table 4. Output of the PMG-ARDL

Panel A: PMG-ARDL output for developed countries				
variables	**Coefficients**	**Std. error**	**t-statistics**	**P-value**
FDI	-0.098035	0.031135	-3.148710	0.0020
FEC	0.268710	0.016289	16.49667	0.0000
WOP	0.005484	0.001705	3.216913	0.0016
GDP	0.421632	0.060384	6.982485	0.0000
GDP^2	-0.050003	0.008193	-6.102995	0.0000
Panel B: PMG-ARDL output for developing countries				
variables	**Coefficients**	**Std. error**	**t-statistics**	**P-value**
FDI	0.109439	0.015026	7.283220	0.0000
FEC	0.041431	0.003616	11.45645	0.0000
WOP	-0.004715	0.000429	-10.98396	0.0000
GDP	0.031949	0.003971	8.045935	0.0000
GDP^2	-0.003429	9.65E-05	-35.53470	0.0000

Author's Compilation

The PMG result of the investigation panel of developed countries shows a negative coefficient for FDI, meaning that a one-unit change in FDI will lead to a (0.098035) reduction in carbon emission if all variables are held unchanged. The positive coefficient shows that oil price and carbon emission have a positive relationship, with an average increase of (0.005484) units per year for the ARDL model. However, quadratic GDP adversely affects carbon emission, with a unit change in GDP^2 leading to a (0.050003) reduction in CO2 if everything is equal. This research conforms to the EKC, as income increases in developed economies prioritize investment in clean energy.

The PMG- ARDL result in panel **B** shows that WOP and GDP^2 have a significant adverse effect on carbon emissions, with an increase in WOP causing carbon emissions to decrease by 0.004715 units if all things are unchanged. Similarly, increasing GDP^2 by one unit decreases carbon emissions by 0.003429. However, GDP has a significant positive impact, with industrial activities increasing when GDP increases in developing economies, resulting in an increase in carbon emissions. Furthermore, foreign direct investment has significant positive effects, with an increase in FDI causing carbon emissions to increase by 0.109439. Fossil fuel consumption also has a positive relationship with carbon emissions, producing a (0.041431) unit increase in carbon emission. Therefore, developing countries must place greater emphasis on luring investments that have the potential to generate a greater number of technical impacts and direct a significant amount of FDI.

4.1 *Result and discussion*

According to the findings, FDI and quadratic GDP have a considerable and detrimental impact on the number of carbon emissions produced by industrialized nations. However, the remaining variables have a significant positive effect on climate change. The finding shows that increased FDI reduces carbon emissions in developed countries. This is true because developed nations tend to divert their resources from increasing production to investing in renewable or clean energy. Furthermore, high tech industries in developed countries have shown that the transfer of foreign direct investment and superior management techniques have a beneficial effect. Through the introduction of environmentally friendly technologies and optimal management strategies, these investments can reduce emissions and improve the environment, thus improving the overall quality of life in these developed countries. Li et al. (2022). However, the result of this exploration is consistent with the findings of Ahmad et al. (2022). The research reports an increasing relationship between GDP and carbon emission such that an increase in GDP by one unit will increase carbon emission by (0.421632) if all things are equal. These results support Likhachev et al. (2022), which suggests a positive relationship between economic expansion and environmental deterioration in advanced economies. However, the sign of GDP^2 is negative and statistically significant at all levels of conventional significance, indicating an agreement with the (EKC). Therefore, the findings of this paper suggest that if all things remain unchanged, a unit increase in GDP^2 will drop carbon emissions by 0.050003. This shows that these developed countries can use their significant economic resources to support renewable energy projects and, as a result, improve environmental quality. This suggests that in industrialized countries, the ratio of carbon emissions to economic growth (polluting intensity) was higher in the early stages of economic development but decreased beyond a certain level of economic growth. As a result, wealthy nations would produce and consume more environmental pollution commodities in the early stages of their development, but their squares accelerate environmental performance. Similarly, energy-related businesses and industries will experience strong growth followed by a decline at a specified threshold or turning point. Furthermore, since these countries are wealthy, they invest extensively in renewable energy technology by diversifying their energy portfolios, lowering the oil demand rise. Thus, the result of this investigation provides credence to the EKC framework and thus aligns with the study of Zhang et al. (2023),, Huang et al. (2023) and Haneklaus et al. (2022), which is in contrast with the findings of Mikayilov et al. (2018).

Oil prices have a statistically significant and favorable effect on CO2 emissions in developed nations over the long run. Furthermore, higher crude oil prices generate economic circumstances that contribute to greater energy consumption and CO2 emissions in advanced nations, showing that higher crude oil prices have long-term causal consequences on the economy's CO2 emissions. However, the findings of this study agree with Samour et al. (2020), which found that a rise in oil prices improves the current account balance and economic growth of oil-exporting nations, which in turn leads to an increase in investments and nonrenewable energy consumption. Furthermore, this exploration provides a significant positive relationship between fossil fuel consumption and carbon emission. A one-unit increase in fossil fuel energy consumption produces a 0.268710 increase in carbon emission if all variables are unchanged. The result of this finding is consistent with a study by Huang et al. (2023), who explored the link between fossil fuel consumption and the industrial value added on c02 emissions in the economies of the G-20. In the panel of developing nations, the study found that there is also a substantial inverse relationship between carbon emissions and the the price of oil and squared GDP. If all exogenous variables are constant, a one-unit increase in oil price will reduce carbon emission by (0.004715), making sense because price and quantity are inversely related. On the other hand, the fall in oil prices has the propensity to increase fossil fuel energy consumption, resulting in higher emissions. However, the study also confirms the workings of the environmental Kuznets curve (EKC) in developing economies. The research reports a reduction in carbon emission by (0.003429) if GDP^2 increases by one unit. This is so because countries are trying to pay more attention to maintaining environmental quality as they become richer. Therefore, the significance of these results cannot be overstated since they suggest that a reduction in greenhouse gas emissions will occur if countries transition from using fossil fuels and toward renewable energy sources. This shows that countries with solid economic development say GDP^2, may use their economic muscle to motivate the use of renewable energy, which will reduce c02 emissions, reducing the consequences of climate change. According to this analysis, the remaining variables, GDP, FEC, and FDI, positively affect carbon emissions. This investigation shows that if GDP increases by one unit, carbon emissions will increase by (0.031949) since emerging economies focus primarily on increasing output and production. Moreover, if the ceteris - paribus assumptions hold, a unit increase in FEC will lead to a 0.041431 increase in climate change, and this is because fossil fuel is one of the significant drivers or determinants of global warming. In contrast, FDI has a significant positive relationship with carbon emissions. A unit increase in FDI will require a 0.109439 increase in carbon emission. This is because increasing the output level, modernizing the economy, and fostering economic development are all significantly aided by

FDI, which plays a significant role in these three areas. However, this has increased environmental concerns and reduced the constraints placed on environmental policies to decrease environmental degradation, particularly in developing countries. Therefore, the increase in FDI in emerging economies will produce carbon emissions.

5. Conclusions

The study examines the impact of economic growth on carbon emissions from 15 developed and developing countries from 1991 to 2019 using the PMG-ARDL model. For advanced nations, our study revealed that GDP, oil prices and fossil fuel consumption have positive effects, while FDI has negative effects on CO2 emissions. In emerging countries, all variables showed a positive effect on environmental degradation except oil prices and quadratic GDP. In general, the results reported in this work confirm the EKC framework in both panels of countries. Therefore, the study proposes that the governments of these countries adopt a strategy for the consumption of renewable energy, implement construction codes that require energy-efficient materials and appliances, and provide incentives to companies and homeowners to invest in energy-efficient upgrades. This can reduce traditional energy consumption in general and make the transition to renewable energy more feasible.

Limitation

Researchers need assistance obtaining various control variables that would benefit their investigation. Future research may examine the connection by including other control variables for various groupings of nations using various approaches such as CS-ARDL, FMOLS, and DOLS. Despite this, the tests demonstrated that the variables in the research and the rigorous technique used are adequate.

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