“Renewable energy transition, urbanization, and environment nexus in the Middle East and North Africa: Cross-sectional dependence analyses”

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ARTICLE INFO	Haider Mahmood and Maham Furqan (2025). Renewable energy transition, urbanization, and environment nexus in the Middle East and North Africa: Cross-sectional dependence analyses. *Environmental Economics*, *16*(1), 89-101. doi:10.21511/ee.16(1).2025.07
DOI	http://dx.doi.org/10.21511/ee.16(1).2025.07
RELEASED ON	Wednesday, 26 March 2025
RECEIVED ON	Sunday, 22 December 2024
ACCEPTED ON	Friday, 14 March 2025
LICENSE	This work is licensed under a Creative Commons Attribution 4.0 International License
JOURNAL	"Environmental Economics"
ISSN PRINT	1998-6041
ISSN ONLINE	1998-605X
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
59	0	5

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BUSINESS PERSPECTIVES

LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine
www.businessperspectives.org

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RENEWABLE ENERGY TRANSITION, URBANIZATION, AND ENVIRONMENT NEXUS IN THE MIDDLE EAST AND NORTH AFRICA: CROSS-SECTIONAL DEPENDENCE ANALYSES

Abstract

The renewable energy transition could support a clean environment in any region as per sustainable development goals. Thus, this paper aims to explore the impact of renewable energy transition on CO_2 emissions in the fossil fuel-dependent 11 MENA economies from 2001 to 2023. For this purpose, the study employs novel cross-sectional dependence (CSD) techniques to find robust results. The results expose that income per capita positively influences emissions with a coefficient of 14.325. However, the square of income per capita reveals a negative connection with a coefficient of –0.765, which supports the environmental Kuznets curve hypothesis. Moreover, urbanization increases emissions with a coefficient of 0.512. Contrariwise, the renewable energy transition mitigates emissions with a coefficient of –0.803. The study concludes that urbanization increases and renewable energy transition helps to mitigate emissions. Thus, the process of the renewable energy transition should be accelerated to further support environmental sustainability, and urbanization should be checked to reduce its environmental problems.

Received on: 22nd of December, 2024
Accepted on: 14th of March, 2025
Published on: 26th of March, 2025

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Keywords carbon emissions, sustainable development goals, renewable energy, the environmental Kuznets curve, urbanization

JEL Classification Q56, O44, P18

INTRODUCTION

The MENA region primarily relies on fossil fuels for both energy production and manufacturing sectors, which are highly carbon-intensive and can have severe environmental consequences. However, some MENA countries are progressively moving toward renewable energy transition (RET), which can help reduce fossil fuel usage and mitigate emissions. For instance, a shift from fossil fuels toward renewable sources could help MENA economies for a smooth RET to protect the environment from fossil fuel dependence. Some MENA countries are moving to cleaner sources of energy to produce electricity, which could reduce emissions in their economies and also boost their energy exports to support sustainable economic growth. The RET can improve energy efficiency in buildings, industry, and transportation sectors, potentially decreasing aggregate energy utilization and emissions. In the same way, improving energy efficiency in the industrial sector by reducing the consumption of fossil fuels could reduce emissions levels. The shift to renewable energy in the water industry can also improve energy efficiency in the MENA region.

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Conflict of interest statement:
Author(s) reported no conflict of interest

The increasing urbanization is another problem in the MENA region, which would raise energy demand and carbon emissions. For instance, increasing urbanization can increase the demand for buildings and infrastructure, which would raise the demand for cooling energy as the MENA has a hot climate. Moreover, lightning and heating also need energy, which depends on fossil fuels in this region. Thus, urbanization could be responsible for increasing emissions. Rising urbanization could also put pressure on the transportation sector and can also result in traffic congestion, which is responsible for the overuse of fuel in vehicles. Urbanization can be responsible for deforestation and could reduce carbon sinks. In addition, it can give rise to the manufacturing sector, which is usually pollution-oriented in this region. On the whole, urbanization can increase emissions due to increasing economic activities and aggregate demand for products and energy.

The above discussions highlight the importance of RET in combating emissions. Moreover, urbanization and economic growth may raise emissions. A comprehensive investigation of the fossil fuel-dependent MENA region is pertinent to capturing the role of RET and urbanization on the environment. The present study takes a ratio of renewable energy consumption (REC) to fossil fuel consumption to capture the effect of the RET for a sample of 11 MENA economies from 2001 to 2023. Moreover, the present analysis utilizes novel cross-sectional dependence (CSD) econometric techniques to estimate unbiased and efficient results. Therefore, the environmental challenges of the MENA region could be managed by proper urban planning and effective RET in the region.

1. LITERATURE REVIEW AND HYPOTHESES

The concept of the renewable energy transition (RET) is rare in environmental literature. However, most literature estimates the effect of renewable energy consumption (REC) on emissions. Ridzuan et al. (2020) probed Malaysia and indicated that economic progress and urbanization increased emissions. However, the REC and agriculture sector reduced pollution. Besides, the environmental Kuznets curve (EKC) hypothesis was substantiated. Hassan and Hussein (2024) investigated Somalia and concluded that REC condensed carbon emissions and urbanization contributed to emissions over time. Regmi et al. (2024) examined the EKC framework to instigate the impact of agricultural inventions and REC on emissions from 1990 to 2018 and validated the EKC hypothesis in Nepal. Moreover, agricultural innovation and REC reduced emissions. In addition, urbanization also contributed to environmental quality. Unidirectional causality from agricultural innovation and REC to emissions was also substantiated. Se. Katircioğlu and Sa. Katircioğlu (2018) explored Turkey and found that urbanization and non-REC contributed to emissions. Thus, the EKC between emissions and urbanization was not supported.

In a study on green finance in China, Kassi et al. (2024) revealed that green securities had a stronger impact on reducing emissions in comparison to green credits. Moreover, REC has helped improve environmental quality. However, economic growth, urbanization, and foreign direct investment (FDI) had heterogeneous effects. Han et al. (2024) investigated China and found that green finance and REC significantly improved the environment. Nevertheless, urban population and affluence exacerbated ecological footprints. The authors emphasized mitigating urbanization's adverse effects on the environment by promoting digital and green transitions. Shu et al. (2024) probed China and concluded that natural resources and urbanization elevated emissions. REC and fintech development fostered ecological balance. Sagheer and Ashraf (2024) examined China from 1995 to 2022 and revealed that sustainable agricultural practices and REC mitigated emissions. Urbanization has accelerated emissions, which puts pressure on balancing urban development with environmental conservation. Amin et al. (2024) analyzed China from 1990 to 2019 and indicated that urbanization and income contributed to environmental degradation. However, REC alleviated emissions. Moreover, natural resources increased emissions. Lian et al. (2023) focused on China from 2000 to 2019 and concluded that REC improved carbon efficiency. Population, urbaniza-

http://dx.doi.org/10.21511/ee.16(1).2025.07

tion, and fossil energy also affect carbon efficiency. Social upgrading reduced carbon efficiency. Shang et al. (2023) analyzed China from 1975 to 2020 and reported that environmental technology and REC condensed emissions. Nevertheless, financial development and natural resources increased emissions.

The literature has also investigated different panels of countries. For instance, Borozan (2024) explored the influence of REC on emissions in the EU and found that institutional quality had different impacts on emissions in EU regions. Nevertheless, REC reduced CO_2 emissions, and income increased emissions in all convergence clubs. Alavijeh et al. (2024) scrutinized the impacts of REC on human development (HD) in EU countries from 2000 to 2019 and found that REC enhanced human development at lower quantiles but reduced at higher quantiles. Furthermore, affluence and urbanization exerted a positive effect. Conversely, emissions are negatively affected by human development. Hamed and Özataç (2024) investigated the GCC countries and concluded that financial development and FDI increased pollution. Nevertheless, financial development and institutional quality enhanced renewable energy investments, which could support a clean environment. Bousrih (2024) examined the GCC countries from 2000 to 2022 and found that economic activity increased emissions. R&D investments enhanced environmental quality. However, urbanization's role in emissions was inconclusive.

In a study on BIMSTEC economies, Bilgili et al. (2024) analyzed data with quantile regression. An N-shaped EKC was corroborated. REC mitigated emissions across quantiles. Moreover, energy intensity and urbanization reduced air quality. Feng et al. (2024) investigated the G20 and concluded that REC, fintech, and political stability reduced pollution. However, urbanization and affluence contributed to emissions. Thus, prioritizing REC along with environmentally friendly financial products would help achieve the SDG of combating climate change. Zhu et al. (2024) analyzed BRICS economies from 1998 to 2021 and revealed that natural resource rents, urbanization, and economic growth exacerbated carbon emissions. REC, R&D expenditures, and digitalization mitigated emissions. The authors underscored the importance of targeted policies addressing SDGs 7, 12, and 13. Gyamfi et al. (2024) examined South Asian economies and confirmed that imports, REC, and human development reduced CO_2 emissions. However, exports and urbanization increased emissions. Thus, improving REC could support a clean environment.

In a study on a panel of 54 nations from 2003 to 2017, Mamkhezri and Khezri (2024) found that the intensity effects of R&D had spillovers, which reduced emissions. Moreover, high-tech clean energy adoption helped to reduce emissions. The EKC hypothesis was also substantiated due to clean energy in the model. It could help in attaining SDGs. Kusiyah et al. (2024) scrutinized the effect of urbanization in 23 highly urbanized nations by moderating the role of REC in the model and found that urbanization and industrial growth escalated emissions. Nonetheless, REC reduced them. Tang et al. (2024) analyzed BRI nations and concluded that REC adoption and institutional quality reduced emissions. Thus, strengthening institutional frameworks could help in advancing renewable energy systems. Xu et al. (2023) probed 91 middle-income nations from 2000 to 2020 and found that fintech accelerated the shift toward REC by improving efficiency and access to finance. Moreover, income, industry, urbanization, and FDI also influenced the energy transition.

Some studies have worked on the ASEAN and African economies. For instance, Ehigiamusoe (2023) examined environmental degradation in ASEAN and concluded that REC, trade, and FDI alleviated pollution. Nevertheless, non-REC and economic progress exacerbated it, and financial development moderated the effects of energy consumption on emissions. Moreover, urbanization negatively influences environmental quality. Kwakwa (2023) analyzed 32 African countries from 2002 to 2021 and found that the agriculture, industry, and service sectors increased emissions. REC mitigated the impact of the agriculture and industry sectors and exacerbated the impact of the service sector. Moreover, trade, urbanization, and income increased emissions. Esily et al. (2023) investigated energy poverty, REC, and the environmental nexus in North Africa from 1993 to 2021 and indicated that energy poverty, economic progress, and non-REC reduced environmental quality. However, REC played a good role in mitigating degradation. In addition, environmental deterioration shared a feedback effect with urbanization and energy usage.

In a study on most urbanized economies, Kuldasheva and Salahodjaev (2023) analyzed annual data from 2000 to 2015 and concluded that REC alleviated pollution. Moreover, institutional quality mediated the REC and environment nexus. Murshed et al. (2023) studied the influence of financial inclusion and REC on CO_2 emissions in 22 evolving economies from 2008 to 2018 and concluded that financial inclusion increased emissions. Nevertheless, this relationship was moderated by energy efficiency, which helped to reduce emissions. REC curbed CO_2 emissions and economic progress, trade, and urbanization exacerbated emissions. Vardar et al. (2023) scrutinized 47 developing nations from 2000 to 2018 and revealed that green finance and REC reduced the ecological footprint. However, economic progress, trade, and urbanization increased environmental degradation. Moreover, green finance and REC mitigated ecological impacts. Irfan et al. (2022) explored 20 major mineral-exporting countries from 1980 to 2020 and found that mineral markets facilitated the energy transition. Financial markets inversely impacted sustainable energy goals. Urbanization and carbon intensity negatively affected energy transition. REC and FDI promoted the energy transition, respectively.

In a big panel of 70 nations, Bhattacharya et al. (2020) concluded that countries with higher REC and urbanization belonged to low carbon emissions intensity. However, industrialization hampered this transition. Wen et al. (2022) investigated Africa from 1990 to 2019 and concluded that non-REC, urbanization, and FDI increased emissions, but REC and trade reduced emissions. Moreover, unidirectional causality from non-REC to emissions and feedback between REC and emissions were also reported. Khalid et al. (2022) examined G-7 nations from 1988 to 2018 and substantiated that REC and globalization improved the environment. Nevertheless, urbanization, economic progress, and non-REC deteriorate it. Furthermore, the EKC was observed between urbanization and emissions. Cai et al. (2021) scrutinized Asia from 1990 to 2018 and confirmed the EKC hypothesis. REC and agriculture output reduced pollution. Nevertheless, non-REC and urbanization exacerbated environmental degradation. Koengkan et al. (2020) analyzed five Southern Common Market countries from 1980 to 2014 and identified feedback between fossil fuels and emissions. Moreover, REC and urbanization caused REC.

By analyzing Asian developing nations, Salim et al. (2019) found that urbanization, affluence, and non-REC increased emissions. Nevertheless, REC reduced pollution. The EKC hypothesis was supported. Thus, REC and strategic urban planning improved sustainable development. Sepehrdoust and Zamani (2017) investigated oil and non-oil-based nations from 2001 to 2012 and showed that REC, population, and internet usage mitigated carbon intensity. In addition, the industries contributed to both income and emissions. However, urbanization reduced CO_2 emissions in non-oil importing countries. Rafiq et al. (2016) analyzed 22 evolving economies and showed that affluence increased emissions. Nevertheless, REC showed a minor effect. Non-REC increased emissions, and trade reduced emissions. Nevertheless, urbanization increased energy intensity but could not impact emissions.

The literature shows the prominence of urbanization, economic growth, and renewable energy consumption in determining emissions. However, the testing of the renewable energy transition, considering the ratio of renewable energy consumption to fossil fuels, is scant in literature and missed in the MENA region. Thus, the present analysis aims to fill this literature gap and presents the following hypotheses:

H1: *Renewable energy transition can significantly condense CO_2 emissions by substituting fossil fuels with renewable energy consumption in the MENA economies.*

H2: *Urbanization can increase CO_2 emissions due to higher energy demand in urban areas.*

2. METHOD

The EKC theory of Grossman and Krueger (1991) is utilized to estimate the impact of income on emissions. It explains that earlier economic

http://dx.doi.org/10.21511/ee.16(1).2025.07

growth may increase energy demand, which is a scale effect. Nevertheless, economies may shift to cleaner industries over time. For instance, replacing the energy-intensive natural resource sector with sustainable sectors would result in a composition effect in the MENA region (Halabi et al., 2015). Furthermore, regulatory measures can also drive cleaner technologies, which is a technique effect. Besides, the MENA region's abundant solar and wind resources can be used for electricity generation (Tsikalakis et al., 2011). Thus, renewable energy consumption (REC) may play a crucial role in transitioning MENA economies from the first to the second stage of the EKC by enhancing energy efficiency and reducing emissions. However, the environmental effects of REC depend on the scale and pace of the renewable energy transition (RET). A RET is defined as a ratio of REC to total fossil fuel consumption, which serves as an indicator of reduced dependence on fossil fuels and amplified REC (Mohsin et al., 2021). Thus, RET would help in shaping the EKC. In addition, the MENA region is among the most urbanized regions in the world (Yehya et al., 2024). It may contribute to deforestation (Peerzado et al., 2019), emissions from construction (Fisch-Romito, 2021), and fossil fuel-dependent transportation (Salem et al., 2023). Moreover, urbanization may increase energy demand through increased industrial activity and pollute the environment in fossil fuel-reliant MENA economies. It may also increase the demand for cleaner energy due to a rising standard of living in urban areas. Thus, the net effect of urbanization and RET remains an empirical question, which is tested in the following EKC framework:

$$CE_{it} = f\begin{pmatrix} GDPPC_{it},\ GDPPC_{it}^{\ 2}, \\ URB_{it},\ RET_{it} \end{pmatrix}. \quad (1)$$

In equation 1, t is a period from 2001 to 2023 and i represents 11 MENA economies, which are Algeria, Kuwait, Morocco, Oman, Qatar, Saudi Arabia, Egypt, Iran, Iraq, Israel, and the UAE. The sample of MENA economies and time samples are selected based on the data availability. Table 1 displays the proxies and sources of data for each variable mentioned in equation 1.

To estimate the model, CSD-based techniques are employed to account for the expected interdependencies among variables in the MENA region. MENA economies have strong trade ties and shared geographical characteristics (Saud et al., 2023), which may lead to CSD in the model. To test the CSD issue statistically, Pesaran's (2021) CSD methodology is applied, along with the Breusch-Pagan (B-P) test (Breusch & Pagan, 1980) and the Pesaran-Scaled (P-S) LM test (Pesaran et al., 2008). Moreover, Slope Heterogeneity (SH) is tested by using Pesaran and Yamagata's (2008) Δ-statistic and Δadj-statistic. Later, the stationarity of all series is tested using the CSD-based CADF and CIPS unit root tests (Pesaran, 2007). After ensuring the stationarity of variables, the study may proceed to cointegration analysis with the following Kao et al.'s (1999) test:

$$y = \beta' X + e. \quad (2)$$

where y is the dependent variable and X is an independent variable. β' is the estimated coefficient of the independent variable. The residual of Equation 2 is tested for stationarity. The stationary residuals will indicate potential cointegration in the model. However, Kao et al.'s (1999) test ignores the SH in analysis. To further validate cointegration in the presence of the SH, Pedroni's (2004) approach is applied by utilizing the following statistical tests:

$$T^2 N\sqrt{N} Z_{\hat{v}\,N,T} = \frac{T^2 N\sqrt{N}}{\sum_{i=1}^{N}\sum_{t=1}^{T}\frac{1}{\hat{L}_{11i}^{2}\hat{e}_{i,t-1}^{2}}}, \quad (3)$$

Table 1. Explanation of variables

Variables	Proxies	Units of measurement	Sources of raw data
CE_{it}	Natural logarithm of CO_2 emissions per capita	Tons	World Bank (n.d.)
$GDPPC_{it}$	Natural logarithm of Gross Domestic Product (GDP) per capita	Constant 2015 USD	World Bank (n.d.)
$GDPPC_{it}^{\ 2}$	Square of $GDPPC_{it}$	Square term	World Bank (n.d.)
URB_{it}	Percentage of the urban population in total population	Both types of population in total number of persons	World Bank (n.d.)
RET_{it}	A ratio of REC to fossil fuel consumption	Both energy proxies in exajoule	Energy Institute (2024)

$$T\sqrt{N}Z_{\hat{\rho}N,T-1} = T^2\sqrt{N}\frac{\left(\sum_{i=1}^{N}\sum_{t=1}^{T}1/\hat{L}_{11i}^2\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i\right)}{\left(\sum_{i=1}^{N}\sum_{t=1}^{T}1/\hat{L}_{11i}^2\hat{e}_{i,t-1}^2\right)}, \quad (4)$$

$$Z_{t\,N,T} = \frac{\left(\sum_{i=1}^{N}\sum_{t=1}^{T}1/\hat{L}_{11i}^2\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i\right)}{\sqrt{(\tilde{\sigma}_{N,T}^2\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^2)}}, \quad (5)$$

$$Z_{t\,N,T}^{*} = \frac{\left(\sum_{i=1}^{N}\sum_{t=1}^{T}1/\hat{L}_{11i}^2\hat{e}_{i,t-1}^{*}\,\Delta\hat{e}_{i,t}^{*}\right)}{\sqrt{\left(\tilde{s}_{N,T}^{*2}\sum_{i=1}^{N}\sum_{t=1}^{T}1/\hat{L}_{11i}^2\hat{e}_{i,t-1}^{*2}\right)}}, \quad (6)$$

$$T\sqrt{N}\tilde{Z}_{\hat{\rho}N,T-1} = T\cdot\frac{1}{\sqrt{N}\left(\sum_{t=1}^{T}\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i\right)} \times\sum_{i=1}^{N}\left[\frac{1}{\sum_{t=1}^{T}\hat{e}_{i,t-1}^2}\right], \quad (7)$$

$$\frac{1}{\sqrt{N}Z_{t\,N,T}} = \frac{1}{\sqrt{N}\left(\sum_{t=1}^{T}\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i\right)} \times\frac{1}{\left[\sum_{i=1}^{N}\left(\hat{\sigma}_i^2\sum_{t=1}^{T}\hat{e}_{i,t-1}^2\right)\right]}, \quad (8)$$

$$\frac{1}{\sqrt{N}Z_{t\,N,T}^{*}} = \frac{1}{\sqrt{N}\left(\sum_{t=1}^{T}\hat{e}_{i,t-1}^{*}\ddot{A}\hat{e}_{i,t}^{*}\right)} \times\frac{1}{\sqrt{\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{s}_i^{*2}\hat{e}_{i,t-1}^{*2}\right)}}. \quad (9)$$

where N is the number of countries. T is the number of time periods. $\hat{e}^2_{i,t-1}$ is the square of the estimated residuals from the panel cointegration regression. $\hat{e}^{*}_{i,t}$ is bias-corrected residual. $\tilde{\sigma}^2_{N,T}$ is the panel-wide variance of estimated residuals. $s^{*2}_{N,T}$ is an adjusted panel-wide variance estimate. $\hat{\lambda}_i$ is an estimated autoregressive term in the residual-based test equation. $\hat{L}^2_{11t}$ is the long-run variance of residuals for country i. $\tilde{\sigma}^2_{N,T}$ is the panel-wide variance of estimated residuals. Pedroni's (2004) technique cares about the SH in analysis but ignores the presence of the CSD in the model. Thus, Westerlund's (2007) method is employed with test statistics in Equations 10-13, which cares for both the SH and CSD in the model.

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\Omega_i}{SE(\widehat{\Omega_i})}, \quad (10)$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\Omega_i}{\Omega(1)}, \quad (11)$$

$$P_t = \frac{\widehat{\Omega_i}}{SE(\widehat{\Omega_i})}, \quad (12)$$

$$P_a = T\hat{\Omega}. \quad (13)$$

where Ω_i is error correction term for country i. $SE(\Omega_i)$ is the standard error of Ω_i. $\Omega(1)$ is the long-run variance estimate of Ω_i. After a comprehensive cointegration analysis, the CSD-based AutoRegressive Distributive Lag (ARDL) of Chudik et al. (2017) is applied to find the long and short-run effects in the following way:

$$\begin{aligned} CE_{it} &= a_i + \sum_{j=1}^{k}g_{ij}CE_{it-j} \\ &+\sum_{j=0}^{k}b_{1ij}GDPPC_{it-j} + \sum_{j=0}^{k}b_{2ij}GDPPC_{it-j}^2 \\ &+\sum_{j=j}^{k}b_{3ij}RET_{it-j} + +\sum_{j=1}^{k}b_{4ij}URB_{it-j} \\ &+\sum_{j=0}^{k}c_{1j}\overline{CE_{it}} + \sum_{j=0}^{k}c_{2j}\overline{GDPPC_{it}} \\ &+\sum_{j=0}^{k}c_{3j}\overline{GDPPC_{it}^2} + \sum_{j=0}^{k}c_{4j}\overline{RET_{it}} \\ &+\sum_{j=0}^{k}c_{5j}\overline{URB_{it}} + e_{it}. \end{aligned} \quad (14)$$

where e_{it} is an error term for country i at time t. a_i is an intercept, which is heterogeneous across countries. k is the optimal lag length. The variables with bars represent the cross-sectional averages of the respective variables. The coefficients (g) capture the effects of lagged carbon emissions on current carbon emissions. The coefficients (b) capture the effects of level and lagged independent variables on current carbon emissions. The coefficients (c) capture the effects of cross-sectional averages of variables on current carbon emissions. The coefficients are normalized to find the long-run results. The error correction term is added to find the short-run impacts.

http://dx.doi.org/10.21511/ee.16(1).2025.07

3. RESULTS

Table 2 shows the results of CSD and SH tests. The test statistics for CE_{it} have CSD with 117.654, 69.957, and 54.415 values. So, carbon emissions in one country are affected by emissions in other MENA countries. Similarly, $GDPPC_{it}$ has CSD with 231.894, 63.722, and 61.324 values. Thus, the economic performance of one nation is affected by the growth of other MENA countries, which shows regional economic integration. Similarly, the $GDPPC_{it}^2$ also reveals CSD with 219.543, 38.176, and 30.218 values. URB_{it} carries CSD with values 91.217, 42.467, and 33.333. Thus, urbanization trends in the region are interconnected. The RET_{it} also has significant CSD with values of 156.654, 31.525, and 29.467. Thus, the RET is also integrated within the MENA economies. So, RET in one country may be influenced by similar policies of RET in other MENA countries. Lastly, the residual has CSD with values of 742.857, 121.679, and 83.241, which corroborates a strong CSD in the model. Table 2 also presents the estimates of Δ and Δadj statistics to test slope heterogeneity, which is confirmed with values Δ = 22.962 and Δadj = 30.014.

Table 2. Cross-sectional and slope heterogeneity tests

Variable	CSD			Slope heterogeneity	
	B-P LM	P-S LM	Pesaran	Δ	$Δ_{adj}$
$C_{Ei}t$	117.654	69.957	54.514	–	–
	(0.000)	(0.000)	(0.000)		
$GDPPC_{it}$	231.894	63.722	61.324	–	–
	(0.000)	(0.000)	(0.000)		
$GDPPC_{it}^2$	219.543	38.176	30.218	–	–
	(0.000)	(0.000)	(0.000)		
URB_{it}	91.217	42.167	33.333	–	–
	(0.000)	(0.000)	(0.000)		
RET_{it}	156.654	31.525	29.467	–	–
	(0.000)	(0.000)	(0.000)		
Residual	742.857	121.679	83.241	22.962	30.014
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table 3 shows the CADF and CIPS results. The unit root tests are conducted both at the level and first difference of all variables with and without trends. The results corroborate the existence of unit roots in level variables. However, the high negative statistics are verified in the first differenced series. Thus, the integration level is I(1), which is suitable for further cointegration analysis.

Table 3. Stationarity tests

Variables	Level		Differenced	
	C	C&T	C	C&T
CADF				
CE_{it}	0.496	0.516	–3.654***	–3.824***
$GDPPC_{it}$	0.682	0.769	–4.186***	–4.394***
$GDPPC_{it}^2$	0.258	0.482	–3.984***	–4.239***
URB_{it}	1.224	0.952	–3.631***	–3.905***
RET_{it}	–0.602	–0.996	–5.724***	–6.385***
CIPS				
CE_{it}	1.125	1.052	–3.254***	–4.356***
$GDPPC_{it}$	0.825	0.408	–5.112***	–4.963***
$GDPPC_{it}^2$	0.752	0.541	–4.521***	–5.249***
URB_{it}	0.826	0.429	–5.547***	–4.729***
RET_{it}	–1.052	–0.921	–4.964***	–5.524***

Note: *** stationarity at 1%. C is intercept and T is trend.

Table 4 shows the cointegration results. The estimates of the Pedroni test show that in within-dimension panel tests, the *v* statistic is –3.354, which suggests the presence of cointegration in the panel. Similarly, the ADF statistic is –4.541, which again supports the existence of cointegration. For the between-dimension group tests, the rho statistic is –2.942. Thus, the Pedroni test suggests the existence of cointegration. The Kao test is also presented in Table 4, which is based on the residual of the model. The ADF statistic is –4.874. Additionally, the Westerlund test is applied, which cares about CSD and slope heterogeneity in the model. Three out of four test statistics (Gt, Pt, and Pa) are negative and significant. All tests corroborate cointegration in the model.

Table 5 presents the findings from the CSD-based ARDL. In the long-term, GDP per capita has a positive coefficient of 15.412, which specifies that GDP per capita is leading to a rise in carbon emissions. However, its squared term ($GDPPC_{it}^2$) is negative and significant with a coefficient of –0.779, which corroborates the EKC hypothesis. Thus, emissions increase initially with rising GDP per capita and decrease after reaching a certain threshold point. Urbanization raised emissions with a coefficient of 0.642. Therefore, rising urbanization contributes to higher emissions, which may be due to increased industrial activity and energy consumption in urban areas; *H1* is validated. Lastly, the RET has a negative coefficient of –0.785, which indicates that shifting toward REC helps mitigate emissions. Consequently, *H2* is also validated.

Table 4. Panel cointegration

Tests	Statistics	*p*-value	Weighed-statistics	*p*-value
Pedroni (2004)				
Panel statistics				
v	–3.354	0.000	–3.154	0.000
rho	–1.125	0.128	–1.241	0.336
PP	–0.965	0.237	–0.846	0.324
ADF	–4.541	0.000	–3.579	0.000
Group statistics				
rho	–2.942	0.000	–	–
PP	–1.064	0.241	–	–
ADF	–0.796	0.387	–	–
Kao et al. (1999)				
ADF statistics	–4.874	0.000	–	–
Variance	0.003	–	–	–
Westerlund (2007)				
Statistic	Value	*Z*-value	*p*-value	–
Gt	–3.941	–2.542	0.000	–
Ga	–1.746	–0.819	0.432	–
Pt	–4.254	–3.705	0.000	–
Pa	–5.654	–3.815	0.000	–

Table 5. ARDL results

Variable	Coefficient	S.E.	*t*-statistics	*p*-value
Long run				
$GDPPC_{it}$	15.412	4.352	3.541	0.000
$GDPPC_{it}^2$	–0.779	0.371	–2.102	0.029
URB_{it}	0.642	0.217	2.954	0.000
RET_{it}	–0.785	0.188	–4.179	0.000
Short run				
$GDPPC_{it}$	13.249	2.308	5.741	0.000
$GDPPC_{it}^2$	–0.706	0.142	–4.964	0.000
URB_{it}	0.524	0.162	3.241	0.000
RET_{it}	–0.698	0.154	–4.521	0.000
ECT_{t-1}	–0.412	0.095	–4.358	0.000

In the short run, ECT_{t-1} is negative. Thus, any deviation from the long-run relationship is corrected at a speed of 41.2% per year. The statistically significant positive and negative parameters of $GDPPC_{it}$ and $GDPPC_{it}^2$ again corroborate the existence of the EKC. In addition, urbanization raises emissions and RET has a negative effect.

4. DISCUSSION

The results of this study expose a non-linear effect of GDP per capita on emissions. Early economic growth raises emissions due to rising industrial activity, energy usage, and higher demands for energy-intensive products. Thus, an early level of growth is responsible for higher production and consumption activities, which has contributed to environmental degradation in the fossil fuel-based MENA economies. However, the findings showed a negative effect of the squared of income on emissions, which supports the EKC hypothesis. This indicates that rising GDP per capita can help MENA economies reduce emissions after a threshold is reached. Thus, after that threshold point of economic growth, the MENA economies have adopted cleaner technologies to improve energy efficiency, which has a pleasant effect on the environment. Thus, the GDP per capita has an inverted U-shaped effect on carbon emissions. A similar validity of the U-shaped EKC is reported by Mamkhezri and Khezri (2024) in the panel of 54 economies assuming high-tech clean energy adoption to shape the EKC. Similarly, Salim et al. (2019) corroborate the EKC hypothesis in Asia by taking REC in the EKC framework. However, this study validates the EKC hypothesis by incorporating a comprehensive proxy for RET, which is measured as the ratio of REC to fossil fuel consumption. This approach influences the second phase of the EKC through two key channels by increasing REC adoption and/or reducing reliance on fossil fuel consumption.

Urbanization raises emissions. Thus, hypothesis (*H2*) is substantiated and urbanization increases CO_2 emissions in the MENA region due to higher energy demand in urban areas. The results suggest that the expansion of urban areas in the MENA region expands industrial activities, traffic congestion, greater energy consumption, and an overall shift toward more energy-intensive lifestyles. Moreover, urbanization could lead to a rise in demand for infrastructure, transportation, and residential energy, which has a great potential to contribute to the urban carbon footprint. Policymakers should focus on this issue in the MENA region to devise the policies toward adoption of energy-efficient technologies in urban areas. For instance, energy-efficient buildings should be designed in the hot climate of the MENA region. The efficiency of public transportation systems should be enhanced to reduce the use of private vehicles for urban transportation. Electricity should be produced from cleaner sources to mitigate the environmental problems of urban electricity consumption. Consistent with the findings of the present research, several studies using the Impacts, Population, Affluence, and Technology

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(IPAT) model also find the positive effect of urbanization on emissions (Hassan & Hussein, 2024; Han et al., 2024; Shu et al., 2024; Kusiyah et al., 2024). However, these studies overlook the potential nonlinear relationship between income and emissions in the model. In contrast, the present research validates the positive impact of urbanization within the EKC framework, which highlights that rising urbanization is prolonging the first phase of the EKC in the MENA region by raising emissions in the model.

RET mitigates carbon emissions. Thus, hypothesis (H1) is substantiated. Thus, RET significantly condenses CO_2 emissions by substituting fossil fuels with renewable energy consumption in the MENA economies. A shift from fossil fuels toward REC in the natural resource-rich MENA region can mitigate environmental problems. The MENA region is mostly sunny around the year. Therefore, the MENA governments should subsidize solar energy projects in the region. Moreover, the MENA governments should apply taxes on fossil fuel consumption and should subsidize the REC to foster the RET in the region. Testing the effect of RET on emissions is rare in the literature. However, all reviewed literature has found the negative effect of REC on emissions and carbon intensity.

CONCLUSION

The renewable energy transition has great potential to reduce the environmental problems from the energy sector in the fossil fuel-dependent MENA region. However, over-urbanization could have adverse environmental effects in the region due to fossil fuel dependency in the urban areas. Thus, this study aims to investigate the effects of the renewable energy transition and urbanization on CO_2 emissions within an EKC framework in 11 MENA economies from 2001 to 2023 by using CSD-based ARDL and cointegration techniques. The long-term estimations corroborate the EKC hypothesis. Carbon emissions can rise in the early stages of growth due to rising energy demand that serves higher economic activities. However, economic progress has pleasant environmental outcomes at a later stage of growth. Moreover, urbanization raises emissions. This finding realizes the fact of ever-growing urbanization in the MENA region, which is among the most urbanized regions in the globe. This heavy urbanization has environmental consequences due to rising aggregate demand and energy consumption in urban areas. The renewable energy transition is helping to reduce emissions and shape the second phase of the EKC. The short-run effects of all variables are in line with the long-run findings. The study concludes that the transition to renewable energy is helping to reduce emissions, and urbanization is accelerating emissions in the long and short run.

The findings emphasize that the renewable energy transition helps improve the environment. Policymakers should accelerate the process of renewable energy transition by implementing supportive policies. For instance, the MENA government should subsidize renewable energy projects and invest in renewable infrastructure to raise renewable energy production in the region. Policymakers should support research and development activities in clean energy technologies to utilize regional-specific resources to produce cleaner energy. For instance, the MENA region has plenty of sunlight throughout the year. So, electricity should be generated up to the full potential of solar energy in the region. Taxing fossil fuel consumption can raise local energy prices, which can discourage reliance on these sources. The resultant revenue generated can be strategically invested in developing cleaner energy infrastructure across the region. Moreover, urbanization is raising carbon emissions in this over-urbanized MENA region. Thus, policymakers should promote energy-efficient buildings and public transport systems. For this purpose, tight environmental laws related to the construction of buildings and transportation should be introduced. Fossil fuel-based vehicles should be replaced with electric or energy-efficient vehicles in urban areas. Renewable energy consumption should be encouraged through subsidies in urban areas, and fossil fuels should be taxed to support the renewable energy transition in urban areas.

AUTHOR CONTRIBUTIONS

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ACKNOWLEDGMENT

The authors extend their appreciation to Prince Sattam bin Abdulaziz University for funding this research work through the project number (PSAU/2024/02/31262). All utilized data for analysis are available at Mendeley Data (Mahmood, 2025).

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