SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 12, No. 1.1, (2026), pp. 1817-1827
Open Access. Online & Print

DOI: 10.5281/zenodo.11425232

INVESTIGATING THE MODERATING ROLE OF EDUCATION IN THE NEXUS BETWEEN URBANIZATION AND RENEWABLE ELECTRICITY TRANSITION IN THE MENA REGION

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Received: 10/10/2025
Accepted: 10/11/2025

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ABSTRACT

Urbanization often results in increasing electricity consumption, and education can play an effective role in Renewable Electricity Transition (RET) in any economy to support the Sustainable Development Goals (SDGs). This study aims to analyze the impact of economic growth and urbanization on RET in 17 MENA countries from 1990-2021 by employing Cross-sectional Dependence (CD) techniques, and also tests the moderating role of education in the connection between urbanization and RET. In the long and short run, economic growth significantly enhances RET, and urbanization negatively affects RET. The result suggests that rapid urban expansion increases electricity demand and reliance on fossil fuels, which is a hurdle in the way of RET. Education shows a direct positive impact on RET in the long and short run. However, education could positively moderate the nexus between education and RET only in the long run. The study suggests that MENA governments should promote education and control excessive urbanization to support RET in the MENA region.

KEYWORDS: SDGs, Renewable Electricity Transition, Urbanization, Education, Economic Growth.

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1. INTRODUCTION

The MENA is among the highly urbanized regions of the world. The urban population is expected to exceed 70% by 2030 (UN-Habitat, 2022), which can be responsible for pressure on infrastructure and ecosystems. Thus, urbanization may contribute to worsening air quality (Karimi and Shamsipour, 2019). Moreover, urban areas emit 70% of energy-related CO2 emissions in the MENA region, which is due to fossil fuel production in this region (Al-Mulali et al., 2013). However, urbanization may offer an opportunity for sustainability, which can be possible with compact city models, green infrastructure, and Renewable Energy (RE) integration (Salah and Fawaz, 2022).

The Renewable Electricity Transition (RET) can promote sustainable development, which can also help in achieving energy security. For instance, urbanization can transform energy demand (Yang et al., 2016a) and would change the pattern of energy consumption through industrial composition. Thus, urbanization can generate hurdles or opportunities for the RET. Therefore, the relationship between urbanization and RET is complex, which may depend on technological innovation, economic structure, and social factors (Cui et al., 2023; Bashayreh et al., 2024).

On the positive aspects of urbanization, it can enhance energy efficiency through economies of scale and infrastructure planning (Wu and Lin, 2022). However, urbanization may accelerate aggregate energy demand, which cannot be supplied only by renewable sources (Moyo et al., 2025; Liu et al., 2020). Education can be considered as a moderating factor in this nexus and would shape efficiency behaviors and technology adoption capacity (Akram, 2022; Jia et al., 2022). The literature has acknowledged that educational attainment is associated with greater environmental awareness and improved energy efficiency (Akram, 2022; Quarcoo et al., 2025; Wang et al., 2021a). Thus, education can also play its role by fostering institutional capacity for sustainable urban growth (Daoudi, 2024). Though studies on the moderating effect of education in the connection between urbanization and renewable electricity transition are scant in the literature.

Most studies have just examined the direct association between urbanization and energy demand or between education and renewable energy adoption (Bashayreh et al., 2024; Sart et al., 2022), which highlights a gap to investigate how education moderates the effect of urbanization on RET. Education can spread awareness among the urban population to adopt renewable electricity sources to avoid electricity from fossil fuels. Thus, this study aims to empirically examine the moderating impact of education on the connection between urbanization and RET in the highly urbanized MENA region. In this way, this study augments the literature by exploring the role of education as a human capital dimension in sustainable electricity transition. The findings of this research may inform policymakers and urban planners by identifying the role of education in urban areas to foster renewable electricity adoption.

1. LITERATURE REVIEW

2.1. Urbanization and Energy Demand

Urbanization may shape the energy consumption of any economy. For instance, Moyo et al. (2025) conducted Landsat-based spatio-temporal analysis in Botswana from 2005-2020, and found that urban expansion increased by 12 km^2, which was responsible for increasing land surface temperature by 2.1°C and cooling-related electricity demand. Jiang and Ye (2023) investigated Chinese cities from 2006-2018 and found that urbanization significantly increased electricity intensity due to industrial reformation. Cui et al. (2023) explored Zhejiang Province in China from 2000-2020 and identified a U-shaped nexus between urbanization and household electricity usage. Su (2020) analyzed Taiwan from 1998-2018 and found a 0.52% annual rise in urban electricity usage due to the structural change in energy demand. However, a 0.02% decline in rural areas was also observed, which corroborated a rebound effect.

Ceausescu et al. (2025) analyzed Romania from 1990-2022 and reported that trade openness and RE mitigated CO2 emissions, and the Environmental Kuznets Curve (EKC) was validated. Nevertheless, urbanization, Financial Development (FD), and non-renewable electricity raised emissions. Bashayreh et al. (2024) examined Jordan from 1990-2022 and found that 24% increase in RE reduced CO2 emissions with urbanization rates between 0.78 and 0.91. However, these effects were insignificant outside this range. Wang et al. (2021b) investigated China from 2000-2017 and found causality between urbanization, electricity usage, and economic progress. Song et al. (2022) examined 30 Chinese provinces from 2000-2019 and found that industrial innovations mediated the impact of urbanization on electricity demand with nonlinear behavior. Solarin (2014) analyzed Togo from 1971-2009 and found a causality from urbanization to growth. Moreover, unplanned urban expansion damaged energy systems. Solarin and Shahbaz (2013) examined Angola from 1971-2009 and found feedback between urbanization and electricity usage.

Oteng-Abayie and Mensah (2024) investigated and confirmed that urbanization increases energy intensity in Sub-Saharan Africa (SSA) from 1980-2019. However, the quality of urbanization in some regions helped improve clean transitions. Kaur and Luthra (2018) examined Punjab, India, and found a sharp rise in electricity demand due to rapid urbanization during 1990-2010. Sbia et al. (2017) investigated the UAE from 1975-2011 and found the EKC connection between urbanization and electricity usage. Thus, efficiency gains were observed in a highly urbanized economy. Yang et al. (2016b) explored Shaanxi, China, from 2000-2013, and showed that urbanization rates were found to be a better predictor for industrial electricity demand compared to economic growth.

Chen (2024) investigated Chinese cities from 2010-2021 and found that RE innovation promoted urbanization by stimulating infrastructure. This renewable adoption was raised through technology diffusion. Taleshmekaiil et al. (2021) explored Tehran and found that RE transitions in urban areas depended on financial incentives, technology, and education. Bao and Xu (2019) examined Chinese provinces from 1997-2015 and reported a feeble causality between urbanization and RE with regional heterogeneity, which was due to variations in governance and resource endowments. Wu and Lin (2022) investigated China from 2000-2020 and revealed a U-shaped connection between urbanization and residential energy usage. Thus, energy consumption rose at a higher rate of urbanization. But low urbanization was matched with efficiency gains.

Avtar et al. (2019) argued that uneven planning in developing countries reduced coordination between urbanization and RE. Farzana et al. (2023) explored Southeast Asia from 1991-2020 and showed that urbanization raised RE adoption, which was due to FD, trade openness, and remittance flows. Yin and Qamruzzaman (2024) explored BIMSTEC countries from 1995-2021 and found that urban growth hindered RE adoption. Moreover, globalization and public-private partnerships also moderated this connection. Yusoff et al. (2023) investigated Malaysia from 1971-2020 and reported that urbanization and economic development raised RE with infrastructure and policy development. Gyamfi et al. (2025) examined South Asia from 1990-2022 and highlighted a negative effect of urbanization on RE due to infrastructure and technology gaps.

Owojori and Erasmus (2025) found the positive effect of green public-private partnerships on sustainable urbanization. Li and Yao (2009) examined China from 1980-2007, and urbanization increased energy consumption with industrialization. Thus, urban construction without energy management was responsible for resource depletion. Perea-Moreno et al. (2018) conducted a global bibliometric study from 1977 to 2017 and revealed that urban RE achieved sustainability in China, the USA, the UK, Germany, Italy, and India. Salim and Shafiei (2014) inspected OECD from 1980-2011 and found that urbanization influenced non-RE more than RE. Stewart et al. (2018) found that urbanization complemented with technology and governance shaped energy demand patterns in favor of RE. Aslam et al. (2024) investigated the technological aspects of urban energy transitions. The authors found that digital infrastructure enhanced electricity supply reliability, which reduced inefficiencies in urban energy usage. Thus, urban technological innovation mediated sustainable energy management.

Shi et al. (2022) analyzed 30 Chinese provinces and found a rebound effect between urban and rural areas. Efficiency gains in one area were replaced by energy intensity in another area. Liu et al. (2020) found that urbanization stabilized industrial electricity consumption. However, household consumption accelerated due to lifestyle changes. Bruggeman and Dehaene (2017) studied electrification policies and found that electrification shaped the distribution of urbanization in Belgium, which assimilated rural and industrial areas. He (2020) analyzed Guangzhou from 1949-2016, and found an association between urbanization, commercialization, and electricity usage. A coefficient of electricity was found as 1.28, which reflected a strong interdependence of economic and energy consumption activities. Urbanization increased electricity usage through industrial transformation and metropolitan development.

Gregori and Tiwari (2020) investigated Chinese provinces and found feedback between urbanization and electricity usage. Moreover, trade openness and economic growth further promoted this relationship. Fang et al. (2022) analyzed BRICS using the period 1990-2015 and showed that urbanization and globalization reduced both RE and non-RE usage, which indicated an efficiency trend in these economies. However, income growth and education raised energy demand. Yang et al. (2016a) found that early stages of urbanization increased overall demand without boosting RE usage. Thus, urbanization was responsible for more fossil-fuel consumption. However, at later stages, policy and technology helped accelerate the RE share.

2.2 Education and Energy Demand

Education is also an effective driver of the RET in literature. For instance, Adom (2021) investigated the mortaring role of education in 45 African countries and found that FD reduced electricity usage. Moreover, education further moderated the relationship between FD and electricity usage. Thus, the indirect effect via education amplified energy efficiency. Quarcoo et al. (2025) investigated SSA from 1990-2020 and found a positive impact of education on electricity usage. However, country-specific results varied significantly. Akram (2022) investigated BRICS economies from 1993-2018 and found that improved electricity access significantly enhanced educational attainment in Brazil and China. However, this relationship was weak in India, Russia, and South Africa.

In the micro-level studies, Mulamba (2021) surveyed the South African Community at the household level and found that higher education significantly increased energy-saving practices of efficient lighting and appliance management. Thus, this micro-level evidence revealed that education improved behavioral mechanisms to foster sustainable energy practices. Wang et al. (2021a) surveyed four first-tier Chinese cities and found that higher education with greater personal energy-saving consciousness and commitment improved energy-efficient behavior. Li et al. (2022) explored urban households in China from 2014-2016 and showed that education significantly improved household electricity efficiency. Thus, human capital enhanced the capacity to adopt energy-saving technologies.

Gill and Lang (2018) investigated the impact of environmental education in the US and found that targeted energy lessons reduced electricity consumption by about 8%. However, these effects were found to be short-term. Sart et al. (2022) examined emerging markets from 2000-2018 and found that educational attainment positively influenced RE. In the Chinese provinces, Jia et al. (2022) investigated the period of 2000-2021 and found that education and urbanization reduced energy consumption and emissions. However, some regional differences were also reported. For instance, Eastern provinces increased total energy usage, and Western provinces reduced it. Daoudi (2024) examined the Energy Transition Project in Morocco and found that RE could be enhanced with community engagement through education. Adepoju et al. (2022) conducted a bibliometric review for Nigeria and SAA from 2000-2022 and reported the positive impact of human capital on RE usage.

Cheng et al. (2024) explored Asian economies and demonstrated that education enhanced environmental awareness and RECT. Moreover, educational policy was complemented by environmental taxation and technology to enhance its effectiveness. Dintchev et al. (2000) analyzed South African educational policy and found that educational initiatives reduced electricity bills. In SAARC countries, Jamshid et al. (2022) stated that education and economic progress enhanced RE during 1995-2015. However, urbanization, FDI, and FD reduced it. Owolabi et al. (2024) explored Nigeria and revealed that electricity access reduced inequality. However, its interaction with education increased inequality. Kyeremeh et al. (2024) investigated Ghana and found that higher education promoted modern cooking fuels for male-headed households.

The reviewed literature demonstrated that urbanization has different effects on energy demand. Mostly, urban growth intensifies electricity consumption due to industrialization and lifestyle changes. However, efficiency gains were also observed at a higher level of urbanization. Literature signifies that RE adoption depends on institutional quality and technology diffusion. Moreover, education played its moderating role by shaping behavioral patterns and promoting energy-efficient technologies. Thus, sustainable urbanization requires an integrated educational policy to promote technological innovation in the energy sector. The inquiry into the moderating role of education in the connection between urbanization and RET is scant, and the present research contributes to this literature gap.

2. METHODOLOGY

Rising urbanization is a major source of energy demand in the MENA region, which can be responsible for environmental degradation in this region with rising transportation and electrification in urban areas (Al-Mulali et al., 2013). Due to excessive demand for electricity in urban areas, urbanization can reduce the focus on RET. However, urbanization may change energy usage patterns in favor of RE (Yang et al., 2016a). Thus, urbanization could also help in RET. Therefore, there is a need to identify the exact effect of urbanization on RET in any economy and region. So, we hypothesize the direct effect of urbanization on RET in a highly urbanized MENA region. Moreover, education is increasingly recognized as a moderating factor to improve the behavior of the urban population in promoting energy efficiency and RET (Akram, 2022; Quarcoo et al., 2025; Adom, 2021; Wang et al., 2021a). Following this stream of literature, we hypothesize direct and moderating effects of education in the nexus between urbanization and RET. Along with urbanization and education, economic progress can provide finance for RET in any economy, and Figure 1 reflects the hypothesized relationships.

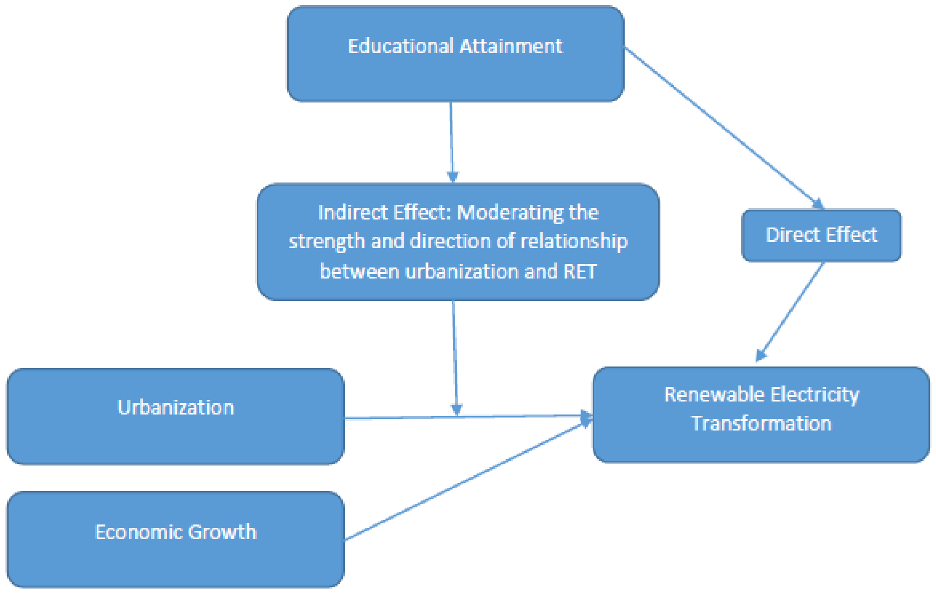

Figure 1: Conceptual Diagram of the Hypothesized Models.

Following the literature, the empirical models are hypothesized as follows:

Model 1: RET_{it} = f (Y_{it}, URB_{it}) (1)

Model 2: RET_{it} = f (Y_{it}, URB_{it}, EDU_{it}, URB_{it}*EDU_{it}) (2)

RET_{it} is the natural log of the renewable electricity percentage of total electricity production, which is a proxy for RET. Y_{it} is the natural log of Gross Domestic Product (GDP) per capita in constant USD, which is a proxy of economic growth. URB_{it} is the natural logarithm of the proportion of the urban population in the total. EDU_{it} is the natural log of the sum of the primary and secondary pupils as a percentage of the population, which is a proxy for educational attainment. This proxy is widely used in cross-country environmental economics (Bhattacharya et al., 2016; Chankrajang and Muttarak, 2017). Bhattacharya et al. (2016) advocate that aggregate enrollment in basic education exhibits a high correlation with educational attainment, and it also reduces the possible endogeneity from the lagged educational attainment effect in the panel data. Moreover, basic education enrollment reflects the societal capacity to internalize environmental awareness to support regulatory compliance (Stevenson et al., 2013). In equation 1, we hypothesize the direct effects of economic progress and urbanization on RET. Moreover, the education variable is added in equation 2 to test its direct and moderating effects on RET. The data is obtained from the World Bank (2025) for the period 1990-2021. The maximum possible time range of data is collected as per its availability from the World Bank (2025) for 17 MENA economies. Some series are interpolated to complete the series.

The MENA countries are highly connected due to their geographically closed economies, common energy mix, and some common economic policies. Thus, we can expect Cross-sectional Dependence (CD) in the series and models of the MENA region. **Therefore, we apply the CD test on the hypothesized series and the models in equations 1 and 2. For this purpose, we apply Pesaran's (2021) CD test:**

$$CD_{adj} = \left[\sqrt{\frac{2}{n(n-1)}}\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} p_{ij} - \mu\right] / \sigma \quad (3)$$

p_{ij} is capturing the covariance between variables to check the possible CD in the series. μ and σ are averages and their deviations. The same procedure can be adopted for the error term of equations 1 and 2 to test the CD in these equations. Slope Heterogeneity (SH) may also be expected in equations 1 and 2 due to a possible heterogeneous relationship between the hypothesized relationships in both equations 1 and 2.

For this purpose, Pesaran and Yamagata's (2008) procedure is applied as follows:

$$\Delta = \sqrt{n}\left(\frac{S_n-k}{\sqrt{2k}}\right) \quad (4)$$

$$\Delta_{adj} = \sqrt{n}\left(\frac{S_n-E(S_n)}{\sqrt{Var(S_n)}}\right) \quad (5)$$

Equations 4 and 5 assume individual heterogeneous slopes (Si) for each MENA economy, and SN is the average of all MENA economies. $Var(S_n)$ is the variance to understand the variation in the slopes. In addition, we can also expect a unit root in the series of equations 1 and 2.

To serve this purpose, Pesaran's (2007) CADF test is utilized with the following equations:

$$\Delta y_{it} = b_0 + b_{1i}y_{it-1} + b_{2i}\overline{y_{t-1}} + b_{3i}\overline{\Delta y_t} + \sum_{j=1}^{k} b_{4ij}\Delta y_{it-j} + e_{it} \quad (6)$$

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i \quad (7)$$

Equation 6 will be tested for a null hypothesis (b_{1i}=0), which could indicate the unit root problem in the series of any MENA economy. The rejection of this hypothesis would validate a stationary series.

$$\Delta RET_{it} = a_{1i}RET_{it-1} + a'_{2i}x_{it-1} + b_1\overline{RET_{t-1}} + b_2\overline{x_{t-1}} + \sum_{j=1}^{k} a_{3ij}\Delta RE_{Tit-j} + \sum_{j=0}^{k} a'_{4ij}\Delta x_{it-j} + e_{it} \quad (12)$$

x is a vector of independent series. Both RET and x will be regressed with their lags of original values and with their lags of the average of all MENA economies. Moreover, the differences of RET and x are added in the equation to remove possible endogeneity in the model.

Moreover, the CIPS statistic is calculated by taking the average of CADF, which could recheck the evidence of a unit root in equation 6. In the presence of a unit root and the CD, we may apply Westerlund's (2007) cointegration technique to verify the existence of cointegration in equations 1 and 2.

This test assumes the following 4 statistics to verify cointegration in the following way:

$$G_t = n^{-1}\sum_{i=1}^{n}\frac{\widehat{\Omega_i}}{\widehat{\sigma_i}} \quad (8)$$

$$G_a = n^{-1}\sum_{i=1}^{n} t\widehat{\Omega_i} \quad (9)$$

$$P_t = \frac{\sum_{i=1}^{n}\widehat{\Omega_i}}{\sqrt{\sum_{i=1}^{n}\widehat{\sigma_i}^2}} \quad 10)$$

$$P_a = \sum_{i=1}^{n} t\widehat{\Omega_i} \quad (11)$$

The evidence of cointegration can be accepted if the null hypothesis of no-cointegration is rejected for any one test statistic from equations 8-11.

In the presence of cointegration, we can proceed with long and short-run effects. In the presence of the CD and SH, Chudik et al.'s (2017) ARDL technique can be applied in the following way:

3. DATA ANALYSIS

In Table 1, the CD test statistics for RET_{it}, Y_{it}, URB_{it}, EDU_{it}, and their interaction term (URB_{it}*EDU_{it}) are significant at the 1% or 5% levels, which indicates the presence of CD among the MENA countries in the mentioned series. Thus, policy changes in one country may have spillovers in other MENA countries, which reflects strong economic and environmental interconnections among MENA economies. Furthermore, the significant CD statistics of the residuals from models 1and 2 also confirm the CD in the error terms of the models. Thus, we apply second-generation econometric methods to account for such interdependence in unit root, cointegration, and long and short run analyses. In addition, the SH tests (Δ and Δadj) are also statistically significant for both models. Thus, we infer that the relationships between variables differ across countries.

Table 1: CD And SH Results.

Variables	CDadj	SH (Δ)	SH (Δadj)
RET_{it}	5.684 (0.000)		
Y_{it}	2.318 (0.021)		
URB_{it}	7.043 (0.000)		
EDU_{it}	5.931 (0.001)		
URB_{it}*EDU_{it}	3.872 (0.004)		
Residual of Model 1	6.589 (0.000)	29.183 (0.000)	29.524 (0.000)
Residual of Model 2	6.242 (0.000)	28.015 (0.001)	29.156 (0.000)

Table 2 presents the results of the second-generation CIPS and CADF tests. At the level, all variables (RET_{it}, Y_{it}, URB_{it}, EDU_{it}, URB_{it}*EDU_{it}) are statistically non-stationary, with the test statistics being above the critical values and having a unit root problem. However, after first-differencing (Δ), all variables become stationary. So, the variables are integrated of order one, which is suitable for cointegration and short and long-run analysis.

Table 2: Stationarity Analyses.

Variables	Level		Δ	
	C	C&T	C	C&T

CIPS test				
RET_{it}	-1.982	-2.045	-3.215***	-3.412***
Y_{it}	-0.723	-0.812	-2.987***	-3.204***
URB_{it}	-0.389	-0.572	-3.256***	-3.301***
EDU_{it}	-1.045	-1.130	-3.621***	-3.710***
$URB_{it}*EDU_{it}$	-2.912	-2.203	-4.512***	-4.945***
CADF Test				
RET_{it}	-2.112	-2.189	-5.642***	-6.104***
Y_{it}	-0.954	-1.042	-4.621***	-4.998***
URB_{it}	-0.587	-0.802	-5.112***	-5.001***
EDU_{it}	-1.638	-1.772	-7.421***	-7.036***
$URB_{it}*EDU_{it}$	-2.201	-2.487	-6.889***	-6.433***

Note: * Reflects Stationary Series At 1%. C Is the Intercept, And T Is the Time Trend.

Table 3 presents the Westerlund cointegration test statistics for Models 1 and 2. In Model 1, the Pt and Pa statistics are significant at the 5% level, and the Gt and Ga statistics are significant at the 10% level, which suggests a long-run cointegrating relationship. For Model 2, the Pt and Pa statistics are significant at the 1% level, which confirms a robust long-run relationship. Overall, the results indicate that both models exhibit long-run equilibrium relationships. So, we move to CS-ARDL-based short- and long-run effects in the MENA panel.

Table 3: Westerlund Results.

Statistics	Model 1	Model 2
Gt	-7.214 (0.092)	-6.487 (0.138)
Ga	-2.184 (0.073)	-2.497 (0.102)
Pt	-7.036 (0.041)	-10.238 (0.000)
Pa	-5.384 (0.029)	-7.512 (0.000)

Table 4 reports the long-run and short-run results from the CS-ARDL estimation for both Model 1 and Model 2. In the long run, economic growth (Y_{it}) accelerates RET in both models. Thus, economic expansion promotes the shift toward RET in MENA countries. Urbanization (URB_{it}) shows a negative effect on RET. Thus, urban growth discourages cleaner energy infrastructure and efficiency improvements. In Model 2, education (EDU_{it}) has a positive effect on RET. Thus, the expansion of educational attainment effectively supports RET. Moreover, the interaction term ($URB_{it}*EDU_{it}$) also raises RET, which implies that the joint effect of urbanization and education promotes RET. Thus, education helps to turn a positive relationship between urbanization and RET.

Table 4: CS-ARDL Estimates.

Variable	Model 1	Model 2
Long run		
Y_{it}	0.156 (0.089)	0.164 (0.017)
URB_{it}	-0.254 (0.012)	-0.314 (0.000)
EDU_{it}	--	0.218 (0.024)
$URB_{it}*EDU_{it}$	--	0.015 (0.015)
Short run		
ΔY_{it}	0.042 (0.210)	0.051 (0.045)
ΔURB_{it}	-0.078 (0.032)	-0.092 (0.008)
ΔEDU_{it}	--	0.061 (0.048)
$\Delta(URB_{it}*EDU_{it})$	--	0.004 (0.120)
ECT_{t-1}	-0.387 (0.001)	-0.321 (0.000)

In the short run, economic growth (ΔY_{it}) continues to have a positive effect on RET with a smaller magnitude compared to the long term in both models. Urbanization reduces RET. Thus, urbanization is a hurdle in way of RET even in the short run. Education retains a positive but weaker effect compared to the long run. However, the interaction term [$\Delta(URB_{it}*EDU_{it})$] is statistically insignificant. Thus, education could not moderate the relationship between urbanization and RET in the short term. The error correction term (ECT_{t-1}) is negative in both models with coefficients (-0.387 and -0.321), which corroborates the correction mechanism of 38.7% and 32.1% annually in Models 1 and 2, respectively. This result also ensures the stability of models.

4. DISCUSSIONS

In the results, the positive impact of economic growth on RET indicates that MENA countries invest more in renewable energy infrastructure and technology with rising national income. This result is aligned with the theoretical expectations of the EKC framework, which explains that nations with higher income levels would shift from fossil fuels to cleaner electricity generation. In the MENA region, rapid economic growth is largely driven by natural resource rents, which could be invested in RE development. Moreover, economic expansion also facilitates private sector participation and technological imports, which are important for renewable electricity generation with a public-private partnership.

The results indicate that urbanization reduces RET in the MENA region. Thus, urban growth in this region put further pressure on existing fossil-fuel-based energy systems rather than facilitating RET. Expanding urban areas may increase aggregated electricity demand, which is difficult to meet with limited RET in the MENA region, as most MENA countries are heavily fossil-fuel-based. Thus, urban planning and RET remain mostly disconnected due to structural and policy challenges in the region. Some MENA countries are investing in their renewable energy programs, but still, the share of renewable electricity in total is minute in the whole MENA region, which reflects insufficient policy about RET. Therefore, urban expansion is expected to hinder the region's renewable electricity transition objectives without strategic investment in smart infrastructure, renewable energy grids, and green urban policies.

The findings suggest that education increases RET in the MENA region. Education may improve environmental consciousness. Thus, education promotes pro-environmental attitudes and supports green policies and initiatives launched by the government. In the MENA region, public understanding of sustainability is still limited. However, improving educational attainment can improve community-level awareness and participation in RE initiatives. Particularly, integrating environmental education and renewable energy topics into curricula can create long-term cultural and behavioral shifts in favor of RET. Moreover, education also positively moderates the relationship between urbanization and RET in our results. It indicates that education improves the urban awareness toward adopting RET, which enhances the capacity of urban populations to adopt RET in the MENA region. Educated citizens are more aware of environmental issues, which could facilitate efficient urban planning, technological adoption, and policy support to promote RET.

5. CONCLUSION AND POLICY IMPLICATIONS

Urbanization and education can potentially determine the RET in any economy. Thus, this research investigates the effects of economic progress and urbanization on RET in 17 MENA countries from 1990-2021 by applying the CD econometrics and also tests the moderating effect of education in this connection. The results corroborate that economic growth consistently enhances RET in the long and short run. It indicates that higher income levels facilitate investments in renewable infrastructure and cleaner technologies, which help to accelerate RET in the MENA region. Conversely, urbanization reduces RET. Thus, rapid urban expansion in MENA economies raises the overall electricity demand in the short and long run and puts pressure on fossil fuel energy sources with limited renewable integration in urban areas. However, education plays a positive role in promoting RET in direct estimates and also plays a positive moderating role in the connection between urbanization and RET in the long run. Thus, education improves human capital to support awareness, innovation, and adoption of clean energy technologies in urban areas. The interaction between urbanization and education offset the adverse effects of urban growth on RET. However, the moderating role of education on the relationship between urbanization and RET is found to be insignificant in the short run, which corroborates that education needs a long time to spread awareness among the urban population to support RET.

The findings suggest short-term and long-term strategies for accelerating RET in the MENA region. In the short run, economic growth increases RET. Thus, policymakers should increase fiscal incentives, reduce regulatory barriers, and encourage private-sector investments in renewable electricity projects in the MENA economies. For this purpose, short-term measures, like the targeted subsidies for rooftop solar and the accelerated grid-integration reforms, should be introduced, which may convert the benefit of economic growth into RET. However, urbanization reduces RET in the short run, which highlights the importance of urgent urban energy planning. In this regard, short-term measures should be taken to improve energy efficiency in urban infrastructure. For instance, energy efficiency standards should be introduced for new buildings, and subsidies should be given to install solar systems in urban buildings.

In the long run, education helps to accelerate RET directly and also indirectly through moderating the adverse effect of urbanization on RET. The results show that the positive moderating impact of education is only found in the long run, which suggests some structural investments in the education sector. Thus, policymakers should integrate energy literacy into national educational curricula and should start technical training programs for school students to promote renewable technologies in the long run. These long-term initiatives can develop a future labor force with environmental awareness, which may support innovation and adoption of RET in urban areas. Moreover, the long-term complementarity between education and urbanization also suggests the coordination of ministries of education, energy, and urban development to activate the coordinated policies in education, energy, housing, and urban planning, which can translate the urban education into responsible citizen behavior with the adoption of RET.

Author Contributions: Conceptualization, H.M. and Y.Y.; methodology, H.M.; software, H.M.; validation, H.M.; formal analysis, H.M.; investigation, H.M.; resources, H.M.; data curation, H.M.; writing—original draft preparation, H.M. and A.P.; writing—review and editing, H.M. and A.P.; visualization, H.M.; supervision, H.M.; project administration, H.M.; funding acquisition, H.M. All authors have read and agreed to the published version of the manuscript.

Acknowledgements: The authors extend their appreciation to Prince Sattam bin Abdulaziz University for funding this research work through the project number (PSAU/2025/02/33179).

REFERENCES

Adepoju, O. O., David, L. O. and Nwulu, N. I. (2022) Analysing the impact of human capital on renewable energy penetration: a bibliometric review. *Sustainability*, Vol. 14, 8852.

Adom, P. K. (2021) Financial depth and electricity consumption in Africa: Does education matter? *Empirical Economics*, Vol. 61, 1985–2039.

Akram, V. (2022) Causality between access to electricity and education: Evidence from BRICS countries. *Energy Research Letters*, Vol. 3, 1–5.

Al-Mulali, U., Ozturk, I. and Solarin, S. A. (2013) Investigating the environmental Kuznets curve hypothesis in seven regions: The role of renewable energy. *Renewable and Sustainable Energy Reviews*, Vol. 25, 827–834.

Aslam, Z., Javaid, N., Javed, M. U., Aslam, M., Aldegheishem, A. and Alrajeh, N. (2024) A new clustering-based semi-supervised method to restrict the users from anomalous electricity consumption: supporting urbanization. *Electrical Engineering*, Vol. 106, 6431–6448.

Avtar, R., Tripathi, S., Aggarwal, A. K. and Kumar, P. (2019) Population–urbanization–energy nexus: a review. *Resources*, Vol. 8, 136.

Bao, C. and Xu, M. (2019) Cause and effect of renewable energy consumption on urbanization and economic growth in China's provinces and regions. *Journal of Cleaner Production*, Vol. 231, 483–493.

Bashayreh, A., Al-Hindawi, H. and Tahtamouni, A. (2024) Modeling the urbanization rate associated with renewable in electricity production and CO_2 emissions: a threshold regression approach. *Discover Sustainability*, Vol. 5, 427.

Bhattacharya, M., Paramati, S. R., Ozturk, I., and Bhattacharya, S. (2016) The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Applied Energy*, Vol. 162, 733–741.

Bruggeman, D. and Dehaene, M. (2017) Urban questions in the countryside? Urbanization and the collective consumption of electricity in early twentieth-century Belgium. *Planning Perspectives*, Vol. 32, 309–332.

Ceausescu, A. I., Alecsoiu, O. R., Panagoret, A. A., Chirculescu, M. F., Panagoret, D. M. and Nitu, R. V. (2025) Electricity generation from fossil fuels and environmental sustainability in Romania: investigating the influence of renewable energy, financial development and urbanization. *Applied Economics*, 1–16.

Chankrajang, T. and Muttarak, R. (2017) Green returns to education: Does schooling contribute to pro-environmental behaviours? Evidence from Thailand. *Ecological Economics*, Vol. 131, 434-448.

Chen, S. (2024) Renewable energy technology innovation and urbanization: Insights from China. *Sustainable Cities and Society*, Vol. 102, 105241.

Cheng, Y., Zhao, G., Meng, W. and Wang, Q. (2024) Resources utilization, taxation and green education: A path to sustainable power generation. *Resources Policy*, Vol. 88, 104389.

Chudik, A., Mohaddes, K., Pesaran, M.H., and Raissi, M. (2017) Is there a debt-threshold effect on output growth? *The Review of Economic Statistics*, Vol. 99, 135-150.

Cui, J., Xie, L. and Zheng, X. (2023) Climate change, air conditioning, and urbanization—evidence from daily household electricity consumption data in China. *Climatic Change*, Vol. 176, 106.

Daoudi, M. (2024) Education in renewable energies: A key factor of Morocco's 2030 energy transition project. Exploring the impact on SDGs and future perspectives. *Social Sciences and Humanities Open*, Vol. 9, 100833.

Dintchev, O. D., Calmeyer, J. E. and Delport, G. J. (2000) Efficient and sustainable usage of electricity in South Africa: The role of the tertiary education institutions. *Engineering Science and Education Journal*, Vol. 9, 53–59.

Fang, J., Gozgor, G., Mahalik, M. K., Mallick, H. and Padhan, H. (2022) Does urbanisation induce renewable energy consumption in emerging economies? The role of education in energy switching policies. *Energy Economics*, Vol. 111, 106081.

Farzana, N., Qamruzzaman, M., Islam, Y. and Mindia, P. M. (2023) Nexus between personal remittances, financial deepening, urbanization, and renewable energy consumption in selected Southeast Asian countries: Evidence from linear and nonlinear assessment. *International Journal of Energy Economics and Policy*, Vol. 13, 270–287.

Gill, C. and Lang, C. (2018) Learn to conserve: The effects of in-school energy education on at-home electricity consumption. *Energy Policy*, Vol. 118, 88–96.

Gregori, T. and Tiwari, A. K. (2020) Do urbanization, income, and trade affect electricity consumption across Chinese provinces? *Energy Economics*, Vol. 89, 104800.

Gyamfi, B. A., Adebayo, T. S., Agozie, D. Q., Bekun, F. V. and Koy, A. (2025) Is sustainable energy consumption, technological advancement and urbanization fast addressing South Asia's green energy expansion deficits? *Environment, Development and Sustainability*, Vol. 27, 19969–19998.

He, Y. (2020) Agricultural population urbanization, long-run economic growth, and metropolitan electricity consumption: An empirical dynamic general equilibrium model. *Energy Strategy Reviews*, Vol. 30, 100498.

Jamshid, A., Villanthenkodath, M. A. and Velan, N. (2022) Can educational attainment promote renewable energy consumption? Evidence from heterogeneous panel models. *International Journal of Energy Sector Management*, Vol. 16, 1017–1036.

Jia, L., Zhang, H. and Xu, R. (2022) The simultaneous impact of urbanization and education on renewable energy consumption: empirical evidence from China. *Transformations in Business and Economics*, Vol. 21.

Jiang, B. and Ye, T. (2023) Uncertain panel regression analysis with application to the impact of urbanization on electricity intensity. *Journal of Ambient Intelligence and Humanized Computing*, Vol. 14, 13017–13029.

Karimi, A. and Shamsipour, A. A. (2019) Spatial and temporal analysis of air pollution in Tehran using MODIS and ground-based data. *Atmospheric Environment*, Vol. 213, 239–251.

Kaur, R. R. and Luthra, A. (2018) Population growth, urbanization and electricity—Challenges and initiatives in the state of Punjab, India. *Energy Strategy Reviews*, Vol. 21, 50–61.

Kyeremeh, C., Fiagborlo, J. D. and Taale, F. (2024) Impacts of education on cooking fuel choice for diverse family sizes and genders in Ghana. *SN Social Sciences*, Vol. 4, 215.

Li, B. and Yao, R. (2009) Urbanisation and its impact on building energy consumption and efficiency in China. *Renewable Energy*, Vol. 34, 1994–1998.

Li, Z., Lv, L. and Zhang, Z. (2022) Research on the characteristics and influencing factors of Chinese urban households' electricity consumption efficiency. *Energies*, Vol. 15, 7748.

Liu, X., Sun, T., Feng, Q. and Zhang, D. (2020) Dynamic nonlinear influence of urbanization on China's electricity consumption: Evidence from dynamic economic growth threshold effect. *Energy*, Vol. 196, 117187.

Moyo, B., Schröder, D. and Moreri, K. (2025) Cloud-computing trend analysis of urbanization impacts on land surface temperature and electricity demand in Gaborone, Botswana. *Remote Sensing in Earth Systems Sciences*, Vol. 8, 283–306.

Mulamba, K. C. (2021) Relationship between education and households' electricity-saving behaviour in South Africa: A multilevel logistic analysis. *Economics and Policy of Energy and the Environment*, Vol. 2020, 51–74.

Oteng-Abayie, E. F. and Mensah, G. (2024) The impact of urbanization and industrial structure upgrading on energy intensities in Sub-Saharan Africa. *Environment, Development and Sustainability*, 1–23.

Owojori, O. M. and Erasmus, L. J. (2025) Public–private partnerships as catalysts for green infrastructure: a three-pronged analysis of economic, environmental, and institutional factors. *Frontiers in Sustainable Cities*, Vol. 7, 1591278.

Owolabi, O., Omeire, M. C., Okwudire, B. O. and Bolujoko, O. T. (2024) Education, electricity access, and income inequality in Nigeria. *International Journal of Energy Economics and Policy*, Vol. 14, 149–161.

Perea-Moreno, M. A., Hernandez-Escobedo, Q. and Perea-Moreno, A. J. (2018) Renewable energy in urban areas: Worldwide research trends. *Energies*, Vol. 11, 577.

Pesaran, M. H. (2007) A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, Vol. 22, 265-312.

Pesaran, M. H. and Yamagata, T. (2008) Testing slope homogeneity in large panels. *Journal of Econometrics*, Vol. 142, 50-93.

Pesaran, M.H. (2021) General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, Vol. 60, 13-50.

Quarcoo, A., Mensah, I. A., Omari-Sasu, A. Y., Kunkuaboor, C. Y. and Nouwati, E. (2025) Revisiting the drivers of electricity consumption in designated Sub-Saharan African regions: Unraveling the role of education. *Heliyon*, Vol. 11, e41345.

Salah, H. and Fawaz, M. (2022) Urban sustainability in the MENA region: Challenges and policy pathways. *Sustainable Cities and Society*, Vol. 76, 103432.

Salim, R. A. and Shafiei, S. (2014) Urbanization and renewable and non-renewable energy consumption in OECD countries: An empirical analysis. *Economic Modelling*, Vol. 38, 581–591.

Sart, G., Bayar, Y., Sezgin, F. H. and Danilina, M. (2022) Impact of educational attainment on renewable energy use: Evidence from emerging market economies. *Energies*, Vol. 15, 2695.

Sbia, R., Shahbaz, M. and Ozturk, I. (2017) Economic growth, financial development, urbanisation and electricity consumption nexus in UAE. *Economic Research–Ekonomska Istraživanja*, Vol. 30, 527–549.

Shi, J. H., Han, Y., Li, X. D. and Zhou, J. Q. (2022) How does urbanization affect the direct rebound effect? Evidence from residential electricity consumption in China. *Energy*, Vol. 239, 122300.

Solarin, S. A. (2014) Multivariate causality test of electricity consumption, capital formation, export, urbanisation and economic growth for Togo. *Energy Studies Review*, Vol. 21.

Solarin, S. A. and Shahbaz, M. (2013) Trivariate causality between economic growth, urbanisation and electricity consumption in Angola: Cointegration and causality analysis. *Energy Policy*, Vol. 60, 876–884.

Song, M., Zhang, L. and Li, M. (2022) The influence path and dynamic relationship between economic development, industrial structure upgrading, urbanization, urban–rural income gap, and electricity consumption in China. *Energy Science and Engineering*, Vol. 10, 4366–4381.

Stevenson, K. T., Peterson, M. N., Bondell, H. D., Mertig, A. G., and Moore, S. E. (2013) Environmental, institutional, and demographic predictors of environmental literacy among middle school children. *PloS one*, Vol. 8, e59519.

Stewart, I. D., Kennedy, C. A., Facchini, A. and Mele, R. (2018) The electric city as a solution to sustainable urban development. *Journal of Urban Technology*, Vol. 25, 3–20.

Su, Y. W. (2020) Residential electricity demand in Taiwan: The effects of urbanization and energy poverty. *Journal of the Asia Pacific Economy*, Vol. 25, 733–756.

Taleshmekaiil, M. R. A., Khatibi, S. M. R., Mohemsaz, M., Azimi, M. H. and Sadeghpour, A. (2021) Investigating the effective factors of renewable energy development in Tehran metropolis. *Mathematical Problems in Engineering*, Vol. 2021, 6636955.

UN-Habitat (2022) *World Cities Report 2022: Envisaging the Future of Cities.* United Nations Human Settlements Programme (UN-Habitat), Nairobi: UN-Habitat.

Wang, N., Fu, X. and Wang, S. (2021b) Economic growth, electricity consumption, and urbanization in China: A tri-variate investigation using panel data modeling from a regional disparity perspective. *Journal of Cleaner Production*, Vol. 318, 128529.

Wang, Y., Lin, B. and Li, M. (2021a) Is household electricity saving a virtuous circle? A case study of the first-tier cities in China. *Applied Energy*, Vol. 285, 116443.

Westerlund, J. (2007) Testing for Error Correction in Panel Data. *Oxford Bulletin of Economics and Statistics*, Vol. 69, 709-748.

World Bank (2025) *World Development Indicators*. Washington, D.C.: The World Bank. https://databank.worldbank.org/source/world-development-indicators

Wu, W. and Lin, Y. (2022) The impact of rapid urbanization on residential energy consumption in China. *PLoS One*, Vol. 17, No. 7, e0270226.

Yang, B., Li, Y., Wei, H. and Lu, H. (2016b) Is urbanisation rate a feasible supplemental parameter in forecasting electricity consumption in China? *Journal of Engineering*, Vol. 2016, No. 1, 2465248.

Yang, J., Zhang, W. and Zhang, Z. (2016a) Impacts of urbanization on renewable energy consumption in China. *Journal of Cleaner Production*, Vol. 114, 443–451.

Yin, C. and Qamruzzaman, M. (2024) Empowering renewable energy consumption through public-private investment, urbanization, and globalization: Evidence from CS-ARDL and NARDL. *Heliyon*, Vol. 10, No. 4, e26455.

Yusoff, N. Y. M., Ridzuan, A. R., Soseco, T., Wahjoedi, Narmaditya, B. S. and Ann, L. C. (2023) Comprehensive outlook on macroeconomic determinants for renewable energy in Malaysia. *Sustainability*, Vol. 15, No. 5, 3891.