

TECHNOLOGICAL ROUTES FOR SUSTAINABLE URBANIZATION AND INDUSTRIAL DEVELOPMENT TO REDUCE CLIMATE CHANGE

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ABSTRACT

The study has objectives to explore the relationships between renewable energy, urbanization, foreign direct investment, urban land area, trade openness, and CO₂ emissions in East Asian countries using data collected from 1990 to 2023. The study has employed ARDL and NARDL models for empirical analysis to ascertain the effects on the economies in the short- and long-run. The results revealed that the linear estimations of urbanization in the short-run are negatively significant in China. The non-linear coefficient estimates positively affect CO₂ emissions in India. The foreign direct investment and renewable energy benefit both countries in short-run. The results coefficient estimations of trade openness have a significantly negative impact on CO₂ emissions in both countries. The estimation coefficients indicate the presence of nonlinear positive shocks in China's urbanization and significant negative impacts of urban land area on CO₂ emissions in both India and China. According to the study, regional policymakers must prioritise the creation of an atmosphere that encourages environmentally responsible businesses by supportive laws and financial incentives.

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INTRODUCTION

The global financial landscape has undergone unprecedented environmental changes, including rapid growth in international trade, the opening of markets, urbanization, and an increase in the volume of economic activities, including foreign direct investment, which has become a significant turning point in global economic growth. Several developing countries, such as China and India, have pursued alternative methods to promote economic growth, including leveraging urban land resources, population engagement, and foreign direct investment inflows. The research examines China and India as case studies, since they rank first and third, respectively, among the highest CO₂ emitters globally. Economic growth has a significant negative impact on CO₂ emissions which causes the climate on an international level. However, there is insufficient research on the impacts of these drivers on the economies of East Asia. However, the rapid economic growth has led to increased industrialization, urbanization, trade openness, and FDI promotion, which in turn has resulted in anticipated environmental concerns in these countries. Numerous research and ideas have focused

on urbanization as the primary factor contributing to ecological changes, particularly due to increased industrial growth. Industrialization and urbanization are two prominent factors contributing to both economic growth and the emission of fossil fuel by-products (Khan and Majeed, 2023). However, it is crucial to note that there is a strong correlation between FDI inflows, urbanization, industrialization, and environmental degradation (Abdouli and Hammami, 2016). There is a strong correlation between financial developments, CO₂ emissions, economic growth, and trade transparency (Jamel and Maktouf, 2017). According to Lv and Xu (2019), trade openness has a positive impact on climate change in the short-run, but in the long-run trade openness has negative consequences on climate change. The urban land area plays a crucial role in both urban development and environmental transformations. There is a direct correlation between the total developed urban road area and the emission of CO₂ emissions. However, a study conducted by Pu et al. (2022) revealed a concerning relationship between CO₂ emissions and urban development areas. FDI brings numerous advantages to the countries that receive it. One of the key benefits is a shared understanding, especially when it comes to fostering economic growth and its subsequent impact on the environment of these countries. Mejia (2023) found that the presence of domestic FDI stocks in different financial sectors can impact the per capita CO₂ emissions that examine non-industrialized countries. An often-cited cause of many environmental issues is the rapid expansion of urban populations. With the rising emissions of petroleum byproducts, ozone-depleting compounds, and the depletion of natural resources, the expansion of urban areas presents significant environmental concerns (Arias-Meza et al., 2023). There is a clear link between the CO₂ emissions of less developed nations, their use of environmentally friendly electricity, and their economic progress. In their review, Saqib et al. (2023) found a connection between variations in the causal relationship between mechanical progress, financial development, and sustainable energy. Several investigations conduct extensive observational research to analyze the effects of urbanization, urban land area, foreign direct investment inflows, renewable energy consumption, and trade openness on environmental degradation. After thorough analysis, the conclusions may be perplexing and the results can differ based on factors such as duration, control variables, and estimation method. In addition, these exams overlook the potential interactions between different factors, which could impact the interpretation of other variables related to the characteristic under study. The review aims to examine the connections between urban population, trade openness, foreign direct investment, urban land area, renewable energy, and CO₂ emissions in India and China to address this challenge. In addition, the review builds upon the prior research in various ways. Firstly, the study explores the influence of FDI and urbanization on environmental pollution in both countries. Furthermore, the research investigates the potential influence of urban land area, trade openness, and renewable energy on environmental pollution. However, there is the initial investigation focused on examining the connection between environmental changes and how they affect the economic growth of both countries. The study shows how increased urbanization and climate change might hurt a nation's economic growth. It will be accomplished by analyzing the relationship between FDI, urban land area, renewable energy, trade openness, and CO₂ emissions. The study employed a unit root test to examine the characteristics of series that undergo both gradual and abrupt structural disruptions. However, the study has employed the ARDL and NARDL models to rectify any inaccuracies and enhance the study comprehension of the short-term impact conclusions. The paper proceeds in the following manner: The "Literature Review" critically analyses significant scholarly works. The next part, under "Model, Methodological Strategy, and Data," provides a detailed description of the empirical model, the chosen methodological strategy, and the process of data collecting. The essay next addresses the empirical findings in the dedicated "Empirical Result" section. Lastly, the section titled "Conclusion and Policy Recommendations" discusses the findings and provides policy proposals.

LITERATURE REVIEW

The environmental contamination in underdeveloped nations is severely adversely impacted by the energy consumption generated by fossil fuels. The phenomenon of urban population growth is associated with a reduction in the release of CO₂ emissions produced by fossil fuels (Mosikari and Eita, 2020). Improving soil quality is greatly aided by the long-term tracking of SOC (Tiruneh et al., 2024). According to Perumal and Timmons (2017), individuals living in urban areas have lower per capita vehicle CO₂ emissions due to the

concentration of high population centers. Urbanization and CO₂ emissions are closely linked in a significant way. The emission of CO₂ contributes to the process of urbanization, as well as affecting the direction of GDP and FDI (Ngong et al., 2022). Population and energy use are positively correlated with CO₂ emissions (Mahmood et al., 2021). Urban land area growth causes ozone-depleting chemical pollutants, fossil fuel byproducts, and natural resource mistreatment (Arias-Meza et al., 2023). According to Yaqoob et al. (2024), the varying impacts of age distribution on CO₂ emissions in countries with different income levels. The focus on practical electricity consumption is to promote sustainable energy usage. Emphasizing the importance of utilizing sustainable energy sources and addressing climate change (Gyamfi et al., 2022). The coefficient of foreign direct investment (FDI) seems to have a long-term beneficial effect on exports and a statistically significant effect (Farid et al., 2023). Domestic FDI is essential to the economic sectors' growth in both developed and developing countries, and it has a major impact on CO₂ emissions per capita (Mejia, 2023). According to Chien (2024), there is a clear correlation between total GDP, development, FDI, and CO₂ emissions. The impact of FDI on China's efforts to conserve energy and reduce emissions has significant implications for environmental pollution (Chen et al., 2022). The ARDL model shows that FDI generates renewable energy. CO₂ emissions are also strongly correlated with fossil fuel energy usage (Ali et al., 2021). China has markedly enhanced its position, whereas Pakistan's score has shown a steady fall, with the exception of the year 2008 (Atique et al., 2024). Life cycle assessment was used in the construction industry to evaluate its emissions. Considering the present and future release dates, a goal of balance was established and successfully communicated across different districts (Liu et al., 2018). The entire developed urban area and its street network are closely connected to CO₂ emissions, whereas the urbanized area is inversely associated with CO₂ emissions. However, the evidence supporting the connection between urbanization and CO₂ emissions is limited (Pu et al., 2022). Urbanization and CO₂ emissions are strongly and positively correlated. There is a relationship between CO₂ emissions and urbanization, GDP, and FD units in a specific direction (Ngong et al., 2022). The complex strategy of land resources will typically contribute to the generation of fossil fuel emissions in local and nearby areas (Li et al., 2023). According to Marcantonini and Ellerman (2015), renewal energy produced by wind energy sources played an identical significant role in reducing CO₂ emissions. These evaluations point to a favorable relationship between real GDP, sustainable energy usage, and CO₂ emissions (Aydoğan and Vardar, 2020). The ongoing COVID pandemic has resulted in a favorable connection between hydroelectricity and the energy sector, resulting in a decrease in CO₂ emissions (Ope Olabiwonnu et al., 2022). The impact of innovative progressions on reducing CO₂ emissions varies significantly depending on the scale of measurement. The study also examines the potential for variation and diversity in the causal impact of technological advancement on economic growth and sustainable energy (Saqib et al., 2023). According to Abdulqadir (2023), there exists a negative correlation between trade, urbanization, economic expansion, and CO₂ emissions. Godil et al. (2021) utilized a QARDL model to examine the relationship between industrial development, transportation, economic growth, and environmental pollution in China. Their findings revealed a negative influence of these factors on environmental pollution. Abid et al. (2023) revealed that there was no significant short-term relationship between inflation, trade openness, economic growth, and environmental degradation. According to Chebbi et al. (2011), trade openness has a direct and favorable effect on CO₂ emissions in both the short- and long term. Jamel and Maktouf (2017) claim that a reciprocal causal association exists between economic progress, trade openness, and CO₂ emissions. In the short term, trade openness has a notable beneficial effect on CO₂ emissions. However, in the long term, trade openness has a large negative effect on CO₂ emissions (Lv and Xu, 2019).

RESEARCH METHODOLOGY

Data Availability

The study investigates the connections between trade openness, FDI, urbanization, urban land area, renewal energy, and CO₂ emissions. The research suggested the use of an econometric model for future analysis, which this study uses as a foundation for the study analysis. The study has adopted Omri et al (2020) method to develop the econometric model to find the relationships between the economic factors, and CO₂ emissions for

both East Asian countries. The study has added new literature and methodology to fill the research gap to explore the relationships between trade openness, urbanization, FDI, and CO₂ emissions in both East Asian countries. The data has been collected from 1990 to 2023 from the World Bank Database and the International Monetary Fund Database (Table 1).

Table 1. The study variables description

Variables	Abb.	Definitions	Data Collection Sources
CO ₂ emissions	CO ₂	Major climate change factor CO ₂ emissions measured in kilotons	https://climatedata.imf.org.com
Renewable energy	RE	Clean energy produced by sources of wind and solar	https://climatedata.imf.org.com
Urban Population	UP	Population in urban agglomerations of more than one million	https://databank.worldbank.org.com
Urban Land Area	ULA	A complex structure of social, cultural, and economic activities coexists in urban areas measured in square kilometers	https://databank.worldbank.org.com
Trade openness	TO	The trade openness ratio is exports + imports / GDP	https://databank.worldbank.org.com
Foreign direct investment	FDI	Investments inflow in the country in the industrial and agriculture sector	https://databank.worldbank.org.com

Following the idea and suggestion put out by Omri et al (2020), the study employs a long-run econometric model for estimating CO₂ emissions in East Asian economies. The specific model used is referred to as econometric model 1.

$$CO_{2t} = \alpha_0 + \alpha_1 RE_t + \alpha_2 UP_t + \alpha_3 ULA_t + \alpha_4 TO_t + \alpha_5 FDI_t + \epsilon_t \quad (1)$$

The random distributed error term (ϵ). The equation shows the estimated long-run results. Therefore, to understand and show the short-run effects results, the study has to recast the equation to the ARDL model to correct the error, as shown below in econometric Model 2. The run for a randomly distributed error is denoted by (ϵ). The equation represents the anticipated results over an extended period. Consequently, the research reformulates the equation into the ARDL model to correct the imprecisions to better understand and present the results on short-run consequences, as shown in econometric Model 2:

$$\Delta CO_{2t} = \alpha_0 + \sum_{k=1}^n \delta_{1k} \Delta CO_{2t-k} + \sum_{k=1}^n \delta_{2k} \Delta RE_{t-k} + \sum_{k=1}^n \delta_{3k} \Delta UP_{t-k} + \sum_{k=1}^n \delta_{4k} \Delta ULA_{t-k} + \sum_{k=1}^n \delta_{5k} \Delta TO_{t-k} + \sum_{k=1}^n \delta_{6k} \Delta FDI_{t-k} + \phi_1 CO_{t-1} + \phi_2 RE_{t-1} + \phi_3 UP_{t-1} + \phi_4 ULA_{t-1} + \phi_5 TO_{t-1} + \phi_6 FDI_{t-1} + \epsilon_t \quad (2)$$

Pesaran et al. (2001) state that equation 2 is derived from equation 1 by applying the error-correcting method to the ARDL model. The short-run results are shown in the attached estimates, which are based on the 1st difference variables in equivalence. The study has applied the ARDL model to incorporate variables with varying integration orders, such as 1(0) and 1(1). The study focuses on determining the asymmetric effects of renewal energy, and urbanization on CO₂ emissions. The analysis employed the partial sum technique to categorize urbanization, FDI, urban land area, trade openness, renewable energy, and CO₂ emissions into negative and positive series as shown in equations 3i-3iv:

$$RE_{\phi}^{+} = \sum_{n=1}^{\phi} \Delta RE_{\phi}^{+} = \sum_{n=1}^{\phi} \max(RE_{\phi}^{+}, 0) \quad (3i)$$

$$RE_{\phi}^{-} = \sum_{n=1}^{\phi} \Delta RE_{\phi}^{-} = \sum_{n=1}^{\phi} \min(RE_{\phi}^{-}, 0) \quad (3ii)$$

$$UP_{\phi}^{+} = \sum_{n=1}^{\phi} \Delta UP_{\phi}^{+} = \sum_{n=1}^{\phi} \max(UP_{\phi}^{+}, 0) \quad (3iii)$$

$$UP_{\phi}^{-} = \sum_{n=1}^{\phi} \Delta UP_{\phi}^{-} = \sum_{n=1}^{\phi} \min(UP_{\phi}^{-}, 0) \quad (3iv)$$

The variables that represent the total of the particles are then substituted into equation 2, as seen in econometric Model 4 below.

$$\Delta CO_{2t} = \alpha_0 + \sum_{k=1}^n \alpha_{1k} \Delta CO_{t-k} + \sum_{k=1}^n \alpha_{3k} \Delta RE_{t-k}^{+} + \sum_{k=1}^n \alpha_{3k} \Delta RE_{t-k}^{-} + \sum_{k=1}^n \alpha_{3k} \Delta UP_{t-k}^{+} + \sum_{k=1}^n \alpha_{3k} \Delta UP_{t-k}^{-} + \sum_{k=1}^n \alpha_{3k} \Delta ULA_{t-k}^{+} + \sum_{k=1}^n \alpha_{3k} \Delta ULA_{t-k}^{-} + \sum_{k=1}^n \alpha_{3k} \Delta FDI_{t-k}^{+} +$$

$$\sum_{k=1}^n \alpha_{3k} \Delta FDI_{t-k}^{-} \phi_1 CO_{t-1} + \phi_2 RE_{t-k}^{+} + \phi_2 RE_{t-k}^{-} + \phi_2 UP_{t-k}^{+} + \phi_2 UP_{t-k}^{-} + \phi_2 ULA_{t-k}^{+} + \phi_2 ULA_{t-k}^{-} + \phi_2 trade_{t-k}^{+} + \phi_2 trade_{t-k}^{-} + \phi_2 FDI_{t-k}^{+} + \phi_2 FDI_{t-k}^{-} + \epsilon_t \quad (3)$$

The dependent variable, CO₂ emission, is a measure of CO₂ produced and is measured in kilotons; the independent variables are urbanization, urban land area, renewal energy, trade openness, and FDI their measuring value is quad Btu.

RESULTS AND DISCUSSIONS

The study used the unit root test to examine the impacts of alterations made to the structure and asymmetry of the selected variables. Both take structural breakdowns into account and not the test's methodology. The objective of the unit root test is to make dependable and evocative assumptions.

Unit Root Test Analysis

The unit root test analyses the data set for research variables of Indian and Chinese economies. The validity of the ARDL technique enables its usage for analysis. The study focuses on two specific case examples: India and China. The study analyses both the asymmetric and symmetric influences of these factors on CO₂ emissions. Table 2 shows unit root test coefficients results with and without break.

Table 2: The unit root test results with and without break

	Unit root with break				Unit root without break		
	I(0)	Break date	I(1)	Break date	I(0)	I(1)	
India							
CO ₂	-5.0314*	2002			I(0) -3.025*		I(0)
RE	-7.014***	2013			I(0) -1.258	-4.025**	I(1)
UP	-3.021	2015	-8.023***	2023	I(1) -1.023	-6.0247***	I(1)
ULA	-2.986	2005	-5.021**	2014	I(1) -1.124	-4.022**	I(1)
TO	-3.874	2010	-6.002***	2020	I(1) -0.903	-6.024***	I(1)
FDI	-8.959***	2020			I(0) -3.025*		I(0)
China							
CO ₂	-7.021***	2010			-2.003	-3.0254*	I(1)
RE	3.034	2014	-5.027*	2018	I(1) 0.814	-3.0024*	I(1)
UP	-1.945	2018	-9.023***	2005	I(1) -1.987	-7.0245***	I(1)
ULA	-1.854	2015	-7.025***	2010	I(1) 0.745	-3.128*	I(1)
TO	-5.024***	2019			I(0) -3.251*		I(0)
FDI	-3.142	2023	-6.235***	2012	I(1) -0.502	-6.025***	I(1)

Note: * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

According to ARDL model results, the FDI, urbanization, and trade openness have significantly negative impacts on CO₂ emissions in the long run in China as well as in India (Table 3). Economic growth has a significant negative impact on CO₂ emissions in the short- and long-run in China and India East Asian countries. Renewable energy has a positive significant impact on CO₂ emissions in the long run in both countries. The results reveal that the increase in urban land area negatively impacts environmental pollution. In long-runs of renewable energy, a 1% increase in innovation causes China's and India's CO₂ emissions to decrease. According to the control variables, the Indian economy is observing a decrease in CO₂ emissions, while both economies are observing an increase in trade openness, and China's FDI inflows result in a decrease in CO₂ emissions. According to ARDL mode analysis, the renewal of energy, urbanization, trade openness, FDI, and urban land area decrease CO₂ emissions in the short-run in China. Table 3 represents the ARDL model analysis results for the impact of variables on CO₂ emissions.

Table 3. The results of ARDL model analysis for CO₂ emissions

Details	India		China	
	Coeff.	t-value	Coeff.	t-value
Short-run				
$\Delta(RE)$	0.024	1.949	-0.045**	3.35
$\Delta(RE (-1))$				

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Δ (UP)	-0.025	2.003	-0.041***	3.0245
Δ (UP (-1))	-0.059***	8		
Δ (ULA)	0.006	1.642	0.006	1.035
Δ (ULA (-1))	-0.0002	0.527		
Δ (TO)	0.004***	4.022	0.035***	6.202
Δ (TO (-1))	0.006***	4.014		
Δ (FDI)	0.04	0.503	0.213	2.003
Δ (FDI (-1))	-0.007	0.024	-0.321**	3.031
Long-run				
RE	-0.027*	2.035	-0.045**	1.89
UP	-0.037***	5.023	-0.025*	2.035
ULA	-0.005*	2.027	-0.024	1.589
TO	-0.004**	3.031	0.043***	5.231
FDI	0.034	0.621	2.02**	2.036
C	14.02***	9.031	5.014	1.023
Diagnostics				
F-test	7.985***		7.02***	
ECM (-1)	-0.402***	13	-0.39***	4.0232
LM	2.003		2.002	
Res.	0.947		1.001	
Cus.		Σ	Σ	
Cus-Sq.	Σ		Σ	

Note: * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

However, these variables have a negligible influence on Indian CO₂ emissions. Both extended and brief durations have unique results. However, policymakers want long-run results to formulate policies for reducing CO₂ emissions and it is effective because long-run plans are formulated based on projections. Renewable energy is the one factor that decreases CO₂ emissions in both countries. China and India have made significant investments in industrialization, and the growth of these businesses producing a wide range of goods has a significant influence on the people living in these countries, boosting employment and raising living standards overall. These groups have increased CO₂ emissions, artificially lowering climate value. The real GDP, the energy produced by fossil fuels, and CO₂ emissions have Granger causalities in the long run (Liu, 2021). The results show that although FDI only lowers emissions in India, renewal energy lowers CO₂ emissions in China but not in India. Ultimately, renewable energy causes China's emissions to rise while India's emissions decrease. In light of the exploration directed by Ragoubi and Mighri (2021), it has been found that exchange receptiveness emphatically affects CO₂ emissions. Nonetheless, this is neutralized by an essentially bad roundabout impact, which eventually brings about a general negative and huge complete impact. In light of the discoveries, it is clear that the usage of sustainable power has an impeding and essential impact, while financial development fundamentally affects CO₂ emissions. The use of sustainable power sources emphatically affects decreasing CO₂ emissions in the short run (Elbadri et al., 2023). Table 4 shows that the expansion in urbanization emphatically affects the lessening of CO₂ emissions in both India and China in the short run. Based on the analysis conducted, it can be observed that the error runs are distributed in both economies in both the NARDL and ARDL models. After analysing the CUSUM tests, it is evident that the stability condition is satisfied in both economies.

Table 4. NARDL short and long-run estimates of CO₂ emissions

Variables	India		China	
	Coefficient	t-Stat	Coefficient	t-Stat
Short-run				
Δ (RE_POS)	-0.092*	2.003	-0.023*	2.035
Δ (RE_POS (-1))				

Δ (RE_NEG)	-0.042	1.024	-0.038	1.056
Δ (RE_NEG (-1))	-0.036*	2.064		
Δ (UP_POS)	-0.054***	5.034	-0.001	0.829
Δ (UP_POS (-1))	-0.083***	7.046		
Δ (UP_NEG)	-0.023	1.862	0.002	1.059
Δ (UP_NEG (-1))				
Δ (ULA)	-0.005	0.609	-0.001*	2.056
Δ (ULA (-1))				
Δ (TO)	0.023***	5.001	0.004***	4.237
Δ (TO (-1))	0.006**	2.87		
Δ (FDI)	-0.053	1.057	0.302	1.086
Δ (FDI (-1))	-0.047	0.986	-0.245	1.679
Long-run				
RE_POS	-0.063**	3.072	-0.08**	3.063
RE_NEG	-0.04	2.047	-0.266	1.578
UP_POS	-0.015*	1.702	-0.045*	1.795
UP_NEG	-0.035*	2.034	0.03	0.879
ULA	0.009	0.781	-0.035***	3.0254
TO	-0.006*	2.024	0.034***	3.231
FDI	-0.078**	2.359	1.564	1.0245
C	15.03***	15.35	9.024	2.065
Diag.				
f-value	8.035***		5.034**	
ECM (-1)	-0.654***	5.876	-0.354**	3.022
LM	1.356		1.022	
Res.	1.865		0.989	
Cus.	S		S	
Cus-sq.	S		S	
W-S (RE)	0.56		3.034*	
W-L (RE)	3.713**		4.243**	
W- S (UP)	1.358		1.087	
W-L (UP)	4.056**		5.025**	

Note: * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

NARDL and ARDL model results show that urbanization growth affects CO₂ emissions in the long-run (Table 4). Furthermore, the LM test suggests that there is no auto relation present in the economies. Renewable energy has a significant positive impact on environmental pollution both in China and India, Especially, in India the increase in the use of renewable energy decreases CO₂ emission in the long-run. The results of the non-linear ARDL model are much more reliable as compared to the linear ARDL model results both in the short- and long-run for China and India. Reducing CO₂ emissions in India is a priority for the urban land area, while the impact of FDI on the economy is significant. However, there is a short-term increase in CO₂ emissions in the two countries due to genuinely rather large increased exchange straightforwardness. The criteria of the FDI reliance theory are supported by the urgent portion of FDI dependence, which is closely linked to CO₂ fluxes (Mejia, 2022). Ghazouani and Maktouf's study from 2024 revealed some amazing findings on the relationships between various factors. They discovered a reciprocal relationship between CO₂ emissions, financial improvements, and common resources. Moreover, it discovered a one-way relationship between exchange simplicity and CO₂ emissions.

Discussions

Different outcomes arise from trade about petroleum derivatives: trade openness leads to an increase in side effects related to non-renewable energy sources, but exchange extension causes a decrease in side effects related to petroleum products (Wang et al., 2023). According to Muhammad and Khan (2021), green energy use and social globalization have a significant role in the decrease in CO₂ emissions in both developed and developing nations. According to Xia et al. (2022), the correlation between CO₂ emissions and the flood impacts of urban land-use thickness was negative, but the correlation between CO₂ emanations and urban land-use efficiency was positive. Variations occurred in the rates of progress in urban expansion and petroleum product results, leading to an increase and a subsequent decrease. Moreover, Zhu et al. (2023) found that their spatial connectivity was increasingly tight. According to Sun (2017), strengthening the structure of area use and effectively managing the flow and use of carbon in urban areas may significantly contribute to the development of a low-carbon economy. According to Irilli and Veneri (2014), a city's spatial layout has a significant influence on driving patterns and the ensuing level of CO₂ emissions per traveler. The African drive for moderate development strongly promotes FDI in member countries compared to non-member countries. The CWA drive influences the occurrence of natural contamination through FDI (Duodu et al., 2022). With the use of order-and-control guidelines and the restraint of market-based motivational impulses, FDI reduces pollution emissions (Fu et al., 2024). According to Uzair et al. (2022), the release of CO₂ has a negative impact on population density, whereas economic development has a positive impact on population density in the long run. Furthermore, there exist rapid cause-and-effect relationships between economic growth and population density, as well as between CO₂ emissions and population density. The future is expected to bring an increase in urbanization, GDP (Gross domestic product), and population growth. This will result in increased CO₂ emissions due to heightened energy demand and consumption (Halдар and Sharma, 2022).

CONCLUSIONS AND RECOMMENDATIONS

The study has examined the relationships between urbanization, trade openness, urban land area, foreign direct investment, renewable energy, and CO₂ emissions in two East Asian countries India and China from a period of 1990 to 2023. The study has applied the Unit root test with ARDL and NARDL models, both models have been used to approve whether the macroeconomic factors of the study are direct or indirect. The study found that urbanization has a significant impact on ecological changes in China, and short-run indirect measures are important for both countries. Renewable energy and foreign direct investment (FDI) have a notable and beneficial effect on CO₂ emissions in long-run in both China and India, although non-linearity appears to be particularly important in India. Urbanization and the expansion of urban land areas have significant and negative effects in both countries, as indicated by the coefficient assessment. In the indirect model, the coefficients for urbanization and FDI positive shocks are crucial and have a negative impact in both countries. The findings show that both FDI and urbanization contribute positively to the reduction of CO₂ emissions in both nations. The positive judgments of trade openness and urbanization have a considerable detrimental influence on both economies; unfavorable appraisals of urbanization are more significant in India. The findings show that enhancing environmental quality, FDI, renewable energy, and urbanization have a major effect on East Asia's economy. The results of the study inspire government authorities and stakeholders to learn from these economies and make informed decisions. Given the imbalance of the NARDL model analysis, it is important for strategy makers and investors to carefully weigh the advantages and disadvantages of these activities when considering how to establish a sustainable atmosphere. It is important to instrument actions expected to reinforce the low cost through protection environmental principles.

Future Research Suggestions

Future studies can take into account green innovation technology and look at how it affects urban land area and urbanization in particular, as well as how it decouples economic growth from greenhouse gas emissions. It is also recommended that the forestation element be included in future studies because it is one of the variables that is closely related to environmental changes, GDP growth, urbanization, and industrialization. Furthermore, future studies that look at the connection between FDI, GDP growth, and environmental pollution should make use of more current data.

Declarations**Availability of Data and Material**

The study has collected the data related to CO₂ emissions, and renewable energy from International Monetary Fund Database Website “<https://climatedata.imf.org.com>”, However, data related to urban population, urban land area, trade openness foreign direct investment has been collected from World Bank Database website “<https://databank.worldbank.org.com>”.

Competing Interests

Authors have not declared any competing interest of this research.

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Authors' Contributions

In "Technological Routes for Sustainable Urbanization and Industrial Development to Reduce Climate Change," MA and MAK were key. MA reviewed sustainable urbanization literature, developed the conceptual framework, designed the study methodology, and made policy suggestions to integrate technology to reduce urban carbon footprints. MAK evaluated sustainable technologies for industrial development, conducted case studies, and developed prediction models for sustainability implications. MAK and MA on data collecting and manuscript writing, using an interdisciplinary approach to bridge urban planning, industrial expansion, and climate change mitigation to explore sustainable development technologies.

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