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RESEARCH ARTICLE

Carbon emission reduction potential of renewable energy, remittance, and technological innovation: empirical evidence from China

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Abstract

Although the effects on environmental quality have not yet been extensively studied, some studies demonstrate that renewable energy, remittances, and technical innovations contribute to a country's socioeconomic development. The current study utilizes annual data from 1990 to 2020 to evaluate the impact of renewable energy, remittances, and technical innovation on carbon dioxide (CO_2) emissions in China. By using the autoregressive distributed lag (ARDL) bounds testing, the research was able to reveal persistent associations between CO_2 and the regressors. Long- and short-run ARDL results also demonstrated that CO_2 emissions rise alongside economic development, but the using renewable energy, remittances, and technical advancement help to lower emissions in China. The reliability of these results was determined using fully modified ordinary least squares (FMOLS), dynamic ordinary least square (DOLS), and canonical cointegrating regression (CCR). Considering these significant determining, several policy suggestions are proposed.

Keywords: Carbon emission; Climate change; Renewable energy; Remittance; Technological innovation; Sustainable development

Introduction

The world is becoming more aware of environmental issues as the negative effects of environmental degradation become more noticeable (Raihan et al., 2018; Jaafar et al., 2020; Isfat & Raihan, 2022). It is because of this realization that countries are finally beginning to take action to reduce environmental destruction (Raihan et al., 2021a; Islam et al., 2022; Voumik et al., 2022a). Because ecological decline is a given result of economic growth, swift implementation of environmental regulations is challenging for policymakers (Begum et al., 2020; Raihan et al., 2021b; Raihan & Said, 2022). Therefore, macroeconomists and environmentalists alike devote their research efforts to understanding the interplay between the two (Voumik et al., 2022b). However, policymakers are still on the hunt for environmentally friendly options that will have the least impact on economic metrics (Raihan & Tuspekova, 2022a). Both developing and developed countries have spent time and resources over the years searching for answers to the environmental degradation that has led to global warming and climate change (Raihan et al., 2019; Raihan et al., 2022a). Despite having signed the Paris agreement, many countries are in danger of failing to meet their carbon reduction targets because of their focus on economic growth (Raihan et al., 2022b). A number of reports have highlighted the role that various factors, such as a flourishing economy, renewable energy sources, and cutting-edge technology, can play in lowering emissions (Raihan & Tuspekova, 2022b; Raihan & Tuspekova, 2022c).

Since the structure of production and, thus, the economy is centered mostly on fossil fuels for several nations, the earlier-mentioned studies are often feasible in terms of the efficient use of energy and the transition from fossil sources to renewable sources (Raihan et al., 2022c). Due to the high prices associated with investing in technology to improve energy efficiency and diversify the portfolio of renewable energy, the financial sector is seen as a critical resource in supporting environmental expenditures. As a result, there has been a surge in recent years in the number of studies devoted to identifying the causes of environmental degradation (Raihan et al., 2022d; Raihan et al., 2022e; Raihan & Tuspekova, 2022d). Aid for development is a crucial resource for countries that want to finance ecological investments with public funds (Wang et al., 2021; Raihan et al., 2022e). Yet, those who oppose public spending argue that subsidies like these only serve to expand the private sector and drain the economy. The value of remittances as financial aid is underappreciated. As a fundamental part of the global financial system, they aid in reducing environmental damage (Wang et al., 2021).

Since remittance's effects on the ecosystem occur indirectly through several paths, there are not many studies on the connection between the environment and remittance. The increase in remittances, which boosts individuals' discretionary money, enables the first route. Increasing wealth has negative effects on the environment because more people can afford to buy things that take a lot of energy. Conversely, an increase in disposable income stimulates the economy by simultaneously increasing the number of people working and the quantity of goods produced (Ahmad et al., 2019). The environmental impact of increased output due to economic expansion varies with the level of economic development. The second path analyzes the impact of remittances on household spending. Increased production and consumption both lead to a spike in energy consumption. As the need for energy grows, so does the likelihood that it will pollute the environment (Raihan et al., 2022f). A third option arises when more money is moved from remittances into the banking system.

An intricate process of transmission was developed, with room for expansion via additional variables concerning the environment and remittances (Ahmad et al., 2019). One common belief is that migrants can use the extra cash in their pockets as a result of remittances to further their education. A better understanding of environmental issues, gained via education, may help curb practices that contribute to pollution. One potential source that is often overlooked is international trade. An overvalued currency can hurt a country's competitiveness internationally because of remittances by revealing a public moral hazard problem and limiting the range of exports. Finally, as remittances are an important source of financing for developing countries, sponsoring initiatives with a focus on promoting renewable energy technology modifies their environmental repercussions (Wang et al., 2021). Recognizing the complex interplay between remittances and other factors influencing environmental conditions is, thus, essential.

In the face of rising CO_2 emissions, China plans to embark on a low-carbon transition by working toward carbon neutrality by 2060. China has ratified the Paris Agreement under the UNFCCC and agreed to adopt CO_2 emission-reduction measures to meet the applicable targets for addressing climate change, adding to its domestic commitment to cut CO_2 emissions. At the recently concluded COP26 in Glasgow, China revised its earlier vow to phase out coal use, instead promising to minimize coal usage. Since China has set a target of reaching carbon neutrality by 2060, this adjustment reflects the country's position that CO_2 emissions will peak by 2030 and steadily fall. However, in order to reach carbon neutrality by 2060, the country has pledged to diversify its national energy portfolio by increasing the share of renewables (wind and solar) and decreasing the share of coal. To attain carbon neutrality, economies around the world are searching for the necessary components to decouple CO_2 from economic growth (Raihan et al., 2022g). To further this goal, China plans to use targeted decoupling strategies. Specifically focusing on the 2060 carbon-neutrality goal, it is committed to achieving these interconnected objectives through the implementation of novel efforts to create a modern energy system. This modernization is expected to take the form of a shift to clean energy, increased energy efficiency, and reduced reliance on fossil fuels for power production (Raihan et al., 2022h). Applying cutting-edge technologies across the board, not just in the energy sector, might be seen as an innovative strategy for achieving low-carbon growth in China.

Currently, technological advancement is the most significant contributor to mitigating global climate change (Raihan & Tuspekova, 2022b). The improvement of environmental legislation has resulted in a steady growth of direct environmental technologies to lower CO_2 emissions (Chen & Lee, 2020). Technological innovation plays a significant role in the economic restructuring and optimization process. It is changing conventional economic development from a production-driven mode to an innovation-driven mode aids in reducing CO_2 emissions generated by industrialization (Raihan et al., 2022b). Furthermore, technological innovation is regarded as a vital element in improving the energy efficiency of a country (Raihan et al., 2022e). Advanced technologies enable the economy to achieve a certain amount of production while consuming less energy (Raihan et al., 2022f). In addition, technical progress allows the economy to transition from depletable to renewable energy sources to fulfill energy demands. As a result, technological innovations cut energy consumption and CO_2 emissions from the burning of fossil fuels (Raihan et al., 2022h). Technological innovation may help alter and upgrade China's industrial structure, and it is an important source of driving force for high-quality economic growth. Therefore, researching the influence of technological innovation on environmental sustainability is critical both theoretically and practically for increasing China's economic growth and lowering carbon emissions.

Given these circumstances, the primary objective of this study is to draw conclusions about the potential effects of economic growth, renewable energy use, remittances, and technological innovation to reduce CO_2 emissions in China. There are three ways in which this study can enrich the current body of literature and inform policy decisions. In the first place, this study is innovative because it makes an original effort to shed light on the connection between remittances and CO_2 emissions by assessing the reduction potential of remittances. Second, we used a range of diagnostic tests and cointegration regression models (ARDL, DOLS, FMOLS, CCR) to ensure the accuracy of our findings. Finally, the study concluded with proposals and recommendations for developing effective policies on reducing emissions and promoting sustainable development. The findings of this study will be useful to researchers, politicians, environmentalists, and governments in their efforts to develop an eco-friendly ecosystem through the responsible use of economic growth and remittances.

Literature Review

The effects of economic growth and remittances on CO_2 emissions have been documented in numerous empirical investigations. A variety of research including several countries, factors, and methodologies were considered. Zafar et al. (2022) investigated the connection between remittances, economic expansion, and CO_2 emissions from 1986 to 2017. The findings demonstrated that, in contrast to economic expansion, which increases CO_2 emissions, remittances help to slow down ecological deterioration by negatively affecting emissions. In Pakistan and Bangladesh from 1980 to 2016, Wang et al. (2021) investigated the relationship between CO_2 emissions, remittances, and economic growth. Remittances, GDP, and CO_2 emissions have a long-term relationship that was predicted using the panel cointegration approach. Its findings revealed that economic growth and an improvement in remittances received both helped the panel's chosen nations' emissions to decline. On the other hand, the short-run ARDL study showed that a rise in economic growth and remittance inflow led to a significant increase in CO_2 emissions. Additionally, Neog and Yadava (2020) examined the relationship between remittances and CO_2 emissions. The study looked at how remittances, economic development, and CO_2 were related in India in asymmetric ways between 1980 and 2014. The findings showed that a positive surprise in remittances led to an increase in CO_2 emissions, as opposed to a negative shock. In addition, Yang et al. (2020) compared CO_2 emissions, economic growth, and remittances in a selection of G-20 countries using annual data from 1990 to 2019. A selection of G-20 countries' economic growth and CO_2 emissions were positively correlated, according to two models. Furthermore, it was discovered through research that remittances greatly decreased CO_2 emissions.

Renewable energy sources including wind, hydro, solar, and many others have gained appeal as an eco-friendly alternative to traditional fuels like coal, gasoline, and oil. These forms of energy have the potential to deliver non-carbon clean energy at levels comparable to those given by carbon-based energy while simultaneously reducing atmospheric concentrations of greenhouse gases. Over the past few years, numerous research have been conducted to understand how and to what extent the use of renewable energy can reduce carbon dioxide emissions. For instance, Raihan and Tuspekova (2022a) reported a positive relationship between economic growth and CO_2 emissions while a negative relationship between renewable energy use and CO_2 emissions in Peru utilizing the data over 1990-2018. By using an advanced panel quantile regression model, Azam et al. (2022) reported a positive relationship between economic growth and CO_2 emissions, and a negative relationship between renewable energy and CO_2 emissions in the top-five emitter countries, covering the data from the period from 1995 to 2017. By utilizing data from 1990 to 2019, Raihan et al. (2022g) reported a positive relationship between economic growth and CO_2 emissions, and a negative relationship between renewable energy and CO_2 emissions in Argentina. Zoundi (2017) analyzed the relationship between CO_2 emissions and the utilization of renewable energy in 25 African economies from 1980 to 2012. Raihan and Tuspekova (2022e) utilized data over 1990-2019 and reported that economic growth increases CO_2 emissions while renewable energy reduces CO_2 emissions in Nepal. According to Cherni and Jouini (2017), renewable energy use reduced CO_2 emissions as Tunisia's economy grew, while the use of fossil fuels increased emissions. Raihan and Tuspekova (2022f) reported a positive association between economic growth and CO_2 emissions, and a negative relationship between renewable energy consumption and CO_2 emissions in India over the period 1990-2020. Chen et al. (2019) reported that the use of renewable energy sources is inversely related to China's CO_2 emissions between 1980 and 2014. By using data over 1990-2019 for Brazil, Raihan and Tuspekova (2022g) found a positive relationship between economic growth and CO_2 emissions while a negative link between renewable energy consumption and CO_2 emissions. Liu et al. (2017a) utilized time data over 1992-2013 to establish a negative association between renewable energy use and CO_2 emissions in the BRICS countries. Furthermore, by using time data over 1970-2013, Liu et al. (2017b) revealed a positive association between economic growth and CO_2 emissions while a negative association between renewable energy use and CO_2 emissions in Indonesia, Malaysia, the Philippines, and Thailand.

Furthermore, the relationship between technological innovation and CO_2 emissions has been examined comprehensively in recent years as increased research and development (R&D) spending can enhance economic production efficiency and resource usage efficiency. Technological advancements are expected to have a major effect on pollution reduction. With the help of environmental protection programs, new technologies have reduced CO_2 emissions and improved environmental performance in many countries. Previous research shows that a lot of focus has been placed on the potentially positive effect of technological innovations on CO_2 emissions. Most academics choose patents as a measure for technological innovation because they protect company and intellectual property rights that help create technologies to address environmental problems. According to Chen and Lee (2020), technical innovation in high-income nations efficiently decreases CO_2 emissions and is thus considered environmentally beneficial green technology innovation. Several studies have shown that technological innovation reduces CO_2 emissions. Raihan et al. (2022b) utilized time data over 1990-2019 to establish a positive association between economic growth and CO_2 emissions while a negative association of renewable energy use and technological innovation with CO_2 emissions in Malaysia. In addition, by using time data over 1990-2020, Raihan et al. (2022f) reported a positive link between economic growth and CO_2 emissions whereas a negative relationship of renewable energy use and technological innovation with

CO_2 emissions in Indonesia. According to Shahbaz et al. (2020), China's technological innovation efficiency have a significant positive impact on environmental performance. Raihan et al. (2022h) reported a positive association between economic growth and CO_2 emissions while a negative association of renewable energy use and technological innovation with CO_2 emissions in Bangladesh. Ahmed et al. (2016) reported that technological innovation improves environmental quality by reducing CO_2 emissions in 24 European nations. Furthermore, Raihan and Tuspekova (2022b) revealed the positive effects of economic growth on CO_2 emissions, and the negative effects of renewable energy use and technological innovation on CO_2 emissions in Kazakhstan utilizing the data over 1996-2018. It is now commonly acknowledged that technical advancements play a significant role in lowering emissions while maintaining economic growth; as a result, any improved understanding of the process of technological innovation is likely to expand our knowledge of mitigation options.

Despite the promising economic growth and remittances in China, the mechanisms of knowledge accumulation remain a mystery, and the true potential of renewable energy use and technological innovation to reduce CO_2 emissions is yet unknown. Therefore, the present study intends to fill up the existing literature gap in the case of China by examining the CO_2 emission reduction potential of economic growth, renewable energy, remittances, and technological innovation using several econometric approaches.

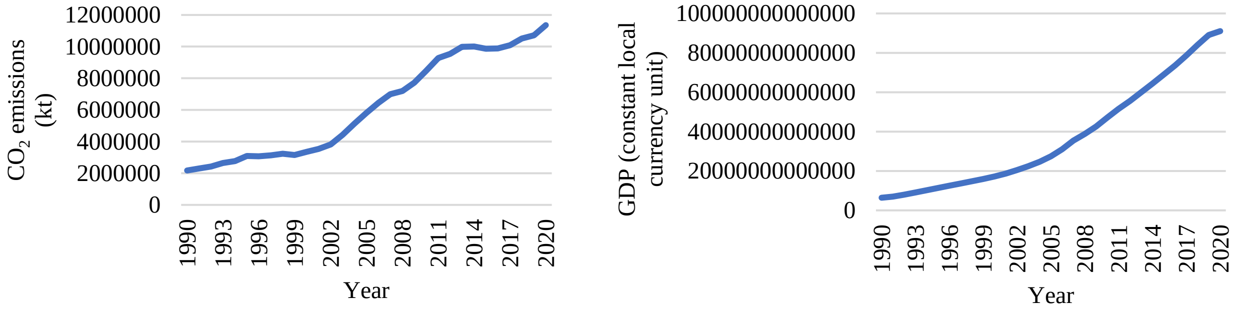
Methodology

Data

Using annual data from 1990 to 2020, this study investigated the impact of economic growth, renewable energy, remittances, and technological innovation on China's CO_2 emissions. The information came from the World Bank's World Development Indicators (WDI) (World Bank, 2022). The variable names and their measurement unit are presented in Table 1. All the variables were logged to ensure conformity to normality. Moreover, the annual trend of the study variables is presented in Figure 1.

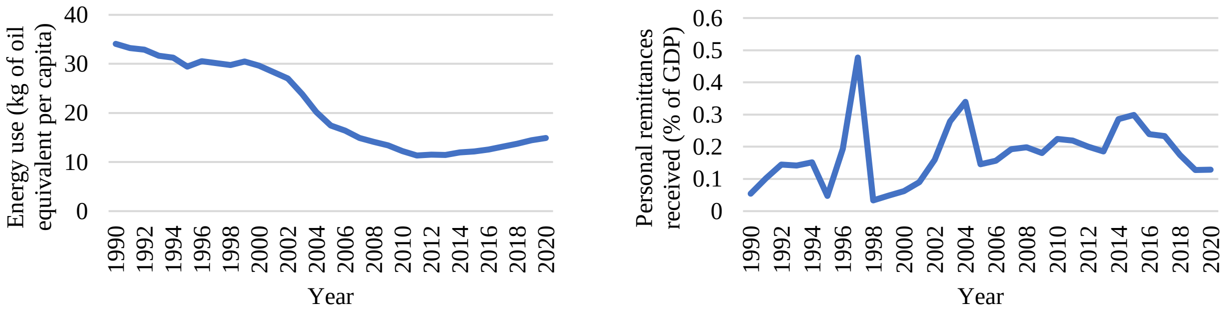
Table 1. Variables with description

Variables	Description	Logarithmic structures	Measurement	Sources
CO_2	CO_2 emissions	LCO2	Kilotons	WDI
GDP	Economic growth	LGDP	GDP (constant local currency unit)	WDI
RE	Renewable energy	LRE	% of total final energy consumption	WDI
RM	Remittance	LRM	Personal remittances received (% of GDP)	WDI
TI	Technological innovation	LTI	Number of patent applications	WDI



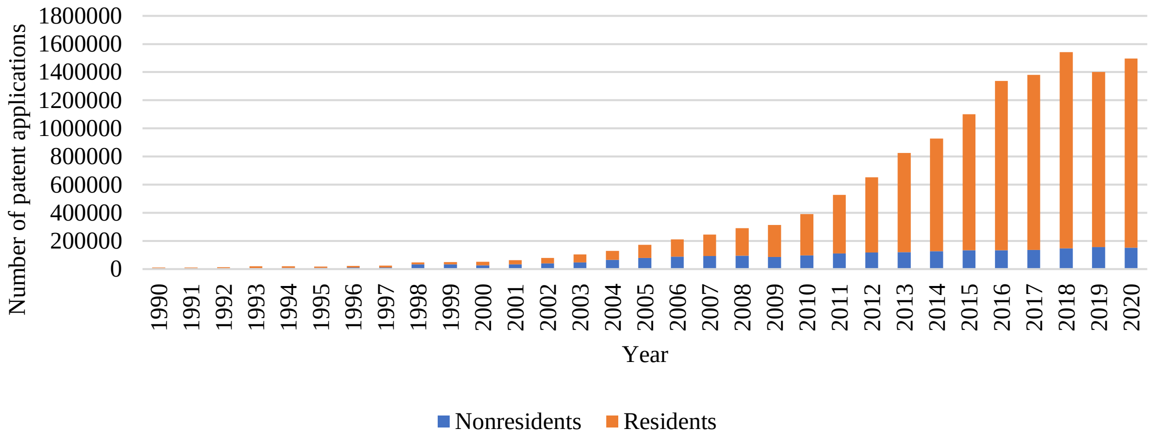
(a) CO_2 emissions

(b) Economic growth



(c) Renewable energy

(d) Remittance



(e) Technological innovation

Figure 1. Annual trends of the study variables

The results of multiple normality tests are shown alongside a description of the data in Table 2. Aside from LRE, all the other variables have skewed-down values. It was clear that the dataset was normal because the skewness values were near to zero. In addition, kurtosis values below 3 were indicative of platykurtic variables. All the variables are normally distributed, as shown by the Jarque-Bera and probability values.

Table 2. Statistical summaries of the variables

Variables	LCO2	LGDP	LRE	LRM	LTI
Mean	15.49228	30.94357	2.972484	-1.885070	11.92112
Median	15.57761	30.94626	2.858766	-1.743394	12.06294
Maximum	16.24519	32.14215	3.528817	-0.739770	14.24859
Minimum	14.59178	29.48701	2.428336	-3.398328	9.223947
Std. Dev.	0.568082	0.830101	0.418653	0.619149	1.688196
Skewness	-0.113307	-0.134554	0.049932	-0.761010	-0.075365
Kurtosis	1.418219	1.752156	1.258076	2.134028	1.623464
Jarque-Bera	3.298122	2.104814	2.932183	2.015410	2.476864
Probability	0.192230	0.349096	0.140003	0.221418	0.289838

Strategies for Estimation

This investigation started with the data on all the important factors. In this study, the empirical model was then defined by drawing on previous studies. Several cutting-edge econometric techniques were applied to the defined empirical model to produce trustworthy findings for use in policymaking. Because of this, the stationarity property of the time series data was the initial focus of the inquiry. When the integration order of the series was defined, the study confirmed the stated model's long-term relationship. Following is our econometric model formulation for this investigation.

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 RE_t + \tau_3 RM_t + \tau_4 TI_t + \varepsilon_t \qquad (1)$$

where τ_1, τ_2, τ_3, and τ_4 represent the coefficients of the regressors. Moreover, εt represents an error term.

The analysis followed the method proposed by Pesaran et al. (2001), known as the ARDL model, as an effective estimating methodology to expose both short- and long-term relationships among the parameters of the specified model. This method has many advantages over the previous cointegration methods. The integration property of a series needed to be discovered before employing other cointegration procedures, whereas this method did not necessitate any such preliminary testing. By considering the lag length of the variable, the ARDL model can be utilized to account for endogeneity. Second, it is applicable in any investigational series integration scenario. Finally, the ARDL model maintains validity even with a little number of observations (Raihan & Tuspekova, 2022e). As indicated in Equation (2), the ARDL bound testing strategy can be written using the econometric model given in Equation (1).

$$\begin{aligned}\Delta LCO2_t = {} & \tau_0 + \tau_1 LCO2_{t-1} + \tau_2 LGDP_{t-1} + \tau_3 LRE_{t-1} \\ & + \tau_4 LRM_{t-1} + \tau_5 LTI_{t-1} \\ & + \sum_{i=1}^{q} \gamma_1 \,\Delta LCO2_{t-i} + \sum_{i=1}^{q} \gamma_2 \,\Delta LGDP_{t-i} \\ & + \sum_{i=1}^{q} \gamma_3 \,\Delta LRE_{t-i} + \sum_{i=1}^{q} \gamma_4 \,\Delta LRM_{t-i} \\ & + \sum_{i=1}^{q} \gamma_5 \,\Delta LTI_{t-i} + \varepsilon_t \end{aligned} \qquad (2)$$

The short-run coefficient needs to be captured once the long-term relationship between series has been established. So, as indicated in Equation (3), we assessed the error-correction model and glean the short-run coefficients.

$$\begin{aligned}\Delta \mathrm{LCO2}_t = {} & \tau_0 + \tau_1 \mathrm{LCO2}_{t-1} + \tau_2 \mathrm{LGDP}_{t-1} + \tau_3 \mathrm{LRE}_{t-1} \\ & + \tau_4 \mathrm{LRM}_{t-1} + \tau_5 \mathrm{LTI}_{t-1} \\ & + \sum_{i=1}^{q} \gamma_1\, \Delta \mathrm{LCO2}_{t-i} + \sum_{i=1}^{q} \gamma_2\, \Delta \mathrm{LGDP}_{t-i} \\ & + \sum_{i=1}^{q} \gamma_3\, \Delta \mathrm{LRE}_{t-i} + \sum_{i=1}^{q} \gamma_4\, \Delta \mathrm{LRM}_{t-i} \\ & + \sum_{i=1}^{q} \gamma_5\, \Delta \mathrm{LTI}_{t-i} + \theta \mathrm{ECT}_{t-1} + \varepsilon_t \end{aligned} \tag{3}$$

The error-correction dynamics and long-term linkages between the series are displayed in the aforementioned equation. The lag length of the series is denoted by q in Equations (2) and (3), and Δ stands for the first difference operator. In addition, ECT stands for the error correction term, and θ is the ECT's coefficient.

As a robustness evaluation, we also employed the FMOLS, DOLS, and CCR on the stated model to look at how different factors throughout time affected the CO_2 output. There were two main factors that prompted the need to employ these methods. To begin, the cointegration condition among the I(1) parameters must be satisfied before the FMOLS, DOLS, or CCR may be used. Second, these methods deal with endogeneity and serial correlation biases that arise from the cointegration relationship. As a result, it yields outcomes with asymptotic efficiency (Raihan & Tuspekova, 2022f; Raihan & Tuspekova, 2022g). The analysis flowchart is shown in Figure 2.

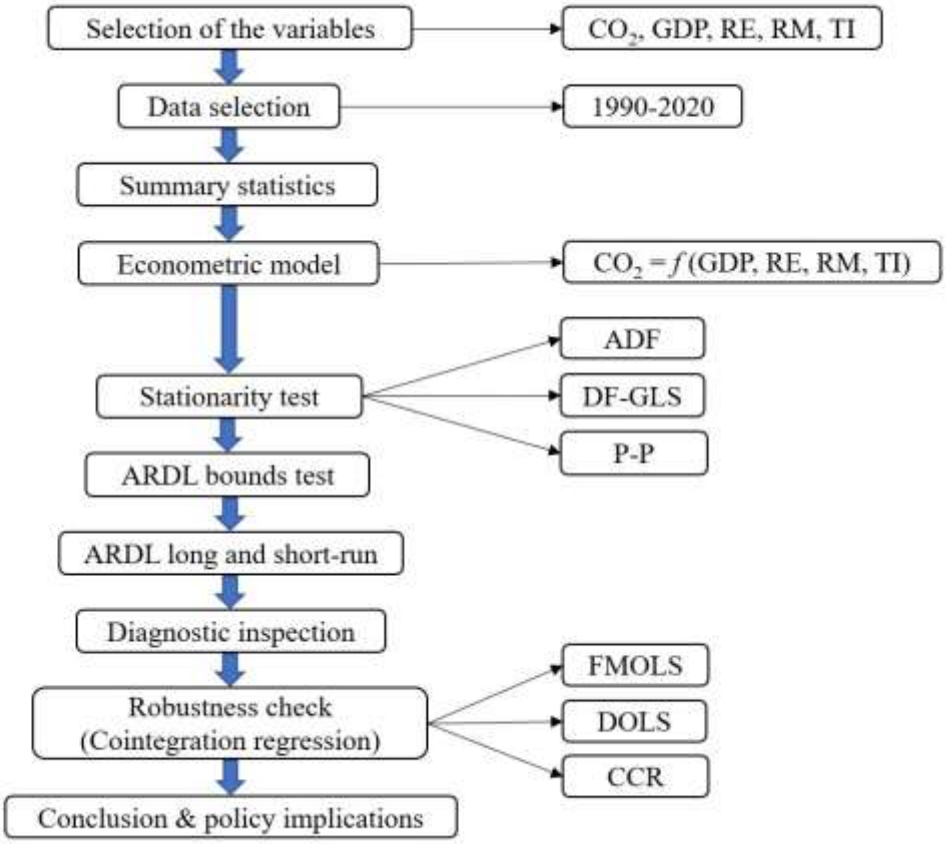


Figure 2. The analysis flowchart

Results and Discussion

The fundamental goal of this study was to investigate the development of a lasting connection between the series under consideration. The evaluation of the unit root test provides crucial information on the integration characteristic of the parameters, which is necessary for employing the approaches in the creation of a long-term interrelationship (Raihan & Tuspekova, 2022h). Therefore, the integration qualities of the series were investigated using a battery of conventional root tests, including the ADF, DF-GLS, and PP tests. The findings of the stationarity test are summarized in Table 3. According to the canonical tests of unit root output, all variables exhibited the unit root problem at level before becoming stationary after the first difference.

Table 3. Unit Root test results

Logarithmic form of the variables	ADF		DF-GLS		PP	
	Log levels	Log first difference	Log levels	Log first difference	Log levels	Log first difference
LCO2	-0.8829	-2.8147**	-0.0448	-2.8654***	-0.9402	-2.9203**
LGDP	-0.6012	-2.4312**	-0.8286	-2.5336**	-0.7498	-2.9232**
LRE	-1.4653	-2.9182***	-1.1148	-2.9076***	-1.1832	-2.9214***
LRM	-0.5267	-3.9012***	-0.6062	-3.1304***	-0.7682	-3.9222***
LTI	-1.0675	-5.1546***	-1.0832	-5.1112***	-1.1694	-5.1609***

The significance levels depicted by *, **, and *** are 1%, 5%, and 10% respectively.

Based on our unit root observations, we found that the series under examination is an I(1) series. Therefore, we used the ARDL-based bounds test technique to evaluate the long- and short-term connections between the series under investigation. Our model's consistent results from each alternative's information criterion led us to settle on the AIC as our lag specification. Table 4 shows that the calculated F-statistic (6.94) for the cointegration analysis is significantly higher than the upper critical threshold. We, therefore, conclude that the independent variable and the regressors are cointegrated.

Table 4. ARDL bounds test results

F-bounds test		Null hypothesis: No degrees of relationship		
Test statistic	Estimate	Significance	I(0)	I(1)
F-statistic	6.942595	At 10%	2.57	3.86
K	5	At 5%	2.86	4.19
		At 2.5%	3.13	4.46
		At 1%	3.43	4.79

Table 5. ARDL long and short-run results

Variables	Long-run			Short-run		
	Coefficient	t-Statistic	p-value	Coefficient	t-Statistic	p-value
LGDP	1.183***	2.342	0.002	0.369***	2.428	0.001
LRE	-0.881***	-3.671	0.000	-0.911**	-3.713	0.013
LRM	-0.754**	-1.467	0.029	-0.667**	-1.376	0.032
LTI	-0.445*	-1.672	0.059	-0.013*	-1.002	0.061
C	19.113	4.494	0.111	-	-	-
ECT (-1)	-	-	-	-0.464	-3.214	0.000
R^2	0.9913					
Adjusted R^2	0.9854					

The significance levels depicted by *, **, and *** are 1%, 5%, and 10% respectively.

Table 5 displays the findings of the ARDL long- and short-run estimation. The empirical results demonstrated a positive and statistically significant coefficient of LGDP, which means that a 1% increase in GDP leads to a 1.18% (long-term) and 0.37% (short-term) increase in CO_2 emissions, respectively. In assertion, China's rapid economic development has negative effects on the environment both immediately and over the long term. In addition, the coefficient of LRE was negative and statistically significant, indicating that a 1% increase in the usage of renewable energy might lead to a 0.88% (long-term) and 0.91% (short-term) reduction in CO_2 emissions. Inferences about renewable energy being beneficial to environmental sustainability were drawn from the outcome. The coefficient of LRM was also negative and statistically significant, showing that an increase of 1 percentage point in LRM results in a decrease of 0.75 percentage points in CO_2 emissions in the long run and 0.67 percentage points in the short run. Both the short-term and the long-term estimates showed that remittances to China have a positive effect on environmental sustainability. In addition, the coefficient of LTI was negative and statistically significant, suggesting that a 1% increase in LTI contributes to the reduction of CO_2 emissions by 0.45% (long-term) and 0.01% (short-term). The results showed that if China invests more in technical innovation, it may be able to slow the rate of environmental deterioration.

The ECT was also found to have very detrimental results. This estimate of 0.464 showed how the short-run equilibrium evolved as it moved toward a stable long-run equilibrium, with annual adjustments of 46%. It demonstrated the value of the feedback system in maintaining stable CO_2 emissions in China. Finally, there was no evidence of serial correlation or heteroskedasticity in the residuals, and the residuals followed a normal distribution without any signs of misspecification, as shown in Table 6 of the diagnostic test findings. Figure 3 further displays the results of the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) stability tests, which demonstrated the model's stability at the 5% significance level.

The findings of the ARDL framework were also tested over the long term with the help of the FMOLS, DOLS, and CCR tests. Table 7 displays the projected results from the use of FMOLS, DOLS, and CCR. The sign and reliability of the FMOLS, DOLS, and CCR results were all shown to be consistent and dependable. This causes them to produce the same results as the ARDL simulations in the long term. Specifically, the data showed that increasing GDP increased CO_2 while increasing renewable energy, remittances, and technical innovation decreased CO_2 emissions. As a result, decisions can be made with an element of certainty based on the findings.

Table 6. Diagnostic tests results

Diagnostic tests	Coefficient	p-value	Decision
Serial Correlation	1.8972	0.277	No serial correlation exits
Heteroskedasticity Test	1.2356	0.187	No heteroscedasticity exists
Normality Test	0.9235	0.234	Residuals are normally distributed

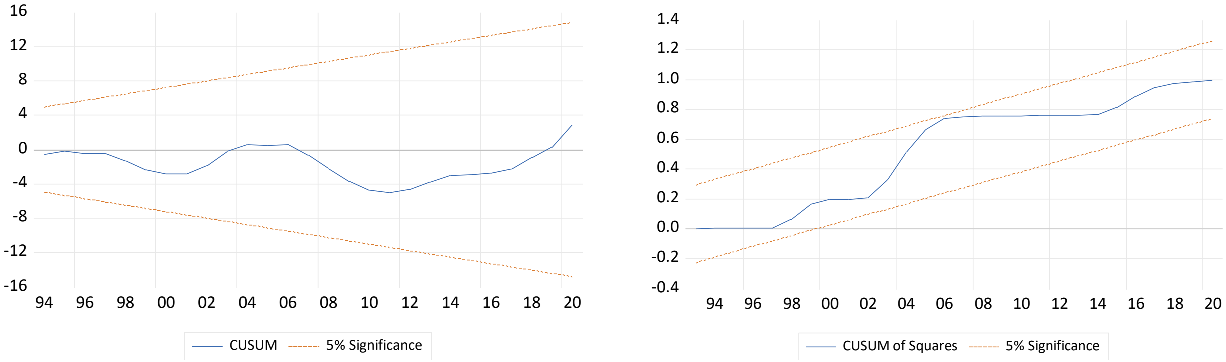


Figure 3. Results of the CUSUM and CUSUMQ test

Table 7. Results of the robustness check

Variables	FMOLS		DOLS		CCR	
	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
LGDP	1.124***	2.418	1.132***	2.154	1.211***	2.223
LRE	-0.819***	-3.864	-0.798***	-3.156	-0.818***	-3.369
LRM	-0.881**	-1.436	-0.862***	-1.723	-0.895***	-1.121
LTI	-0.234*	-1.478	-0.493**	-2.154	-0.359**	-1.953
C	21.713	3.982	19.699	3.294	20.801	3.815
R^2	0.9956		0.9943		0.9967	
Adjusted R^2	0.9813		0.9801		0.9809	

The significance levels depicted by *, **, and *** are 1%, 5%, and 10% respectively.

The present study's result show that as the economy grows, so does the incentive to increase CO_2 emissions, as measured by the gross domestic product (GDP). This indicates that China's efforts to stimulate its economy through techniques that aren't environmentally friendly are counterproductive to the country's efforts to achieve carbon neutrality. This result is consistent with the claims made by Liu et al. (2017b), Azam et al. (2022), Raihan et al. (2022b), Raihan et al. (2022f), Raihan et al. (2022h), Raihan and Tuspekova (2022b), Raihan and Tuspekova (2022e), Raihan and Tuspekova (2022f), Raihan and Voumik (2022), Raihan and Tuspekova (2022g), Raihan et al. (2022g), Raihan and Tuspekova (2022i), and Zafar et al. (2022) in which the authors argued that economic development degrades environmental quality. The availability of affordable, reliable energy sources is also crucial to the success of any economy (Raihan & Tuspekova, 2022j). It's a primary factor in both the final product and the final consumer. There is no denying the importance of energy to people's day-to-day lives. Thus, we included renewable energy sources to test their potential impact on the model's projected CO_2 output. Findings demonstrated that adjustments in China's use of renewable energy resulted in lower CO_2 emissions. Our findings are supported by Liu et al. (2017a), Zoundi (2017), Chen et al. (2019), Liu et al. (2017b), Azam et al. (2022), Raihan et al. (2022b), Raihan et al. (2022f), Raihan et al. (2022h), Raihan and Tuspekova (2022b), Raihan and Tuspekova (2022e), Raihan and Tuspekova (2022f), Raihan and Tuspekova (2022g), Raihan and Voumik (2022), Raihan and Tuspekova (2022k), and Raihan et al. (2022g) who reported that green energy improves environmental conditions.

The present study's result on the negative association between remittances and carbon emissions is in line with the results of Zafar et al. (2022), Wang et al. (2021), Yang et al. (2020) and Ahmad et al. (2019). An increase in remittances in this example has resulted in lower CO_2

emissions through scale-dependent consequences in the production process, namely, a shift toward energy-efficient inputs at the small and medium enterprises (SME) and industrial levels. A person's disposable income can be increased by receiving remittances. Doubtlessly, a household's newfound financial flexibility can be put to use in one of two ways. The first is concerned with financial outlays, and the second is with financial reserves. When the spending pattern is in place, the demand for goods rises, influencing the manufacturing sector and, by extension, the demand for energy. When consumers are actively saving, they spend more of their increased income on interest payments to financial organizations. These businesses lend the money they have raised to industrial groups in order to make interest revenue, which again results in indirect energy consumption. Our results show that, when all the data is considered, remittances tend to move in the direction of renewable energy sources.

Findings from this study indicated that technological progress was inversely related to carbon dioxide emissions. These results stress the need for the government to invest in new technology for the country's manufacturing sector in order to create a setting that is receptive to industrial change. These findings provide essential data for designing policies that adhere to the resolutions adopted at the global climate change conference. The present study's finding is aligned with the previous studied. For example, Ahmed et al. (2016), Raihan et al. (2022b), Chen and Lee (2020), Raihan and Tuspekova (2022b), Raihan and Voumik (2022), Raihan et al. (2022f), Raihan et al. (2022h), and Shahbaz et al. (2020) demonstrated how new technologies can aid in cutting down on carbon dioxide emissions. On the other hand, the results of our study provide useful insight for policymaking and may be trusted because they were derived from state-of-the-art research techniques. These findings can serve as a foundation around which China can build its future technological advancements and environmental policies.

Conclusions and Policy Implications

Using data from 1990 to 2020, this study analyzed the impact of economic growth, renewable energy, remittances, and technical innovation on China's CO_2 emissions. For this reason, the investigation used the FMOLS, DOLS, and CCR long-run estimators in addition to the ARDL model to ensure the reliability of the findings. The economic expansion increases CO_2 emissions, but renewable energy, remittances, and technical innovation reduce CO_2 emissions over the long term, as shown by the outcomes of the ARDL, FMOLS, DOLS, and CCR. There may be major policy implications resulting from this study's conclusions. The study's finding of an inverse relationship between emissions and remittances may motivate governments to take steps to mitigate remittances' detrimental effects on the environment. People can be encouraged, for instance, to invest their remittances in energy-efficient household gadgets. In a similar vein, China may tighten up its existing regulations on controlling emissions. In conclusion, the current research suggests expanding ecological quality improvement efforts in response to a rise in remittance payments.

This study has important policy implications, as it recommends that China implement R&D and technology innovation related to its 2060 carbon neutrality aim. The government of China should increase spending on research and development while simultaneously encouraging private sector funding of R&D to develop technologies that improve environmental well-being. For China to achieve low-carbon growth as soon as possible, the government should prioritize the development of green technologies in this area. China should also look ahead to fostering green economic activities in order to gradually eradicate the negative consequences of economic expansion on the ecosystem. Investment in renewable energy facilities, as opposed to new coal power plants, is one suggestion for China to consider.

This investigation found conclusive evidence that using renewable energy sources helps reduce pollution. Renewable energy sources cut emissions in any scenario, regardless of a country's current emission position. However, there are substantial infrastructure requirements for renewable energy. Once implemented, however, these technologies pay for themselves over time. Energy supply stability in China is essential, and it must begin with the use of renewable energy sources because of their lower cost. Therefore, China requires investment in renewable energy. Moreover, investment in green technologies will increase renewable energy, leading to better ecological quality because renewable energy is driven by technological advancements in the fields of biomass, geothermal, wind, and solar. Finally, green growth has not yet begun in China, as environmental deterioration has increased alongside economic development. Right now, transitioning to a green economy is crucial for long-term prosperity. This study suggests Chinese policymakers use the following tools: (i) reducing or eliminating tax cuts to increase remittances; (ii) encouraging and aiding the financial industry in developing internet applications; and (iii) providing training on ecological consciousness to all private and public sectors, especially educational institutions.

Despite the fact that the current study yielded substantial empirical findings in the case of China, our analysis has some flaws that might be addressed in future research. One of the critical drawbacks of our analysis is the unavailability of the data related to renewable energy use and technological innovation beyond the period of study, which limits the power of the econometric techniques used. However, this study has examined the nexus among economic growth, renewable energy use, remittance, technological innovation, and CO_2 emissions in China. Further studies can explore the potential of other determinants of emission reduction, such as increasing forested areas, recycling products, reducing water and electricity use, changing food habits to organic food, etc.

Furthermore, this study utilized CO_2 as an indicator for environmental degradation from GHGs emissions. More research could be done utilizing consumption-based carbon emissions as a proxy for environmental deterioration, as well as other emission indicators, including nitrous oxide (N_2O), sulfur dioxide (SO_2), methane (CH_4), and other short-lived climate forces (SLCF). Nevertheless, CO_2 emission is regarded as a proxy for environmental pollution in this study, which is not the only cause of declining environmental sustainability. Future research might investigate more environmental pollution indicators, such as water pollution, land pollution.

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