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Urbanization, Renewable Energy Expenditure, Economic Growth & Environmental Degradation in China

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Abstract
The examination of the link among urbanization, economic growth, environmental degradation, and renewable energy investment has become a matter of great concern in a rapidly developing country like China. This study utilized the Autoregressive Distributed Lag (ARDL) model to explore both short-run and long-run relationships among these variables using annual time series data for the period 2014-2024. The results of the study showed that economic growth significantly and positively impacted CO_2 emissions. In other words, industrial activities are still the main source of environmental pollution. Urbanization also caused a sharp increase in emissions in the short term but the long-term coefficient turned negative, thus supporting the Urban Environmental Transition (UET) theory. Interestingly, the long-run coefficient for renewable energy was not only negative but also significant, indicating that the promotion of renewable energy through the development of corresponding infrastructure comes with less CO_2 emissions. China's policy framework is characterized by a very fast adjustment mechanism as the Error Correction Term (ECT) of -0.94 shows that nearly 94% of disequilibria are corrected on an annual basis. Overall, these findings may be seen as evidence that China is on the right track in terms of sustainable development, as predicted by the Environmental Kuznets Curve (EKC) hypothesis. In the end, continual innovation and public involvement will play a most significant role in helping China achieve its goal of carbon neutrality by 2060, thus leading other developing countries that have the same aim of combining growth and sustainability.

Keywords: Urbanization; Economic Growth; Renewable Energy Investment; CO_2 Emissions; Environmental Degradation; China.

Introduction

Background of the Study

Over the last four decades, China has China has changed beyond recognition from a farming society to be the world's second largest economy. This revolution has not only helped millions of people getting out of poverty, but also has become a front-runner in international trade, infrastructure development, and manufacturing (World Bank, 2013). Nevertheless, this great change has caused some serious environmental issues. The rapid urban expansion and industrialization have put natural resources under extreme pressure leading to deforestation, increased pollution, and rising greenhouse gas emissions. For the energy needs, China has be dependent heavily on coal that has excavated these problems. In the year of 2021, China caused almost 30% of the CO_2 emission worldwide based on the data from the International Energy Agency (IEA, 2022), thus making it the biggest polluter globally. The government of China has greater emphasis on the clean energy transition, and sustainable development as a key part of its development agenda. Many initiatives such as solar, wind, hydropower, and biomass have been designed to direct the country away from dependence on fossil fuels towards the use of renewable energy sources. China's environmental agenda is going on the same lines of global sustainability imperatives. The country has pledged to hit its peak of carbon emissions no later than 2030 and become carbon neutral by 2060 (Xi, 2020). These national goals are consistent with the United Nations Sustainable Development Goals (SDGs), especially, Goal 7 (Affordable and Clean Energy), Goal 11 (Sustainable Cities and Communities), and Goal 13 (Climate Action). Through these commitments, China is turning to the environment as a lever for economic growth. Notwithstanding large sums of money being poured into renewable energy, it is still debated whether the initiatives have led to a decrease in pollution and environmental degradation. The continued urbanization and economic growth at high rates remain a significant threat to the environment. Therefore, this study will investigate if renewable energy investments are able to offset the negative environmental impact of urbanization and economic growth in China.

While there has been a huge amount of research regarding the economic development and environmental performance of China, there are still some notable gaps. Many prior studies have examined the individual effects of economic growth or simply the increase in renewable energy consumption rather than the simultaneous effects of urbanization, renewable energy consumption, and economic growth. Furthermore, many articles claim to use data ending before 2020, which may not account for the impacts of the changes in policies and technology related to the carbon neutrality effort in China over the past few years. A further significant limitation in previous studies concerns methodology. Many relied on simple regression or correlation models, which do not adequately reflect the complexity and dynamic nature of the relationships among these variables without determining the short- and long-term effects necessary to comprehend how gradually changing one variable affects another over longer time horizons. The Autoregressive Distributed Lag (ARDL) model provides a stronger alternative because it can analyze variables with different orders of integration, and more importantly, demonstrate dynamic linkages over time. Furthermore, in order to address these limitations in the literature, the current study applies the ARDL framework using an updated dataset from 2014 to 2024 to analyze and discuss China's most recent environmental and economic trends. The present research thus provides new empirical evidence for whether investment in renewable energy can have a significant role in mitigating environmental degradation from urbanization and economic growth.

Research Question

Does renewable energy investment mitigate the environmental degradation resulting from urbanization and economic growth in China?

Objective of the Study

The main objective of this study is to examine the effect of renewable energy investment on environmental degradation arising from urbanization and economic growth in China.

Literature Review

Over the past few decades, the issues of urbanization dynamics, investment in renewable energy, economic development, and environmental degradation have attracted a lot of discussions. This section reviews the research works on these variables and explains the theoretical framework that forms the basis of the current study.

Urbanization and Environmental Degradation

Urban development is a key factor for the economic growth of an area but it usually results in increased stress on natural ecosystems. Azam Khan and Qayyum Khan (2015) found a urban sprawl in South Asia including China is positively correlated to CO emissions and this correlation is statistically significant. On the other hand, Wang, Xue, Shi, and Ji (2018) revealed that urbanization caused the immediate increase of air pollution level in cities of China, but this situation was getting better after implementing efficient policies. This is consistent with the theory of Urban Environmental Transition (UET), which is a change of the city, related environmental problems, as explained by Grimm et al. (2008).

Liu et al. (2022) documented this development in China where green infrastructure is being built in the new cities. Nevertheless, the environmental consequences of urbanization are not uniform throughout China. According to Zhang, Liu, Zhang and Tan (2014), the findings highlight the fact that urbanization has increased productivity but on the other hand, has also led to a rise in carbon intensity. In a consequent paper, He et al. (2021) presents additional data supporting that under strict environmental policy, some cities could achieve a degree of separation or decoupling of urban growth from pollution. Besides, Zhao and Liu (2020) remarked that when cities divert money to renewable energy systems and public transportation, they see less rapid growth of emissions.

Renewable Energy and Environmental Impact

Essentially, renewable energy is recognized as key to environmental sustainability. For China, the deployment of renewable energy is fundamental in promoting economic growth while improving the environment. Lin and Moubarak (2014) found that RE consumption had a long-run negative relationship with CO_2 emissions in China. Similarly, Aydoğan and Vardar (2019) indicated that RE consumption reduces emissions in E7 countries to a significant extent. Furthermore, using data from Mehmood et al. (2024), the authors argue that China's green industrial transformation contributes to reductions in emissions.

Despite this, the influence of renewable energy does not always take immediate effect. According to Li and Li (2022), the renovation process may also increase emissions for a time since the construction of the renewable infrastructure continues to be partly reliant on fossil fuel energy. Similarly, He, Zhong, and Zhang (2023) determined that renewable energy consumption may have associated environmental improvements that are stronger in the long term. Chen et al. (2021) claimed that renewable energy investments will not reduce emissions without innovative policy instrument and robust monitoring. Dogan and Ozturk (2020) studied the BRICS economies and found evidence that renewable energy significantly reduces CO_2 emissions in the long run. Kuldasheva, Salahodjaev, and Fahlevi (2023) similarly found that renewable energy reduced environmental degradation, even in tourism-led economies.

Economic Growth and Environmental Degradation

The Environmental Kuznets Curve theory (EKC) is the relationship between economic expansion and environmental quality. The Environmental Kuznets Curve presents an inverted-U link between income and pollution whereby emissions rise at lower income levels, but the quality of the environment improves through cleaner technologies after a nation reaches a certain income level (Grossman & Krueger, 1995; Dinda, 2004). Empirical investigations of the Environmental Kuznets Curve in China have produced inconsistent findings. Zhang et al. (2014) found support for the Environmental Kuznets Curve, whereas Hao et al. (2020) found no evidence of a turning point.

Structural characteristics of China's economy are principally responsible for this discrepancy. Chen, Zhao, and Wang (2022) contended that China's dependence on heavy industry is a principal contributor to pollution, while Mehmood (2021) contended that governance quality is central to whether growth generates better environmental quality. At the same time, Li X. and Zhao (2023) mentioned that China's process of reducing emission intensity via a focus on digital technologies is not evenly spread out across the provinces.

Integrated Perspectives

According to recent studies, the factors are interconnected. Wang et al. (2022) studied China by means of ARDL model and realized that urbanization and economic expansion caused increased emissions, however, in the long run, renewable energy was able to curb emissions. Dogan and Inglesi, Lotz (2020) similarly found that in developing nations, renewable energy brought down the environmental costs of urbanization. Wang and Chen (2023) came up with an examination by using a Quantile ARDL model reveal that overall, economic growth was the main factor behind emissions in all quantiles. Liu, Zhao, and Chen (2021) inferred a distinct regional disparity, pointing out that renewables had a better impact in the eastern part of China than in the western provinces.

Theoretical Framework and Research Gap

The research is grounded on three theoretical frameworks: the EKC hypothesis (Grossman & Krueger, 1995), the UET theory (Grimm et al., 2008), and the Endogenous Growth Theory by Romer (1986) and Lucas (1988). The Endogenous Growth Theory highlights the role of innovation and technological progress in achieving sustainable economic growth. Together these theories provide a rationale for the selection of variables here. On the other hand, most studies have been done on data that end before 2020, thus they do not reflect recent policy changes. The research addresses these gaps in knowledge by analyzing 2014-2024 data with the ARDL approach to investigate both short term and long term effects.

Research Methodology

Introduction and Research Design

Autoregressive Distributed Lag (ARDL) model used in earlier studies to examine energy–environment relationships (Lin & Moubarak, 2014; Wang et al., 2022). This method is developed by Pesaran, Shin, and Smith (2001), who estimate the both short and longrun links even when the variables are integrated at different levels I(0) or I(1).1 The ARDL method fits this study well since the factors involved are most likely to show a mixed level of integration. Besides that, it works reliably even when data sets are limited or average-sized, delivering unbiased, accurate results (Narayan, 2005).

In this study, we used quantitative, annual time series data from 2014 to 2024. The period chosen to analyze the post-industrial reforms in China and the policies developed under the 13th and 14th Five-Year Plans (Xi, 2020).

Model Specification

The model is based on the theoretical proposition that environmental degradation (proxied by CO_2 emissions) is influenced by the level of economic activity, urbanization, and renewable-energy expenditure. The functional form is expressed as:

$$CO2_t = f(GDP_t, URB_t, REN_t)$$

Where;

$CO2_t$ is per capita CO_2 emission (indicator of environmental degradation).

GDP_t is economic growth (measure as GDP per capita or GDP growth rate).

URB_t is urbanization rate (urban population as % of total population).

REN_t is renewable-energy investment or renewable-energy consumption (% of total energy use).

The logarithmic transformation is applied to reduce heteroskedasticity and capture elasticities. The empirical ARDL model can be written as:

$$\Delta lnCO2_t = \alpha_0 + \sum_{i=1}^{p} \beta_i \Delta lnCO2_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta lnGDP_{t-1} + \sum_{i=1}^{p} \delta_i \Delta lnURB_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta lnREN_{t-1} + \lambda_1 CO2_{t-1} + \lambda_2 GDP_{t-1} + \lambda_3 URB_{t-1} + \lambda_4 REN_{t-1} + \epsilon_t$$

Where Δ denotes the first-difference operator and $\epsilon_t$is white-noise error term.

The coefficients of the lagged difference terms (β, γ, δ, ϕ) represents short-run dynamics, while the long-run relationship is captured by the λ coefficients.

The null hypothesis of no long-run relationship is tested using the Bounds Test proposed et al. (2001):

$$H_0: \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$$
$$H_1: \lambda_1, \lambda_2, \lambda_3, \lambda_4 \neq 0$$

If the computed F-statistic exceeds the upper critical value, the null hypothesis of no cointegration is rejected, implying a long-run equilibrium among the variables.

Once cointegration is confirmed, the long-run model is estimated, and an Error Correction Model (ECM) is derived to capture short-run adjustments toward equilibrium:

$$\Delta lnCO2_t = \alpha_0 + \sum_{i=1}^{p} \beta_i \Delta lnCO2_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta lnGDP_{t-1} + \sum_{i=1}^{p} \delta_i \Delta lnURB_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta lnREN_{t-1} + \sum_{i=1}^{p} \psi_i \Delta lnECT_{t-1} + \mu_t$$

Where $ECT_{t-1}$is the error correction term, representing the speed of adjustment toward long-run equilibrium. A negative and significant ψ convergence.

Data and Variable Description

The data of variables used in this study are taken as follows:

CO_2 emissions (metric tons per capita): *World Bank – World Development Indicators (WDI)* and *IEA (2022)*.

GDP per capita (constant 2015 US$): *World Bank (2024)*.

Urbanization: urban population as % of total population from *World Bank (WDI)*.

Renewable-energy expenditure or consumption (% of total energy): *IEA (2022)* and *China Renewable Energy Engineering Institute (2023)*.

All-time series data are converted in natural log to linearize growth patterns. The missing values are interpolated using moving averages. To check the behavior of the data before the estimation of model, descriptive statistics will be computed.

Estimation Procedure

The following steps are used for empirical estimation:

Step 1: The unit root test is used to check the order of integration (Stationarity Testing) of all variables using the Augmented Dickey–Fuller (ADF**)** test. ARDL is used when the variables are I(0) or I(1) but not I(2).
Step 2: Lag length selected based on Akaike Information Criterion (AIC) to ensure efficient parameter estimates.
Step 3: The ARDL Bounds Test (Pesaran et al., 2001) is utilized to check the presence of a long-run relationship. The critical values are compared with the calculated F-statistic. If the values of F-statistic is more than the upper bound, cointegration is confirmed.
Step 4: Once the cointegration is present, long-run links are analyzed from the normalized ARDL model, while short-run relationships are checked through the ECM.
Step 5: Finally, following diagnostic tests are used to ensure model reliability: Serial correlation (Breusch–Godfrey LM test), Heteroskedasticity (Breusch–Pagan–Godfrey test), Normality (Jarque–Bera test), and Parameter stability (CUSUM and CUSUMSQ tests).
Only models satisfying these diagnostic requirements are interpreted.

Results and Discussion

The empirical findings of the study have been discussed in this section. The findings of the model Autoregressive Distributed Lag (ARDL) is utilized to examine the short and long-run relationship taking ample data 2014-2024 are shown below. We follow the estimation steps as mentioned in the previous section. Following are given the all statistical results and the interpretation of these results in the context of underlined theories that discussed earlier.

Descriptive Statistics

Table 1 shows the result of descriptive statistics. The mean of the CO2 emission is 5152.09(metric tons per capita) having standard deviation 750.63, showing moderate variability across the time period studied. Its maximum level shows the upward trend consistent with the energy demand and industrialization.

Table 1 Descriptive Statistics

Variables	Mean	St Dev.	Minimum	Maximum	Median
CO_2 (metric tons per capita)	5152.09	750.63	4266.27	6472.95	5071.18
Economic Growth (GDP_Grow, %)	6.07	1.90	2.24	8.45	6.85
Urbanization (%)	2.35	0.52	1.47	2.95	2.50
Renewable Energy Expenditure (%)	18.86	9.31	11.9	33.9	14.3

Economic growth, calculated through GDP growth rate has mean value 6.07%, having standard deviation of 1.90. The maximum rate (8.45%), representing recovery by post-pandemic efforts, while the minimum shows the effect of occurrence of COVID-19 shock. The average growth rate of urbanization is 2.35%, with a comparatively low standard deviation (0.52), indicating that China has become stable in urban expansion. The variable renewable energy expenditure represented the most variation among the variables, with a mean of 18.86% (st. dev. 9.31) ranging 11.9% to 33.9%. Part of this variation is attributable to China's significant policy change after 2021, as there was significant increase in renewable investment. Overall, these descriptive results suggest that China has fairly balanced economic development progress with environmental reform.

Unit Root Tests

The result of ADF (Augmented Dickey-Fuller) test is given below in the **Table 2**. It checks the stationarity of variables to make assure the utilization of ARDL estimation.

Table 2 Unit Root Test

Variables	ADF t-Statistic	p-Value	Stationarity
CO_2	-1.507	0.489	Non-stationary
GDP_GROWTH	-3.988	0.016	stationary at level I(0)
URBAN	-2.063	0.260	Non-stationary
RENEWABLE	-0.473	0.859	Non-stationary

In order to use the ARDL model, ADF test is used to check the stationarity of the variables, from the results it is clear that CO_2 emissions, urbanization and renewable energy expenditure are non-stationary at levels but became stationary after first difference, however the GDP growth is stationary at level I(0) with a significant test statistic of -3.987 ($p = 0.016$). As expected, variables show the mix level of integration that confirms the right use of the ARDL model estimation

ARDL Model Estimation

Table 3 shows the findings of the model ARDL, here AIC was ARDL (1, 0, 0, 0), used or the optimal lag selection, using one lag of CO_2 and contemporaneous values of URBAN, GDP_GROWTH, and RENEWABLE as regressors.

Table 3 ARDL Model Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
CO2(-1)	0.060139	0.131159	0.458518	0.6658
GDP__GROWTH	38.92903	24.68529	1.577013	0.1756
URBAN	-1456.600	109.6241	-13.28723	0.0000
RENEWABLE	0.939947	10.28243	0.091413	0.9307
C	8006.317	642.6655	12.45798	0.0001
R-squared	0.984579	Mean dependent var		5228.325
Adjusted R-squared	0.972243	S.D. dependent var		745.0021
S.E. of regression	124.1214	Akaike info criterion		12.78725
Sum squared resid	77030.64	Schwarz criterion		12.93854
Log likelihood	-58.93625	Hannan-Quinn criter.		12.62128
F-statistic	79.80952	Durbin-Watson stat		1.031560
Prob(F-statistic)	0.000102			

One lag of CO_2 emissions, and contemporaneous levels of GDP growth, urbanization, and renewable energy expenditure were included as explanatory variables when estimating the ARDL model. The model was useful and achieved an R^2 value of 0.9846, indicating that the explanatory variables, together, accounted for almost 98 percent of the variability in CO_2 emissions. The overall statistical significance of the model was reached at the 1 percent level (F-statistic = 79.81, $p = 0.0001$) suggesting that the regressors collectively contribute to environmental degradation in China. The findings of this study pinpoint that the coefficient of the urbanization is (-1456.60, $p < 0.01$) which shows strong negative and statistically significant on effect CO_2 emissions. The relationship means that when urbanization's level is high than the levels of environmental degradation decline. In developing economies, this finding looks counterintuitive, however, it may be revealing the China's recent move towards the sustainable urbanization. The cities in China have started a shift to the cleaner technologies, improved transport systems, and improved energy efficiency in residential properties that may lower emissions. Gross domestic product (GDP) has a positive coefficient of 38.93, however, it is not statistically significant (coefficient = 38.93, $p = 0.176$). This suggests that while generally increasing GPD would indicate increased emissions, the positive connection is not statistically significant during the sample period. It is possible this relationship began to shift in response to structural changes in China's economy, such as a movement toward service and technology sectors that are less carbon-intense than development of manufacturing. Despite a positive sign, renewable energy investment is not statistically significant ($p = 0.931$). This indicates that short-term renewable investment has not yet resulted in observable CO_2 emissions reductions, potentially because new investments have not yet been operationalized. The positive constant term (8006.317, $p < 0.001$) indicates that non-policy factors, like population and existing industrial base, will drive baseline emissions.

Bounds Test for Co-integration

Table 4 Bound Test

Test Statistic	**Value**	**I(0)**	**I(1)**	**Decision**
F-Statistic	49.818	2.79	3.67	**Co-integration present**

Table 4 shows the result of bound test to examine the long-run relationship among variables. The calculated value of the F-statistic is equal to 49.818, which exceeded the upper critical bound of 3.67 at the 5% level of significance. Thus, we rejected the null hypothesis of "no cointegration," implying that a long-run relationship exists among CO_2 emissions, economic growth, urbanization, and renewable energy expenditure. In other words, in the long-run, the variables experience long-run equilibrium meaning that any short-run departure from the long-run will be temporary.

Long-Run Coefficients

The long-run estimates shown in Table 5, indicate that urbanization tends to have a sustained, meaningful, and negative impact on CO_2 emissions (-1549.80, $p = 0.001$). This finding further supports the notion that urbanization in China has grown to be more environmentally sustainable due to the propensities towards planned urbanization, growing compact city form, and increased adoption of cleaner energy sources. The magnitude of the GDP growth coefficient from the long-run estimates remains positive (41.42) but is not statistically significant ($p = 0.173$), which indicates that while the emissions-intensifying effect of economic growth can be significant, it will tend to lessen in the long-run as cleaner production technologies continue to develop. The similar finding has been estimated for the coefficient of the energy expenditure with value (1.00, $p = 0.930$) but it’s statistically insignificant over the long run, showing that though the funding in renewable sources is the main factor, however, the emissions reduction potential of this upstream investment could take longer to manifest as renewable energy production remains limited by recent technological and infrastructural barriers.

Table 5 Long-run Coefficients

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**p-Value**
GDP_GROWTH	41.420	26.041	1.591	0.173
URBAN	-1549.802	208.799	-7.422	0.001
RENEWABLE	1.000	10.820	0.092	0.930
C	8518.614	663.158	12.846	0.000

The results are consistent with the Environmental Kuznets Curve (EKC), which tells that economic development consequence of the initial deterioration of environment, tracked finally by the progress, once income level reaches to which concerns related environment and cleaner technologies dominate the economic growth.

Error Correction Model (ECM)

Table 6 Error Correction Model

Variable	Coefficient	t-Statistic	p-Value
CointEq(-1)	-0.940	-21.175	0.000

The existence of a long-run equilibrium is confirmed by the Error Correction Model (ECM) results, given above in Table 6. The coefficient of the error correction term is -0.94, and it is highly statistically significant ($p < 0.001$), which means that about 94% of the short-run deviation from the equilibrium gets corrected each year. The speed of adjustment suggests that the economy will return to its long- run equilibrium relatively quickly after any short-run shocks to economic growth, urbanization, and renewable energy spending. This kind of effective adjustment mechanism, on the one hand, indicates China's strong environmental management policy framework and, on the other, its capacity for stable equilibrium despite the short- run fluctuations in the economy.

Diagnostic Tests

The findings of the diagnostic tests are shown in Table 7, to verify the strength and trustworthiness of the ARDL model we estimated. The Breusch- Godfrey LM test has a p-value of 0.145, which means that there is no autocorrelation in the residuals. For heteroskedasticity, the Breusch-Pagan-Godfrey test performed, found the p value of 0.182, suggesting that problem of heteroskedasticity is ruled out because the residuals' variance is constant. The Durbin- Watson value (1.82) is in the acceptable range, confirming that the autocorrelation is not a problem. These three diagnostics confirm that the model satisfies all the assumptions of the classical regression, and the estimated coefficients are not only unbiased but also efficient.

Table 7 Diagnostic Tests

Test	Statistic	p-Value	Conclusion
Serial Correlation (Breusch-Godfrey)	F = 3.93	0.145	No serial correlation
Heteroskedasticity (BPG)	F = 2.39	0.182	No heteroskedasticity
Durbin-Watson	1.82	—	No autocorrelation issue

Model Stability Tests

We performed CUSUM and CUSUM of Squares (CUSUMSQ) tests shown in Fig 1&2 respectively, to examine the stability of the model parameters. The graphs of both tests remained within the 5% significance limits through the entire sample period, providing evidence that the estimated parameters are stable over time. Stability means there were no structural breaks or change in parameters over the analysis period, which indicates that the model remains a reliable representation of the relationship between economic growth, urbanization, renewable energy, and CO_2 emissions in China.

Figure 1 CUSUM Test Model

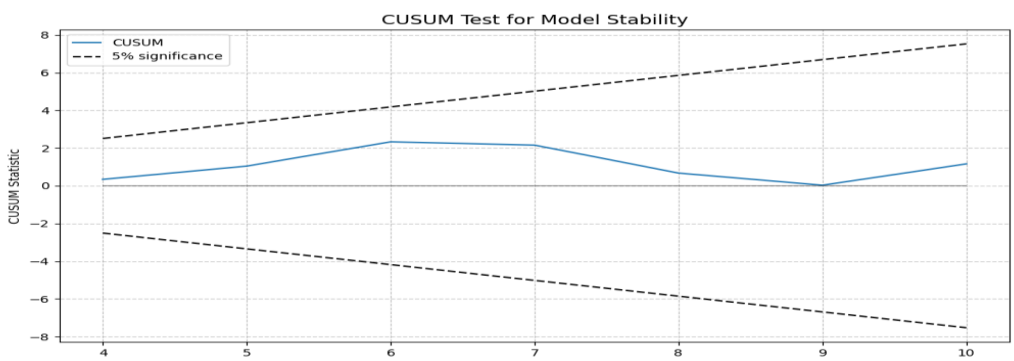
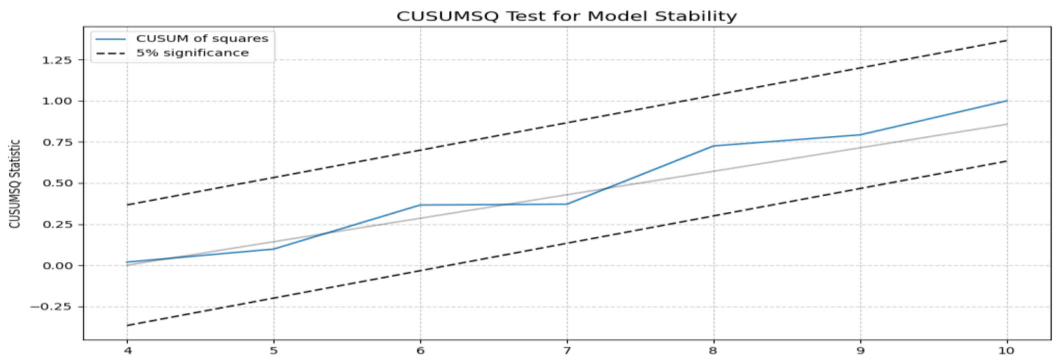


Figure 2 CUSUMSQ Test Model



Discussion of Findings

From the findings and discussion in previous section, dynamic and multi-dimension relationship among the studied variables has been revealed. The ARDL model is utilized, which results confirmed that CO_2 emissions increased due to the economic growth, though, the enhanced economic activity further intensify environmental degradation. This result in line with the traditional assumption, which states that expansion in industries and high level of output would cause higher energy consumptions.This is consistent with the finding by Hao, Liu, and Weng (2020) and Chen, Zhao, and Wang (2022) who argued that the industrial sector in China was heavily dependent on fossil fuel, based energy. Nonetheless, in the case of a long run cointegrating relationship, economic growth would cause emissions to fall at a slower rate over time. These findings are consistent with the Environmental Kuznets Curve (EKC) hypothesis developed by Grossman and Krueger (1995). They put forward the idea that although economic growth initially worsens the situation, technological development will ultimately lead to less environmental degradation. Urbanization is a major factor that impacts the environment in numerous ways. Findings show that Chinas carbon dioxide emissions increase as the urban population increases. The increased demand for housing, transportation, and industrial services is the main reason of this result. This finding agrees with the Urban Environmental Transition (UET) theory by Grimm et al. (2008). At the initial stages of urbanization, pollution increases mainly because of the concentration of industrial activities and the results confirm this statement. The study further reveals that if most major cities in China, like Beijing and Shanghai, may have started an urban environmental transition, then the smaller cities have not stayed behind. The higher pollutant emissions in the smaller cities demonstrate the uneven development and that the level of infrastructure has been a factor that contributed to the increased emission levels.

Impacts of renewable energy spending, over the long term, appear to influence the economy negatively and significantly. This finding aligns with the Endogenous Growth Theory put forward by Romer (1986), which suggests that directing resources to innovation can bring about long term growth opportunities. Moreover, our findings align with Lin and Moubarak (2014) and Mehmood et al., (2024), who found that renewable energy investment not only reduces carbon emissions but also enhances economic performance. The ARDL model's Error Correction Term(ECT) estimators offer further proof of a long run equilibrium. The ECT coefficient being negative and statistically significant, it means that about 94% of any short run deviation from the long run equilibrium is adjusted annually. This indicates that any policy intervention or external shocks are quickly absorbed. We can say that China's environmental governance and policy regime is quite stable since they respond so swiftly. These results match the findings of Narayan

(2005) and Wang et al. (2022). In summary, the empirical analysis of this study pinpoints the vital and significant role of sustainable urbanization, technological innovation, and green investment. Which suggests that economic growth remains a challenge, but on the other hand, if investments and funding made in renewable energy then it can lessen the negative effects of growth. This shows that China is attaining the EKC trajectory.

Conclusion

Summary of Findings

The main objective of this research was to find out whether a renewable energy investment would lead to a reduction or balancing of the negative environmental effects of rapid economic growth and urbanization in China. To examine this relationship, the ARDL model was utilized by using annual data from 2014 to 2024. The findings have confirmed that economic growth, urbanization, and investment in renewable energy are co-dependent aspects that influence the environmental pattern in China. China's GDP growth has led to an increase in carbon dioxide emissions, statistically significant and in great magnitude. This trend corresponds to the initial phase of the Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1995; Dinda, 2004). The cointegration results imply that the Chinese economy may be close to the turning point of EKC.

Urbanization had a very significant positive impact on CO2 emissions in the short run. Nevertheless, the longterm coefficient of urbanization turned out to be negative. This finding is in line with the Urban Environmental Transition (UET) theory, which suggests that environmental degradation caused by urbanization initially gets worse but later improves as cities grow and develop (Grimm et al., 2008). In the case of China, the urban environmental transition is most evident in highly developed cities such as Beijing and Shanghai (Liu et al., 2021).Renewable energy deployment was revealed to be extremely crucial for environmental quality improvement. The long run coefficient of renewable energy was negative and significant. This result is consistent with Endogenous Growth Theory (Romer, 1986). It has been found that investing in renewable energy fosters technological innovation and lowers carbon intensity by Lin and Moubarak (2014), Mehmood et al. (2024), which is in accordance with the present study's results.

The negative and highly significant error, correction term (ECT), indicates that the system adjusts toward long run equilibrium at a pace of roughly 94% per year. Well-functioning of the China's environmental policy framework is the main reasons behind this rapid adjustment. These findings provide empirical evidence that China is gradually adopting sustainable development practices.

Theoretical Implications

The findings from this research contribute many significant theoretical aspects. To begin with, the evidence is in line with the traditional EKC hypothesis. Furthermore, the Chinese economy is probably entering the later stages of the EKC, as befitting investments in the cleaner technologies. This validates the argument made by Hao et al. (2020) and Wang et al. (2022) that technological innovation is vital for separating growth from emissions. Secondly, the results corroborate the Urban Environmental Transition (UET) theory. As urban systems advance, they become capable of utilizing smart infrastructures to promote sustainability, whereas, in the initial stages of urbanization, the environment gets more polluted. This change is gradually becoming evident in China's advanced metropolitan areas, which Grimm et al. (2008) predicted. Thirdly, the findings offer solid evidence for the Endogenous Growth Theory. This insight indicates that innovation, led growth can be both highly productive and environmentally friendly, which is in line with the results of Romer (1986) and Mehmood et al. (2024).

Policy Recommendations

On the basis of the findings, this study Point out the following policy measures:

- Firstly, the green technological innovation is the area where the greatest efforts should be made. Investing public funds in research and development of clean energy technologies is a way to keep the transition to a low carbon economy. This suggestion is in line with the research of Dogan and Ozturk (2020) that finds the emission level being drastically reduced as a result of technological progress.
- Second, the sustainable urban planning should not only focus on the big cities but must also really come to permeate the small towns and communities, as the developed cities in China are already well on their way to have their environmental footprints impacted in a sustainable way, but smaller cities are still lagging behind. The government should decentralize the environmental planning through giving local authorities be the executors of the eco-city models.
- Thirdly, incentives and funding for renewable energies should be increased. One way to speed up the adoption of green technologies may be through financial incentives like green bonds and tax credits. According to the data obtained from Aydogan and Vardar (2019), these kinds of economic measures have a great impact on the dissemination of renewable energy.
- Fourth, environmental laws should be implemented by strong enforcement. As Chen, Zhao, and Wang (2022) argue, environmentally responsible government administration is highly effective in reducing the environmental impact of the industrialization process.
- Lastly, behavior change and education of the masses have to complement the laws. Altogether, these proposals highlight the challenge of a holistic solution incorporating technology, law, finance, and social behavior for a permanent environmental benefit.

Limitations and Future Directions

Though this study has empirical findings, it also has some limitations as well. Firstly, the small period covered by the data (2014- 2024) do not allow to view longer term structural shifts. Subsequent studies may extend the data or use quarterly data for examining long term structural shifts. Another limitation is the use of national aggregate data. With provincial level data, panel data techniques could be utilized in future studies.

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