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RESEARCH ARTICLE

Evaluating Environmental Quality in Upper-Middle-Income Countries: The Influence of Economic Growth, Renewable Energy and Technological Advancement

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Abstract

Carbon dioxide emissions are the primary contributors to environmental damage. Since fossil fuels are the main sources of CO_2 emissions, it is imperative to cultivate alternative energy sources and advance technology to ensure that economic growthremains comparatively environmentally sustainable. This paper empirically analyses the complex relationships between economic growth and environmental degradation, taking into account the environmental Kuznets curve (EKC) theory theory for a panel of 14 upper-middle-income countries over the period 1990-2021. The results show that renewable energy sources can provide environmental sustainability by improving environmental quality. The findings obtained in the long-run estimations prove that both technological development and renewable energy sources can play important roles in ensuring economic sustainability by keeping the environment relatively pollution-free in the 14 selected upper-middle-income countries.

Keywords: *Environmental Kuznets Curve, CO_2 Emissions, Economic Growth, Renewable Energy, Technological Development*
Jel Codes: *L15, O44, Q20, Q50, Q54*

Üst-Orta Gelirli Ülkelerde Çevre Kalitesinin Değerlendirilmesi: Ekonomik Büyümenin, Yenilenebilir Enerjinin ve Teknolojik Gelişimin Etkileri

Özet

Karbondioksit emisyonları, çevresel hasara birincil katkıda bulunanlardır. Fosil enerji kaynaklarının CO_2 emisyonu ürettiği göz önüne alındığında, ekonomik büyümenin çevresel açıdan nispeten sürdürülebilir olmasını sağlamak için alternatif enerji kaynaklarının geliştirilmesi ve teknolojinin ilerlemesi zorunludur. Bu çalışma, çevresel Kuznets eğrisi (EKC) teorisini dikkate alarak ekonomik büyüme ile çevresel bozulma arasındaki karmaşık ilişkileri, 14 yüksek orta gelire sahip ülkeler için 1990-2021 dönemi için ampirik olarak incelemektedir. Ayrıca çalışmada yenilenebilir enerji ve teknolojik gelişmenin kabondioksik salınımını azaltmadaki etkisini de dikkate almaktadır. Araştırma sonuçları, yenilenebilir enerji kaynaklarının çevresel kaliteyi artırarak çevresel sürdürülebilirliği sağlayabileceğini göstermektedir. Uzun dönem tahminlerde elde edilen bulgularda, hem teknolojik gelişmenin hem de yenilenebilir enerji kaynaklarının, seçilen 14 yüksek orta gelirli ülkede çevreyi nispeten kirlenmekten uzak tutarak ekonomik sürdürülebilirliği sağlamada önemli roller oynayabileceğini kanıtlamaktadır.

Anahtar kelimeler: *Çevresel Kuznets Eğrisi, CO_2 Emisyonları, Ekonomik Büyüme, Yenilenebilir Enerji, Teknolojik Gelişim*
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1. INTRODUCTION

The dominant growth model has led to the extraction and consumption of non-renewable resources, mainly contributing to CO2 emissions, environmental degradation, and global warming (Adams et al., 2020; Kartal et al., 2022). Bilgili et al. (2024) recently observed that CO2 emissions constitute approximately 64% greenhouse gas emissions, primarily due to their significant contribution to climate change, adversely affecting the environment, including biodiversity and ecosystems. The most concerning facets of escalating climate change encompass: i) continual increases in global temperature, ii) elevated sea levels, iii) glacial melting and urban flooding, iv) unparalleled extreme weather phenomena, and v) food insecurity (Bilgili et al., 2023, 2024, 2025; Kuşkaya et al., 2023; Xu et al., 2022). In response to the challenges presented by climate change, primarily attributed to carbon dioxide emissions from fossil fuels, researchers and policymakers across the globe are prioritizing the examination of significant sources of carbon dioxide emissions and recommending strategies to mitigate environmental degradation. The UN unanimously endorsed the Sustainable Development Goals (SDGs) in 2015. Safeguarding the natural environment while ensuring economic stability and prosperity for the population is fundamental to the Sustainable Development Goals (SDGs). The Sustainable Development Goals (SDGs) prioritize the Earth, oceans, forests, clean water, and the environment while highlighting the necessity for poverty reduction and prosperity (Eisenmenger et al., 2020). This research explores the key factors and alleviating variables related to environmental pollution in upper-middle-income countries.

Economic literature indicates that GDP growth is essential for mitigating poverty and hunger. It enhances national productivity, income levels, and individual living standards while offering respectable employment opportunities to the global workforce. Growth structures are driven mainly by non-renewable resources, which contribute to (Bilgili & Magazzino, 2022; Ozturk et al., 2023). Numerous studies indicate that economic advancement in both developed and developing countries frequently depends on fossil fuels. The heightened dependence on specific activities unequivocally elevates CO2 emissions and harms the environment, particularly during initial developmental phases. Nevertheless, at elevated development levels, this dependence significantly mitigates environmental harm. This tendency is well-documented in the inverted U-shaped Environmental Kuznets Curve (EKC) theory (Perone, 2024; Hongxing et al., 2021; Naseem et al., 2024). A primary cause for this situation is the significant dependence of industrial growth on pollution-intensive fossil fuels.

Upon achieving significant growth and development, the economy transitions to a predominantly service-oriented model characterized by elevated educational standards and heightened environmental consciousness, which in turn helps safeguard the natural ecosystem. Despite this, economic literature remains divided on the global relevance of the EKC hypothesis and the specific economic models applicable to various countries. This study emphasizes the need to transition to service-oriented growth models to reduce CO2 emissions and lessen dependence on fossil fuel-intensive industrial output, underscoring the significance of economic restructuring for environmental sustainability.

Above all, the main challenge for modern-day growth regimes is excessive dependence on conventional energy sources like fossil fuels to produce and transport goods. For that, policymakers worldwide emphasize the consumption of clean energy to fuel economic activities to limit ecological devastation arising from CO2 emissions.

Economic reports reveal that renewable energy sources—including wind, solar, geothermal, and hydropower—offer various environmental benefits compared to conventional energy sources. These renewable alternatives generate clean energy, substantially decreasing greenhouse gas emissions and mitigating air and water pollution. By harnessing the inherent energy of solar, wind, and hydrologic resources, these technologies promote a more environmentally responsible and sustainable energy framework, ensuring a healthier planet for future generations. The advantages encompass: i) reduced CO2 emissions to enhance environmental quality, ii) mitigation of natural resource depletion, iii) curtailment of deforestation and desertification, iv) assurance of energy security, and v) promotion of sustainable development (Kartal et al., 2022; Sikder et al., 2022). Consequently, the primary objective of this study is to investigate the roles and potentials of renewable energy and technological advancement in achieving environmental sustainability. Furthermore, this research provides significant contributions to existing literature. Initially, it examines the characteristics of both economic growth and industrialization within upper-middle-income countries to assess whether these processes are sustainable and aligned with the Sustainable Development Goals (SDGs) established by the United Nations.

The middle-income countries have the highest CO2 emissions, economic growth, and energy consumption compared to other country groups (Ehigiamusoe et al., 2020). The study of (Dontoh et al., 2024) revealed that the ratio of CO2 emissions to GDP is highest in the upper middle-income country groups followed by in middle-income countries, low-income countries, lower middle-income countries and high-income countries. However, the study showed that this ratio decreased between 1990-2020 because of technological development. This indicates that technological development can play a significant role in reducing CO2 emissions on one hand while ensuring sustainable economic growth on the other.

The study aims to estimate the relationship between variables such as economic growth, renewable energy, technological development, industrialization, and urbanization in 14 upper-middle-income countries between 1990 and 2021 using panel data analysis, and to test the validity of the EKC hypothesis in these countries. The research employed factors and proxies such as GDP growth, renewable energy, technological development, industrialization, and urbanization. The rationale for including the previously mentioned variables and proxies is to evaluate whether upper-middle-income countries are i) transitioning their economies towards environmentally friendly service-oriented models, ii) adopting modern sustainable production methods, and iii) shifting from fossil fuels to renewable energy sources to boost significantly economic growth. This study analyzes the EKC theory, assessing the combined effects of economic growth, renewable energy, technological development, urbanization, and industrialization on carbon dioxide (CO2) emissions. This approach seeks to understand the interactions among these factors and their impact on the environment during economic development. The current study employed an innovative panel ARDL approach, developed by Pesaran and Smith (1995) and refined by Pesaran et al. (1999), which provides advantages over traditional short- and long-run estimates. This is particularly beneficial for studies with small sample sizes, such as this one, which offers several advantages compared to other dynamic models like fixed effects and GMM (Generalized Method of Moments) estimators (Saba, 2023; Shahzad et al., 2021; Wang et al., 2021; Shin et al., 2014).

The subsequent sections of this research are organized as follows: Section II provides an overview of current publications related to GDP growth, urbanization, industrialization, and the utilization of renewable energy and technological development for CO2 emissions. The final portion presents statistics and techniques. Section IV examines the empirical results and subsequently presents conclusions and policy recommendations.

2. LITERATURE REVIEW

Economic growth is a precursor to economic development and is amongst the three pillars of SDGs. That is why both developing and developed countries around the globe place economic growth as their major goal. However, it has challenged biodiversity, ecosystem, and contributed to ozone depletion, which threatens the fundamental dimensions of Earth that are essential for sustainable human survival on the planet that has threatened fundamental earth dimensions, inevitable for sustainable human survival on the planet (Bilgili et al., 2024; Eisenmenger et al., 2020; Mahalik et al., 2021). Apprehending the gravity of the issue, numerous studies have theorized and tested the nexus between a variety of economic indicators (economic growth, energy use, industrial development, and urban expansion) alongside a sustainable environment (Allard et al., 2018; Asongu et al., 2016; Feng et al., 2024; Kartal et al., 2022; Magazzino, 2017; Magazzino et al., 2023; Mensah et al., 2019; Naseem et al., 2024; Ozturk, 2010; Perone, 2024; Sikder et al., 2022; Zoundi, 2017). Considering the importance of GDP growth and environmental preservation, the present study investigates the EKC hypothesis to identify whether economic growth reduces environmental degradation once the threshold point is reached in upper-middle-income countries.

Comprehensive studies in economic literature emphasize a substantial correlation between economic development and the quality of our environment. Sustainable practices boost economic growth and promote a healthier planet for future generations (Eisenmenger et al., 2020; Umar et al., 2021). Notably, (Grossman & Krueger, 1991) pioneered the establishment of the link between GDP growth and the natural environment by introducing the EKC. The EKC hypothesis posits that: i) there is a strong connection between economic growth and air quality; ii) air pollution typically decreases as a country achieves a GDP per capita between $4,000 and $5,000; and iii) trade liberalization impacts Mexico's environment. Furthermore, the authors emphasized the intricate, non-linear dynamics between economic growth and environmental harm, indicating that growth doesn't always negatively affect ecology. An inverted U-shaped correlation exists between GDP per capita and environmental pollution, indicating that rising income first results in increased pollution levels. In contrast, higher economic growth and development levels are linked with falling environmental pollution. In short, the EKC theory articulates that GDP growth is followed by intense ecological degradation at the initial levels of development. However, a country’s ability to alleviate environmental pollution is enhanced as its economy grows. Furthermore, Grossman and Krueger (1991) provided details on the impact of the trade liberalization process on the environment. Above all, it has laid solid foundations to probe economic growth and environmental pollution nexus to devise policies for chasing environmentally sustainable development, in particular (Kostakis et al., 2023; Sikder et al., 2022). Extensive research has significantly validated the EKC theory (Dunyo et al., 2024; Kostakis et al., 2023; Sikder et al., 2022). Notably, (Kostakis et al., 2023) explored the correlation between economic growth and carbon dioxide emissions across Middle Eastern, MENA, and North African countries, analyzing data from 1994 to 2014. Their research focuses on EKC theory, which asserts a distinct correlation between a nation's economic growth and environmental consequences. The study's findings highlight the significant importance of the EKC hypothesis, indicating a troubling trend: as energy consumption increases in these regions, environmental quality generally deteriorates. This underscores the pressing necessity for sustainable energy measures to alleviate detrimental environmental impacts while striving for economic growth. Furthermore, the system remained predominantly dependent on fossil fuels, resulting in considerable pollution and contributing to environmental degradation. The research showed that globalization negatively impacts the environment, yet trade liberalization and population density help alleviate environmental issues and pollution. Besides, (Dunyo et al., 2024) reinforced the idea by substantiating EKC for 58 nations from 2000 to 2020. The study's empirical findings indicated that energy consumption and R&D adversely affect the environment, especially under conditions of uncertainty. This is predicated on the overdependence on fossil fuels driven by CO2 emissions for industrial output and economic expansion. Fossil fuels are major contributors to CO2 emissions and environmental pollution. (Kuşkaya et al., 2023a). Simultaneously, (Mirziyoyeva & Salahodjaev, 2023) examined the impact of economic growth, globalization, and renewable energy utilization on climate change across fifty countries, using CO2 emissions as a proxy for air pollution. The research utilized a two-step GMM estimator for its analysis, positing that this approach provided superior control over heteroscedasticity. An increase of one percent in renewable energy leads to a 0.26% reduction in CO_2 emissions, highlighting its vital role in fighting environmental pollution. Globalization adversely affected CO_2 emissions, although economic expansion validated the Kuznets Curve of Environment concept worldwide. Additionally, establishing an appropriate environment for adopting renewable technology and making substantial investment in the renewable industry was advised. The research also proposed the establishment of an investment-conducive environment to draw ecologically sustainable foreign direct investment and technology transfers. Sikder et al. (2022) emphasized that expansion, urbanization, energy consumption, and industrialization are the principal factors contributing to pollution in 23 emerging nations. The research indicated that energy consumption, urbanization, economic expansion, and industrialization elevate CO_2 emissions. It proposed rules to alleviate this impact, encompassing urban design, environmentally sustainable infrastructure, fiscal incentives for sustainable practices, and energy-efficient technologies. (You et al., 2022) investigated how economic growth and complexity affect ecological conservation by analyzing panel data from 95 countries from 1995 onward 2015. A bi-directional causal relationship was identified among complexity, CO_2 emissions, and economic expansion. The research also revealed that lower-income nations experience adverse impacts on GDP due to economic complexity, underscoring the challenges of leveraging intricate economic frameworks for growth. The report recommended balancing economic complexity and GDP growth while establishing a modest CO_2 emissions target with a schedule and subsequent evaluation. Adams et al. (2020) employed the PM-ARDL methodology. Their findings revealed that energy consumption and economic growth play a significant role in environmental degradation within resource-rich countries, particularly amidst concerns related to economic policy uncertainty and geopolitical issues. This pertains to the management of geopolitical risk and the accommodation of uncertainty to safeguard the natural environment. Zoundi's study (2017) validates the EKC concept in 25 African nations from 1980 to 2012. The results indicate that renewable energy sources are a sustainable choice that substantially improves environmental quality. The use of fossil fuels directly undermines the positive effects of renewable energy on reducing CO_2 emissions. Therefore, prioritizing renewable energy from the start of economic development is crucial for effectively mitigating environmental damage.

A multitude of research, such as those conducted by (Bandyopadhyay & Rej, 2021; Isik et al., 2019; Jalil & Feridun, 2011; Kong & Khan, 2019; Tenaw & Beyene, 2021; Zakaria & Bibi, 2019; Zaman & Moemen, 2017) have substantiated the EKC theory. Analysis has revealed that critical economic indicators, including industrialization, energy consumption, and industrial production, adversely affect the natural environment. The authors contended that traditional, inefficient, and pollutant-intensive energy sources first sustain economic development driven by industrial output. It is understandable, as governments occasionally overlook the detrimental effects of industrialization driven by filthy energy use while grappling with the socio-economic issues linked to reduce per capita income. Secondly, energy consumption predominantly relies on fossil fuels in numerous countries, resulting in considerable environmental degradation due to heightened carbon dioxide emissions and other gasses. This concern has been emphasized in research conducted by (Clarke et al., 2018; Emodi et al., 2018; Koçak et al., 2021; Mensah et al., 2019; Ogola et al., 2012). The consumption of renewable energy is an economic variable that adversely affects the environment (Naeem et al., 2023; Wang, 2021). Renewable energy is essential for mitigating CO_2 emissions, prompting politicians to advocate for clean sources such as hydropower, wind, geothermal, and solar to stimulate economic growth (Liu et al., 2024; Perone, 2024). The primary characteristic of renewable energy sources is their capacity to alleviate environmental degradation through: i) reduced CO_2 emissions, ii) absence of mining and extraction of fossil fuel energy sources, iii) minimal waste production, and iv) insignificant greenhouse gas emissions (Bilgili et al., 2024; Cadelano et al., 2019; Emodi et al., 2018; Khanna et al., 2021; Magazzino et al., 2023; Mensah et al., 2019; Naseem et al., 2024; Umar et al., 2023). Moreover, urbanization is a significant economic indicator intricately linked to the environment (Adams & Klobodu, 2017; Capps et al., 2016; Sikder et al., 2022). Economic literature has produced conflicting results concerning the urbanization-CO2 relationship. A significant body of literature claims that urbanization causes ecological destruction, but another asserts its significance in reducing CO2 emissions (Liu et al., 2024). (Hongxing et al., 2021; Shahbaz et al., 2014; Sikder et al., 2022) contended that urbanization directly and indirectly stimulates CO2 emissions by enhancing economic activity, specifically through i) economic activities and GDP growth, ii) energy consumption, and iii) the carbon-intensive transportation sector in urban areas. The second strand of studies posits that urbanization alleviates environmental pollution by i) optimal land utilization, ii) efficient transportation facilitated by effective governmental interventions, and iii) modifications in the energy preferences of high-income groups (energy ladder theory) (Chen et al., 2022).

3. STUDY METHODS

3.1. Data

The data for this study were meticulously collected from the World Bank Development Indicators (WDIs), focusing on a subset of 14 upper-middle-income countries. The countries examined are Argentina, Albania, Brazil, Colombia, Chile, Fiji, Indonesia, Ecuador, Jamaica, Paraguay, Peru, Serbia, Thailand, and Türkiye. This analysis covers the period from 1999 to 2021, providing extensive data to investigate various socio-economic trends and transformations in these nations. The research collected data on variables like carbon emissions, GDP, renewable energy use, and information and communications technology, which act as indicators of technological advancement, industrial expansion, and urban development. Descriptions of all variables for the selected countries can be found in Table 1.

Table 1: Source of data and Description of Variables for the year 1999-2021

Variable	Full form	Description	Source
CO_2	Carbon Emissions	Carbon dioxide emissions (metric tons per capita)	WDI
GDP	Gross Domestic Product	GDP per capita (constant 2015 US$)	WDI
REN	Renewable Energy Consumption	Renewable energy consumption (% of total final energy consumption)	WDI
ICT	Information and communication technology	ICT goods exports (% of total goods exports)	WDI
INDP	Industrialization	Industry (including construction), value added (% of GDP)	WDI
URB	Urbanization	Urbanization population growth (annual %)	WDI

3.2. Methodology

This study assesses the significance of the EKC theory, focusing on key factors—namely renewable energy use, technological advances, industrial growth, and urbanization—that impact the reduction of CO2 emissions. Within the selected panel group, CO2 emissions serve as a vital indicator of environmental degradation. The EKC hypothesis was investigated in (Kwilinski et al., 2024) where the effects of renewable energy technology, industrialization and urbanization on CO2 emissions were examined. On the other hand, the role of renewable energy and technology on environmental degradation under the framework of the EKC hypothesis in (Ma et al., 2024). Besides, the effects of industrialization and urbanization on environmental degradation were examined in (Ridwan et al., 2024) where the EKC hypothesis was investigated. The research employs a distinctive methodology to explore these relationships thoroughly, as outlined in the following sections.

$$LCO_2 = f(LGDP, LGDP^2, LREN, LICT, LINDP, URB) \quad (1)$$

$$LCO_{2_{it}} = \alpha + \beta_1 LGDP_{it} + \beta_2 LGDP_{it}^2 + \beta_3 LREN_{it} + \beta_4 LICT_{it} + \beta_5 LINDP_{it} + \beta_6 URB_{it} + \epsilon_{it} \quad (2)$$

Equations 1 and 2 define the following variables: CO_2 stands for carbon dioxide emissions, GDP represents gross domestic product, REN indicates renewable energy consumption, ICT denotes technological progress, INDP symbolizes industrialization, and URB refers to urbanization. Additionally, GDP^2 is the square root of GDP. In this context, GDP is a surrogate for GDP growth, whereas CO2 emissions are employed to measure environmental damage. All variables, excluding urbanization, are converted into logarithmic form to enhance analysis. We included detailed descriptive statistics and correlation matrices for all relevant variables to improve data understanding, available in Table 2. This detailed presentation facilitates an analysis of the central tendencies, variations, and correlations among the variables in our study. For EKC hypothesis, the result will be significant that is the inverted U-shaped between economic growth and environmental degradation in case when $\beta_1 > 0$

While $\beta_2 < 0$

(Barak et al., 2024; Guo & Shahbaz, 2024; Kaika & Zervas, 2013; Shouwu et al., 2024). On the other hand, the results for other variables will be significant if $\beta_{it} \neq 0$. Here the results could be positive or negative where $\beta > 0$

indicates the positive effects while

$\beta < 0$

indicates the negative effects between dependent and independent variables.

Table 2: Results of descriptive statistics and correlation analysis

Descriptive Statistics							
	LCO₂	**LGDPP**	**LGDP²**	**LICT**	**LREN**	**LINDP**	**URB**
Mean	0.823	8.635	74.773	-0.683	3.200	3.326	1.616
Median	0.738	8.581	73.641	-0.995	3.327	3.338	1.574
Max	2.042	9.561	91.413	3.357	4.254	3.872	4.556
Min	-0.407	7.487	56.052	-5.279	1.573	2.709	-0.581
Std. Dev.	0.580	0.458	7.934	1.736	0.586	0.264	0.872
Skewness	0.057	0.108	0.253	0.458	-0.422	-0.229	0.573
Kurtosis	2.140	2.874	2.815	2.607	2.487	2.427	4.703
Jarque-Bera	9.663***	0.836	3.894	12.145***	12.548***	7.228**	56.53***
Sum	308	322	322	293	309	322	322
Correlation Matrix							
	LCO₂	**LGDPP**	**LGDP²**	**LICT**	**LREN**	**LINDP**	**URB**
$LCO2$	1						
$LGDP$	0.590***	1					

***LGDP*2**	0.592***	0.999***	1				
LICT	0.329***	-0.135**	-0.132**	1			
LREN	-0.699***	-0.360***	-0.360****	-0.051	1		
LINP	-0.056	-0.179***	-0.174***	0.125**	0.175***	1	
URB	-0.248***	-0.310***	-0.305***	0.352***	0.164**	0.519***	1

Notes: **and *** denote statistical significance at the 5% and 1% levels, respectively.

The table above shows that both mean and median values for all variables are positive except LICT, that is the logarithmic form of technological development. Both mean and mean values indicate that $LGDP^2$ has the highest value compared to the other variables. However, LGDP has the highest mean and median values among the other linear variables. On the other hand, LINP has the lowest standard deviation while LICT has the highest value among the linear variables. Overall $LGDP^2$ has the highest values for both mean, median, maximum, minimum and standard deviation. The significant results of LCO_2, LICT, LREN, LINP and URB indicate that the variables are not distributed normally. Moreover, the correlation matrix indicates that there exists the highest positive correlation between LGDP and LCO_2 while there is the lowest positive correlation between LINP and LICT. On the other hand, there is the highest negative correlation between LGDP and LREN and the lowest negative correlation between LICT and LREN.

3.3. Empirical Analysis

Since the current study conducts panel data analysis, it is normal for cross-sectional dependence and slope homogeneity problems to exist among variables. For this reason, panel cross-section dependence test techniques are used to examine cross-section dependence among variables while panel homogeneous test techniques are used to observe if there exist sloped homogeneity problems in the model. Furthermore, the study uses different panel unit-root test techniques including first-generation and second-generation unit-root test methods to test whether variables that were collected to conduct the current study are stationary. The difference between first-generation and second-generation unit-root test techniques is that the second-generation unit-root test technique provides robust results after considering both cross-sectional dependence and slope homogeneity problems while the first-generation unit-root test technique doesn't. After confirming the stationarity of variables, the study applies panel cointegration testing methods to enquire where there exists the long run cointegration among variables. After confirming that there exists the long-run cointegration among variables, the study applies several long-run estimation techniques to investigate the EKC hypothesis as well as the effects of renewable energy, technological development, industrialization and urbanization on CO_2 emissions. Lastly, the study attempts to analyze panel causality techniques to see whether there exists causality relationship among variables.

3.3.1. Panel cross-section dependence test

The Pesaran cross-sectional dependence (CD) and the Pesaran scaled Lagrange multiplier (LM) tests, outlined by (Bersvendsen & Ditzen, 2021), along with the Breusch-Pagan LM test introduced by (Pesaran, 2021), serve as methods for evaluating cross-sectional dependence among variables in panel data analysis. Equation 3 illustrates the Pesaran CD test:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \tag{3}$$

3.3.2. Panel slope homogeneity test techniques

Like cross-section dependency, panel data models often face homogeneity issues. Therefore, it's crucial to determine if the panel model shows homogeneity problems among variables. We use the slope homogeneity test method developed by (Bersvendsen & Ditzen, 2021).

3.3.3. Panel unit-root test techniques

This study utilizes several unit-root test methodologies to confirm stationarity across all variables. It includes first-generation tests like LLC (Ai, 2009; Levin et al., 2002; Oryani et al., 2022) IPS, and Fisher-ADF (Im et al., 2003; Khandker et al., 2014) alongside the second-generation CIPS unit root tests (Pesaran, 2007).

The LLC and IPS test techniques are primarily derived from the Augmented Dickey-Fuller (ADF) test techniques, as demonstrated in the equation below 4.

$$\Delta X_{i,t} = \alpha_i + \beta_i X_{i,t-1} + \sum_{j=1}^{p_i} \mu_{i,j}\, \Delta X_{i,t-j} + \varepsilon_{i,t} \tag{4}$$

The CIPS test statistics are mainly the average form of the CADF test statistics of cross-sections. It can be expressed as follows:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} t_i\,(N,T) \tag{5}$$

In equation 5, $t_i(N,T)$ refers to the CADF, which is a second-generation unit-root test statistic by nature. This essentially indicates the cross-sectional dependency represented by a single unobserved common factor.

3.3.4. Panel cointegration test techniques

The panel ARDL method is applied in the current study from which both long- and short-run effects can be obtained (Pesaran et al., 2001; Zhang & Ben Naceur, 2019). In fact, it provides more significant and robust results as compared to other estimation models (Liu and Bae, 2018). However, all variables have to be stationary at both level, I(0) and first-difference, I(1) (Pesaran & Smith, 1995).

$$\begin{aligned}\Delta LCO2_{it} = {} & \mu_{0i} + \mu_{1i} LCO2_{i,t-1} + \mu_{2i} LGDP_{i,t-1} + \mu_{3i} LGDP2_{i,t-1} + \mu_{4i} LREN_{i,t-1} \\ & \mu_{5i} LICT_{i,t-1} \ + \mu_{6i} LINP_{i,t-1} + \mu_{6i} URB_{i,t-1} \\ & + \sum_{j=1}^{q-1} \delta_{1i} \Delta LCO2_{i,t-j} + \sum_{j=0}^{q-1} \delta_{2i} \Delta LGDP_{t-j} + \sum_{j=0}^{q-1} \delta_{3i} \Delta LGDP2_{t-j} \\ & + \sum_{j=0}^{q-1} \delta_{5i} \Delta LREN_{t-j} + + \sum_{j=0}^{q-1} \delta_{4i} \Delta LICT_{i,t-j} + \sum_{j=0}^{q-1} \delta_{5i} \Delta LINP_{t-j} + \sum_{j=0}^{q-1} \delta_{6i} \Delta URB_{t-j}\end{aligned} \tag{6}$$

After confirming the long-run co-integration among variables, equation 6 can be converted into a panel error correction model (PECM) as shown in equation 7:

$$\begin{aligned}\Delta LCO2_{it} = {} & \alpha_{0i} + \sum_{j=1}^{q-1} \alpha_{1i} \Delta LCO2_{i,t-j} + \sum_{j=0}^{q-1} \alpha_{2i} \Delta LGDP_{t-j} + \sum_{j=0}^{q-1} \alpha_{3i} \Delta LGDP2_{t-j} \\ & + \sum_{j=0}^{q-1} \alpha_{4i} \Delta LREN_{it-j} + + \sum_{j=0}^{q-1} \alpha_{5i} \Delta LICT_{i,t-j} + \sum_{j=0}^{q-1} \alpha_{6i} \Delta LINP_{it-j} + \sum_{j=0}^{q-1} \alpha_{7i} \Delta URB_{it-j}\end{aligned}$$

$$+\theta ect_{i,t-1} + \mu_{it} \tag{7}$$

The panel FMOLS estimation method is also applied to check robust results. It was initially proposed by Phillips & Hansen (1990) to conduct the time-series data analysis. Later on, the model was extended to panel data analysis by (Phillips & Moon, 1999).

$$\hat{\beta}_{FP} = \left(\sum_{i=1}^{N}\sum_{t=1}^{T}\tilde{X}_{it}X_{it}\right)^{-1}\sum_{i=1}^{N}\sum_{t=1}^{T}\left(\tilde{X}_{it}y_{it}^{+} - \chi_{12}^{+}\right) \tag{8}$$

$\hat{\beta}_{FP}$ refers to pooled FMOLS technique where $\tilde{X}_{it}$ denotes the deterministic trend and stochastic regressors. All these are shown in equation 8.

The study also used interactive fixed effects (IFE) that was proposed by (Kneip et al., 2012). Like FMOLS estimation techniques, IFE test technique also provides robust results. The model was previous applied in (Altıntaş & Kassouri, 2020) to investigate whether the EKC hypothesis. In fact the IFE test technique was used in other recent studies including (Callaway & Karami, 2023; Chen & Yan, 2023; Jin et al., 2025; Ke et al., 2024). This indicates that the IFE test technique is the most updated panel data estimation technique as compared other panel data long run estimation techniques including ARDL, DOLS, FMOLS test techniques and others for which this model is still used in recent studies. The IFE test technique is shown in equation 9.

$$y_{it} = \alpha + \beta_i + \Gamma_t + \theta X_{it} + \sum_{j=1}^{m} \Upsilon_j \mathrm{I}_{it} * X_{it} + v_i(t) + \mu_{it} \tag{9}$$

3.3.5. Dumitrescu and Hurlin's (2012) panel causality test techniques

For panel causal relationship among variables, Dumitrescu & Hurlin (2012) panel causality test techniques are applied. Unlike Granger (1987) causality test technique, it is the robust version that considers both cross-section dependence and homogeneity problems. The model can be shown in equation 10:

$$y_{it} = \alpha_{it} + \sum_{l=1}^{L}\varphi_{it}^{(l)}y_{it-l} + \sum_{l=1}^{L}\psi_{it}^{(l)}x_{n_{it-l}} + \mu_{it} \tag{10}$$

In equation 10, y_{it}, y_{it-l} and $x_{n_{it-l}}$ are the stationary variables that are observed for T period in N cross-section data. Furthermore, α_{it} denotes the constant term while the parameters including $\varphi_{it}^{(l)}$ and $\psi_{it}^{(l)}$ vary among cross-sections.

4. FINDINGS AND THE DISCUSSION OF THE RESULTS

4.1. Panel cross-section dependence test results

Table 3 displays the outcomes related to cross-section dependency among the variables. The findings reveal that there is indeed cross-section dependence. LCO_2, $LGDP^2$, LICT, LINP, and URB show consistent validation at a 1% significance level across all tests. This suggests the existence of spillover effects between variables, suggesting that fluctuations in one country's variable may affect others.

Table 3: Panel cross-sectional dependence test results

Variables	Breusch-Pagan LM (CD-test)	Pesaran scaled LM (CD-test)	Pesaran CD (CD-test)
LCO_2	888.415***	58.77501***	18.822***
LGDP	1456.604***	101.225***	35.616**
$LGDP^2$	1452.750***	100.936***	35.542***
LICT	444.890***	26.232***	5.144***

LREN	514.047***	31.358***	0.787
LINP	582.622***	36.442***	10.278***
LURB	510.668***	31.107***	14.577***

Notes: and *** statistically Significant at the 5% and 1% levels, respectively.

4.2. Panel slope homogeneity test results

Table 4 presents the results of the panel slope homogeneity test, revealing slope heterogeneity among the variables. The delta test result is significant at 10%, while the adjusted delta result holds significance at 5%.

Table 4: Blomquist and Westerlund's (2013) slope homogeneity test results.

	Model
Delta	0.073*
Adj. Delta	0.014**

Notes: *and ** are statistically significant at the 5% and 1% levels, respectively.

4.3. Panel unit-root test results

Table 5 displays the results of the panel unit-root test. The other variables were found to be stationary at the first difference, while the results indicate that both urbanization and renewable energy variables are stationary at a level.

Table 5: LLC, IPS Breitung, IPS, Fisher- ADF and CIPS unit root test results

	LLC	**Breitung**	**IPS**	**Fisher-ADF**	**CIPS**	**Order of integrated**
	Intercept and trend					
LCO_2	2.024	0.260	-0.323	29.594	-2.177	I(0) = 0
LGDP	2.451	7.981	2.924	13.048	-1.603	I(0)=0
$LGDP^2$	2.609	2.993	0.731	16.604	-1.579	I(0)=0
LICT	-3.769***	-1.030	-1.279	36.597	-	I(0) = 1
LREN	-0.958	0.746	−2.614***	54.517***	-	I(0) = 2
LINP	0.561	0.336	0.779	20.162	-	I(0) = 0
LURB	-0.294	0.620	−1.431*	53.159**	-2.864***	I(0) = 2
First difference (intercept and trend)						
ΔLCO_2	-2.999***	-6.407***	-5.935***	88.564***	-4.134***	I(1) = 5
ΔLGDP	-5.114***	-7.548***	-1.807**	111.745***	-3.010***	I(1)=5
$\Delta LGDP^2$	-1.628*	-2.028**	-8.502***	42.414**	-3.013***	I(1)=5
ΔLICT	-9.531***	-5.283***	-12.348***	117.160***	-2.895***	I(1)=5
ΔLREN	-6.085***	-1.603*	-8.229***	113.496***	-14.253***	I(1)=5
ΔLINP	-10.411***	-2.563***	-9.162***	122.950***	-12.177***	I(1)=5
ΔLURB	-6.117***	-2.072**	-7.350***	109.846***	-9.524***	I(1)=5

Notes: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

4.4. Panel cointegration test results

A long-term cointegration relationship exists between the variables, as shown by the panel cointegration test results in Table 6.

Table 6: Panel cointegration test results

Kao Panel cointegration test. (Dependent variable: LCO2)				
			Statistic	**Prob.**
	Modified Dickey-Fuller t		-1.738**	0.0411
	Dickey-Fuller		-1.483*	0.069
	Augmented Dickey-Fuller t		-1.715**	0.043
	Unadjusted modified Dickey-Fuller t		-2.706***	0.003
	Unadjusted Dickey-Fuller t		-1.956**	0.025
Pedroni Panel cointegration test. (Dependent variable: LCO2)				
	Modified variance ratio		**-4.3629*** **	0.000
	Modified Phillips-Perron t		3.461***	0.000
	Phillips-Perron t		-4.464***	0.000
	Augmented Dickey-Fuller t		-4.364***	0.000
Johansen Fisher Panel cointegration test. (Dependent variable: LCO2)				
Hypothesized No. of CE(s)	Fisher Stat. from trace test)	Prob.	Fisher Stat.* (from max-eigen test)	Prob.
None	73.420***	0.000	47.53***	0.002
At most 1	707.900***	0.000	251.5***	0.000
At most 2	605.100***	0.000	461.5***	0.000
At most 3	495.900***	0.000	278.2***	0.000
At most 4	524.900***	0.000	385.7***	0.000
At most 5	136.500***	0.000	96.43***	0.000
At most 6	74.510***	0.000	74.51***	0.000

Notes: and *** statistically Significant at the 5% and 1% levels, respectively.

4.5. Panel long-run cointegration estimation test results

The Hausmann test indicated a preference for PMG over MG. The decision was made to implement the PMG test estimation technique. To ensure robustness, it was also determined to do FMOLS and IFE, which assist in identifying reliable values. Table 7 presents the results, indicating that PMG estimation supports the long-term validity of the EKC hypothesis. Additionally, it shows that technological advancement and urbanization negatively impact CO_2 emissions, but only in the long term. Technological progress was found to be significant at the 5% level, while urbanization was significant at the 1% level. The impact of renewable energy consumption on CO_2 emissions has been shown to be negative in both the long term and short term. The EKC hypothesis was also observed in the FMOLS and IFE models. The comprehensive long-term estimation results indicate that the EKC hypothesis is significant only in the long run. Furthermore, advancements in technology and the use of renewable energy promote the reduction of CO_2 emissions. In line with the above literature conducted by (Mirziyoyeva & Salahodjaev, 2023) where technological development and proper investment for renewable energy development was proposed for keeping the economy relatively environmentally friendly, the study implies that proper investment, especially in technology and renewable energy development can keep the economy of the selected countries relatively environmentally friendly. Moreover, it was indicated in the above literature proceeded by (Zoundi, 2017) that renewable energy sources can ensure environmental sustainability by improving environmental quality. Therefore, the overall findings obtained from the current long-run estimation indicated that both technological development and the development of the renewable energy sources can play significant roles in ensuring economic sustainability by keeping the environment relatively free from being polluted in 14 upper middle-income countries that were selected to conduct the current study.

The results of the current study can be compared with the study by Kwilinski et al. (2024), which examined the effects of technology and renewable energy on CO_2 emissions. The study was conducted under the framework of the EKC hypothesis where variables including industrialization, urbanization and others were used as the control variables. The research area of this study was the European Union (EU) transportation sector from 2007 to 2020. The results of the current study are similar to this study in that the EKC hypothesis was found to be significant, while the effects of renewable energy and technological development on CO_2 emissions were found to be negative. Furthermore, the effect of industrialization on CO_2 emissions was found to be insignificant in the current study. On the other hand, the current study indicated significant negative effect of urbanization on CO_2 emissions in PMG-ARDL estimation technique while the effect is significantly positive in FMOLS technique. Here the effects of industrialization and urbanization for the current study are different as compared to the previous study in a sense that both variables in the previous study was found to be significantly positive.

Meanwhile, the EKC hypothesis was investigated China as upper middle-income country in (Azam & Khan, 2016) where the result indicated the invalidity of the hypothesis. However, the EKC hypothesis that was found to be valid from the study on upper middle-income countries based on panel data estimations imply that sustainable economic growth by ensuring environmental quality is possible even in upper middle-income countries if there exist cooperations among each other. In fact, the cross-section dependence test results that show the cross-section dependence among variables indicate that there exist spill-over effects among all selected countries for which the effect of one independent variable in one country can easily affect independent variable in others. As (Ehigiamusoe et al., 2020) indicated that necessary investment in R&D that ensure environmental through improving technologic efficiency where (Dontoh et al., 2024) specified financial resources to utilize it for R&D that can improve technological development and therefore ensure environmental quality and economic sustainability, the results for the current study imply that ensuring proper investment, especially from financial resources can enhance technological development through enhancing R&D that can ensure sustainable economic growth that is the economic growth with ensuring environmental quality in the upper-middle income countries.

Table 7: The outcomes of the panel ARDL, alongside the robustness findings from the panel FMOLS and IFE estimations.

	MG	PMG	FMOLS	IFE
Variables	Panel A: Long-run estimation			
LGDP	5.561*(0.10)	6.366***(0.001)	40.285***(0.000)	2.966***(0.007)
LGDP²	-0.348(0.912)	-0.296***(0.006)	-2.302***(0.000)	-0.1246**(0.044)
LICT	-0.348 (0.912)	-0.034**(0.011)	-0.028***(0.000)	0.0196***(0.001)
LREN	-0.696*(0.054)	-0.257***(0.000)	-0.585***(0.000)	-0.398***(0.000)
LINP	0.679(0.251)	-0.044(0.515)	0.0007(0.898)	-0.0303(0.581)
LURB	0.705(0.354)	-0.034***(0.009)	0.089***(0.000)	-0.0182(0.160)
Panel B:Short-run estimation				
ECT_{t-1}	-1.096***(0.000)	-0.536***(0.000)		
ΔLGDP	-7.145(0.874)	-20.180(0.624)		
ΔLGDP²	0.407(0.877)	1.187(0.623)		
ΔLICT	-0.017(0.326)	0.007(0.391)		
ΔLREN	0.143(0.297)	-0.393***(0.005)		
ΔLINP	-0.325(0.360)	0.152(0.126)		
ΔLURB	-0.387(0.216)	-0.016(0.606)		
Const	66.825(0.705)	-11.121***(0.000)		
	Hausman test *MG_a vs PMG_b* *Chi-sq. (p-değeri)*	0.85 (0.990) PMG is preferred		
	No of observatios	267		
	Log likelihood	629.770		
	No of groups	14		

Notes: and $***$ statistically Significant at the 5% and 1% levels, respectively.

4.6. Dumitrescu and Hurlin panel causality test results

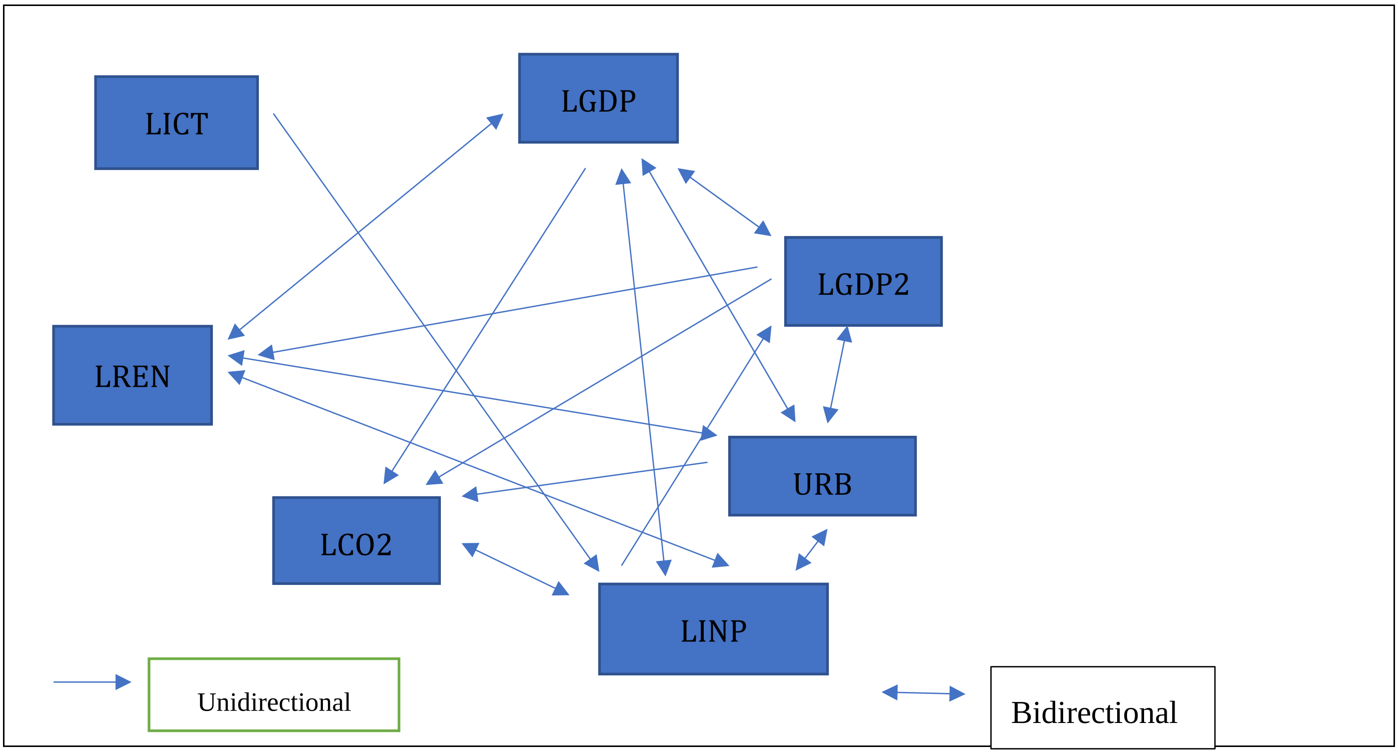
Table 8 presents the findings from the Dumitrescu and Hurlin panel causality tests. These findings indicate a bidirectional causal relationship between industrialization and CO2 emissions, economic growth and renewable energy usage, urbanization, and renewable energy usage, and the connection between industrialization and economic growth. The bidirectional causal link shows that industrialization and economic growth, along with industrialization and CO2 emissions, influence each other mutually. Bidirectional causality shows that urbanization and the use of renewable energy affect both economic growth and renewable energy production consumption. As a result, renewable energy can be used in industrial processes to boost economic growth while minimizing CO2 emissions. There exists a unidirectional causality: economic growth leads to higher CO2 emissions, increased reliance on renewable energy, and drives technological advancements in industrialization. This indicates that CO2 emissions do not contribute to economic growth or urbanization. This indicates the possibility of sustainable economic growth in upper-middle-income countries. The unidirectional causality from economic growth to CO2 emissions is contradictory with the result obtained by (You et al., 2022) where the causality results indicated the bidirectional causality relationship between CO2 emissions and economic expansion. However, this study was conducted in 95 countries that were selected randomly where both low-income, middle-income and high-income countries were included. Figure 1 also shows the graphical representation of panel causality.

Table 8: Dumitrescu and Hurlin panel non-causality test

Null hypothesis	W-stat.	*Zbar-Stat.*	Prob.	Causality flow	Result
LGDP≠ LCO2 **LCO2 ≠ LGDP**	6.060*** 2.867	5.210 0.777	0.000 0.436	**LGDP⇒ LCO2**	Unidirectional
LGDP2≠ LCO2 **LCO2 ≠ LGDP2**	6.010*** 2.867	5.141 0.777	0.000 0.437	**LGDP2 ⇒ LCO2**	Unidirectional
LREN≠ LCO2 **LCO2 ≠ LREN**	1.727 3.475	-0.805 1.621	0.420 0.104	-	İnconclusive
LICT ≠ LCO2 **LCO2 ≠ LICT**	2.162 3.686	-0.285 1.594	0.776 0.110	-	İnconclusive
LINP ≠ LCO2 **LCO2 ≠ LINP**	4.471*** 6.852***	3.004 6.309	0.002 0.000	**LINP⇔ LCO2**	Bidirectional
LURB≠ LCO2 **LCO2≠ URB**	6.060*** 2.867	5.210 0.777	0.000 0.436	**URB⇒ LCO2**	Unidirectional
LGDP≠ LREN **LREN ≠ LGDP**	3.790** 6.145**	2.064 5.338	0.039 0.000	**LGDP⇔ LREN**	Bidirectional
LINP ≠ LREN **LREN ≠ LINP**	3.079** 6.145***	2.064 5.338	0.039 0.000	**LINP□ LREN**	Bidirectional
LICT ≠ LREN **LREN ≠ LICT**	2.144 2.304	-0.304 -0.107	0.760 0.914	-	İnconclusive
URB≠ LREN **LREN ≠ URB**	5.065*** 9.114***	3.837 9.467	0.000 0.000	**URB□ LREN**	Bidirectional
LGDP2≠ LREN **LREN≠ LGDP2**	6.781*** 3.118	6.222 1.129	0.000 0.258	**LGDP2⇒ LREN**	Unidirectional
LICT≠ LGDP2 **LGDP2≠ LICT**	1.924 2.871	-0.563 0.670	0.573 0.502	-	İnconclusive
LINP ≠ LGDP2 **LGDP2 ≠ LINP**	4.331*** 9.123***	2.899 9.694	0.003 0.000	**LIND□ LGPP2**	Bidirectional
LGDP ≠ LGDP2 **LGDP2 ≠ LGDP**	6.077*** 6.145***	5.375 5.472	0.000 0.000	**LGDP□ LGDP2**	Bidirectional
URB≠ LGDP2 **LGPP2≠ URB**	5.162*** 22.407***	4.078 28.526	0.000 0.000	**URB□ LDPP2**	Bidirectional
LINP ≠ LICT **LICT ≠ LINP**	2.997 7.324***	0.833 6.468	0.404 0.000	**LICT⇒ LINP**	Unidirectional
LICT≠ LGDP **LGDP≠ LICT**	2.927 1.916	0.742 -0.573	0.458 0.566	-	İnconclusive
URB≠ LICT **LICT≠ URB**	2.977 3.331	0.807 1.268	0.419 0.204	-	İnconclusive
LGDP ≠ LINP **LINP ≠ LGDP**	9.069*** 4.358***	9.617 2.938	0.000 0.003	**LGDP□ LINP**	Bidirectional
URB≠ LINP **LINP≠ URB**	4.364*** 10.610***	2.946 11.801	0.003 0.000	**URB□ LINP**	Bidirectional
URB≠ LGDP **LGDP≠ URB**	5.063*** 21.372***	3.938 27.085	0.000 0.000	**URB□ LGDP**	Bidirectional

Notes: ** and *** denote statistically significant at the 5% and 1% levels, respectively.

Figure 1: Visualization of the causality results



5. CONCLUSIONS, POLICY RECOMMENDATIONS AND LIMITATIONS OF THE STUDY

This research examined the EKC concept in 14 selected upper-middle-income nations. It analyzed the possible impact of technological advancements, renewable energy adoption, industrial growth, and urban development on fostering environmental sustainability, particularly in reducing CO2 emissions. The study utilized ARDL estimation and incorporated FMOLS and IFE long-run cointegration predictions to evaluate robustness. The aggregate results demonstrated that the EKC hypothesis was significant solely in the long term, and technological advancement can mitigate CO2 emissions exclusively in the long run. On the other hand, the use of renewable energy was found to reduce CO2 emissions in both the short and long term. This shows that renewable energy can act as a substitute for fossil fuels in production processes and can promote sustainable economic growth over time. Furthermore, the negative effect of technological advancement in the long run indicates that such development is essential for preserving economic sustainability over time. The results obtained from the current study are consistent with the findings obtained by (Naimoglu & Akal, 2023) where technological advancement, energy efficiency and renewable energy consumption can ensure the long-run environmentally friendly economic growth in the Türkiye by reducing CO2 emissions. The study indicated that the technological advancement improved energy efficiency while renewable energy consumption reduced the dependency in consuming fossil energy resources in Türkiye. Moreover, the study of (Suki et al., 2022) revealed the EKC hypothesis in Malaysia is valid in the long run where both renewable energy and technological innovation ensure environmental quality by reducing CO2 emissions and ecological footprint consumption.

The panel causality analysis identified one-way causal relationships between economic growth and CO2 emissions, and between urbanization and CO2 emissions. A bidirectional causal link between industrialization and CO2 emissions was found. Additionally, the causal relationships among the explanatory factors were analyzed. Bidirectional causality was found between economic growth and the use of renewable energy, as well as between industrialization and renewable energy consumption, and urbanization and renewable energy use. These factors suggest that renewable energy has the potential to support ongoing economic growth in the selected countries. Policymakers must invest significantly in the development of renewable energy for policy consequences. Moreover, it is imperative to advance technological development to guarantee efficient energy utilization, which is crucial for sustainable economic growth. As it was advised by (Caglar et al., 2025) to make necessary investments in promoting research and development (R&D) that can further develop environmentally friendly technologies, the selected countries can take necessary measures to make necessary investments for R&D and therefore develop technologies that are relatively environmentally friendly.

The study also contains lots of limitations. By considering these limitations, more comprehensive empirical studies can be carried out in the future. For instance, future studies can be conducted on the same issues by applying different other estimation techniques including quantile estimation techniques, Driscoll and Kraay error estimation techniques and different wavelet quantile estimations that provide more robust results. Furthermore, different other environmental degradation indicators including ecological footprint consumption per capita and inverted load capacity per capita that are used recently in different studies to investigate the EKC hypothesis can be used in the future to investigate the same topic. Although CO2 emissions are the main factors that create environmental degradation, ecological footprint consumption considers all other ecological footprint consumptions including land use, deforestation, fishing and others that create environmental degradation. On the other hand, inverted load capacity factor considers both demand (consumption) and supply (production) components of the environmental factors whereas ecological footprint consumption only accounts for the demand component of the environmental factors.

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Panel data test results – Halil Altıntaş

Panel data test results analyses – Mohammad Nadimur Rahman

Abstract and conclusion – Mohammad Nadimur Rahman

CONFLICT OF INTEREST

"The authors declare that there is no conflict of interest."

DATA AVAILABILITY

"The data can be provided upon request by the author(s)."

ETHICAL STATEMENT

"Not applicable."

ARTIFICIAL INTELLIGENCE (AI) USAGE STATEMENT

"No AI-based tools were used in this study."

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