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Adaptation to globalization in renewable energy sources: Environmental implications of financial development and human capital in China

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This research article examines the dynamic impact of globalization, environmental quality, and financial development on renewable energy in China. Promoting renewable energy is crucial for solving global environmental problems. In China's case, no such studies investigate the role of renewable energy as a dependent variable in globalization, financial development, and environmental quality. To check cointegration and long-run/short-run dynamics, this study uses Autoregressive Distributed Lag (ARDL) model, which can predict the actual positive and negative change in the independent variables and their effects on the dependent variable. We also used the Johansen cointegration technique to verify the results of bound testing. The results suggest significant long-run and short-run relationships among the study variables. Furthermore, the causality analysis reveals a bidirectional relationship between renewable energy with globalization, financial development, environmental quality, human capital, and economic growth in the long run. In the short run, renewable energy Granger significantly causes economic growth and carbon emissions.

KEYWORDS

globalization, environmental quality, financial development, renewable energy, China

1 Introduction

Renewable energy is the main proponent of a cleaner environment which posits the strategy of offsetting dangerous greenhouse gasses and ensuring sustainability in economic growth and environmental quality. In line with environmental security and economic growth sustainability, different policies mandate the increase of demand for renewable energy usage (Raihan and Tuspekova, A. 2022). Since 2016, globally in many countries, the fastest growth rate up to 45 percent addition of energy supply has been recorded (International Energy Agency, 2013). To attain sustainable development the factor of energy consumption is essential for all countries. The demand for everlasting usage of energy consumption has increased in past decades due to population growth, economic competitiveness, production improvements, and enhanced lifestyle. As a result of the continuously increasing demand for energy, the world's total energy usage has increased by 44 percent during the period from 1971 to 2014 (World Bank, 2022). Renewable energy usage is a potential tool that does not depend on fossil fuel resources, which currently resist actively against energy markets. Moreover, renewable energy overcomes the substantial increase in environmental degradation. Numerous policy reports and empirical research studies emphasize the crucial and indispensable role of renewable energy sources, including wind, geothermal heat, solar, biofuel, and hydropower which are considered diversified sources of energy supply to mitigate energy issues and environmental degradation (Marques et al., 2011; Chen et al., 2014; Ibrahim et al., 2021).

Globalization is the main factor that generates and increases the level of collaboration and interdependence among various countries' economies. Currently, globalization has changed the political dynamics, energy and labor markets, trade, and foreign direct investment among many countries around the world. However, academic researchers have no consensus yet related to the environmental consequences due to such kind of changes and collaborations. There is an ongoing debate by various researchers (Navarro, 1998; Jorgenson and Givens, 2014; Lv and Xu, 2018; You and Lv, 2018; Hassan et al., 2022) Globally, China is playing a leading role in trade system and continuously contributes to the energy sector from past two decades. Among the world's developing countries, China is one of the countries that extensively espoused trade openness and foreign direct investment. However, the process of globalization has increased the environmental degradation concerns in the Chinese economy. On the other hand, the adoption of the globalization process in China has raised *per capita* income and advanced technological knowledge, which contributes to the increase of usage of renewable energy sources to reduce the intensity of environmental degradation. Kaygusuz argued that the promotion of renewable energy brings continuous modernization in the energy sector as well as supports various goals and sustainable economic development of many countries (Kaygusuz, 2007; Hao et al., 2021).

Improvements in energy efficiency and renewable energy development are two main concerns of many countries to address the issues of climate and environmental changes (Cambridge, 2011; Johansson et al., 2012; Conti et al., 2016; Steel, 2016). Renewable energy sources reduce the total energy usage, air pollution, and emissions of greenhouse gasses (GHGs) while ensuring sustainable economic development. Moreover, as an alternative to fossil energy sources, renewable energy can produce a cleaner energy structure (Liu and Li, 2011; Matsuo et al., 2013; Moncada et al., 2013). Over the last three decades, China vastly used energy consumption for higher economic growth. However, currently, it is challenging for the Chinese economy to control extensive consumption of fossil fuel energy sources and environmental destruction because China is the world's largest producer and consumer of total energy consumption. China is also facing international pressure to handle the issues of increasing levels of GHG emissions (Yu et al., 2021). To achieve sustainable GDP growth, China announced in 2009 that they have ambitious goals and policies to lower the intensity of fossil fuel energy through alternative renewable energy sources (National Development and Reform Commission of China, 2010). China established its national plan and pledge it by the latest submission of the United Nations Framework Convention on Climate Change (UNFCCC) to control fossil fuel energy usage and enhance renewable energy consumption by about 20 percent by 2030 (UNFCCC 2015). However, developing alternative RE sources may influence economic growth. Prior academic studies indicate the economic costs and technological costs of establishing roadmaps of long-term alternative energy strategies (Zhou et al., 2011; Johansson et al., 2012; Raihan et al., 2022a).

The transition from fossil fuel sources of energy to alternative renewable energy generation is a challenging issue. The main primary hurdle in the process of transition to renewable energy sources is higher cost. In this regard, a country must have a solid and sound financial system for efficient services of providing funds, price discoveries, and risk management. Moreover, capital allocation can be increased by well-developed financial markets. Investment in growing industries is supported by the highly developed financial system, while investments made in declining industries will undermine the financial system (Wurgler, 2000). Therefore, there is a substantial role in the financial development of an economy where the adaption of investments in renewable energy sources. Now, there is growing literature that develops an interest in the investigation of the determinants and factors involved in the production and consumption of renewable energy. Many empirical studies (Lin and Moubarak, 2014; Jebli and Youssef, 2015; Alper and Oguz, 2016; Inglesi-Lotz, 2016) have examined the association between economic growth and renewable energy consumption. This study has considered financial development as an important determinant of renewable energy consumption.

Human capital is also considered another important determinant of renewable energy. Human capital provides the knowledge needed to understand environmental and energy security issues. Increasing energy efficiency with the help of human capital can achieve the goal of reducing carbon emissions (Jiang and Hu, 2009). The improvement in the quality of education increase the overall environmental quality (Balaguer and Cantavella, 2018). Increasing the quality of education can help raise environmental awareness and reduce harmful emissions. High-level education promotes eco-friendly technology to help reduce carbon emissions Balaguer and Cantavella, 2018.

This work is different as compared to the previous studies in the following ways: (i) to the best of the authors' knowledge, In the case of China, there are no such studies that investigate the role of renewable energy as a dependent variable in globalization, financial development, and environmental quality, (ii) clarify the role of globalization, financial development, and environmental quality in the renewable energy sector due to a lack of evidence in the literature, (iii) this methodology also allows more reliable monitoring of shocks that trigger changes in business cycle processes, (iv) this knowledge has important policy implications for promoting green energy production in China, developing, and implementing sound economic growth and technological innovation policies.

We also contribute to the existing literature on the energy-GDP-globalization-environment nexus by exploring the asymmetric relationship between these variables. As a result of low explanatory power, we applied the (i) Unit Root Test to examine the integration order, along with an unknown structural break, (ii) The VECM Granger Causality test has been applied to test in the series; (iii) we have applied the Autoregressive Distributed Lag (ARDL) model, along with the Granger causality test, to enrich the literature on globalization-GDP and renewable energy. Although the study has used new techniques and methods, however, a major limitation is the duration of the data.

Following is a list of the remaining sections of this study. The literature review is given in Section 2, the data and conceptual framework are presented in Section 3, the results and discussion are given in Section 4, and the conclusions are presented in Section 5, which is devoted to policy implications.

2 Literature review

In the field of energy economics, there have been numerous studies on the nexus between energy consumption, economic growth, and globalization. The nature of different relationships has been explored over the years, and four theories have been proposed to explain the occurrence of this phenomenon. Most of these studies aimed to find the factors of the growth of renewable energy and their causal relationship between energy prices, economic growth, and renewable energy development making up an economic and environmental index.

This literature review will be focused on the following four themes.

2.1 Renewable energy and globalization

Dreher (2006) explained that globalization bears a positive relationship with renewable energy in developed economies around the globe. In the growing phase of economies, globalization encourages investing in green and sustainable technology for the future (Dreher, 2006). The impact of globalization on ecological relations across fifteen countries has been studied by Saint Akadiri et al. (2019). Their research results show that CO_2 emissions positively affect real income, while globalization and consumption of energy influence CO_2 emissions positively (Akadiri et al., 2019).

Globalization and CO_2 emissions were examined in 87 countries by Shahbaz et al., 2019. High- and middle-income economies are expected to lower carbon emissions through globalization in the future. The ecological collapse of low-income economies will be positively affected by globalization (Shahbaz et al., 2019). Doytch and Uctum (2016) analyzed how globalization can have influences environmental degradation. The results of the study indicated that the globalization of financial growth would adversely affect the environment and increase the return on investment. (Doytch and Uctum, 2016). In a study by You and Lv (2018), they explored the relationship between CO2 emissions and globalization, analyzing data from 85 countries from 1985 to 2013. Economic globalization negatively affects CO2 emissions indirectly, but positively impacts environmental degradation when the effects are directly examined (Ozcan and Temiz. 2022).

2.2 Renewable energy and financial development

The economic and financial sources are very vital for sustainable energy development. Renewable energy projects have always attracted considerable investment in the last decade or so, but financing remains a major problem, which often affects financial infrastructure (United Nations Environment Programme et al., 2014). Many studies started focusing on the overall role and growth of financial development in clean/green energies. (Chang et al., 2016) developed a quantitative financial index for sixteen Asian countries for the development of renewable energy. (Paramati et al., 2016) presented the idea to overhaul the capital markets (stock market) and Foreign Direct Investment (FDI), which will be led emerging market economies to get some high-tech technologies for use in clean/green energy production and future usage. Using the data set for the 20 emerging market economies from 1991 to 2012, their model output, FDI, and utilization of green/clean energy have a positive impact on stock market growth. According to their model output, FDI, and stock market development, clean energy use has a significant positive impact in emerging 20 market economies from 1991 to 2012. Using financial and annual reports from 106 renewable energy companies listed in China, Zhang et al. (2016) conducted another study on China. They found evidence of excessive investment in these companies, which means they invest in less profitable projects while having significant cash flow. Their results show that different financial channels are important for the performance of firms. In this sense, the growth and restructuring of financial markets require proper control and institutional design to maintain healthy investment environments (D. Zhang et al., 016).

2.3 Renewable energy and economic growth

The role of energy consumption structure in China's economic growth and other factors affecting economic reforms has been explored in recent studies (Liu and Li, 2011). In their Computer General Equilibrium (CGE) model, Wei Liu and Li demonstrate that eliminating coal and oil subsidies will lead to an improvement in China's energy consumption structure. A 3% reduction in coal subsidies will lead to a 1.76% increase in fossil fuels. Researchers Shahbaz et al. (2013) used an uncontrolled error correction model to investigate the long-standing relationship between economic growth, growth, capital, trade, and energy use in China. In general, increased energy demand is accompanied by economic growth, which heightens emissions and dependence on energy. Shahbaz et al. (2013) recommend China invest in renewables and improve energy efficiency in the long run. Farhani and Shahbaz (Farhani and Shahbaz, 2014) examined the data period between 1980 and 2009 in 10 MENA countries, and they studied the basic link between conventional and non-conventional energy, emissions, and CO_2 emissions. By using the FMOLS, Pedroni cointegration, and DOLS techniques, results show that the overall level of energy improves CO_2 emissions. Also, long-term Granger causality testing seems to have a bilateral relationship between conventional and unconventional energy and CO_2 emissions. The study (Bölük and Mert, 2014) examined the relationship between renewable energy, development, and the environment Kuznets curve in Turkey using 1961 to 2010 data. CO2 emissions negatively affect renewable energy (excluding hydroelectricity). However, the opposite is short-lived.

2.4 Renewable energy and environmental quality

The impact of energy consumption on the environment can be divided into renewable and non-renewable energy. Panel data or single-country data of time series were used to evaluate these countries' econometric methods and techniques. First, Richmond and Kaufmann (2006) used carbon emissions as a measure of economic growth to separate energy consumption into renewable and non-renewable sources. They examined the data of 36 OCED and Non-OCED countries, using the panel data methodology, from 1973 to 1997. Their estimated evaluations showed that increasing energy consumption from renewable sources reduces carbon emissions and boosts the OECD countries' economic growth. Another study from 2018, used the EKC framework in India to determine the association between CO_2 and renewable energy. According to their findings, the EKC hypothesis existed in India because with the increasing use of renewable energy the overall CO_2 level decreases Sinha and Shahbaz (2018). However, Jin and Kim (2018) used the Granger causality test in their study of thirty countries, their result indicated the bidirectional causal association between carbon emission, nuclear energy, and renewable energy. In twenty-five developing countries, Hu et al. (2018) found similar results. Inglesi-Lotz and Dogan (2018) analyzed the relationship between renewable energy use in Sub-Saharan Africa and environmental quality. Their results indicate a negative and significant relationship between CO_2 emissions and renewable energy. Chen and Lei (2018) used the quantile regression method with 30 countries' data from 1980 to 2014; results indicated the same conclusion. Another study by Chen et al. (2019) in China using data from 1980 to 2014, stated some interesting results. According to their presented results, the EKC hypothesis cannot be established if they exclude renewable energy from the CO_2 function.

2.5 Literature review conclusion

In conclusion, the existing literature (See Table 1) is mostly interested in the development and analysis of overall renewable energy around the world. The evidence is very clear about the positive association between economic growth and renewable energy (Raihan et al., 2022b), but most of these studies used to pool data for developed and under-developed countries. Investing in renewable energy and using sustainable energy is a China priority. China aims to build a green economy through the development of renewable energy (United Nations Environment Programme, 2015). Therefore, most of these studies are not specifically connected with the Chinese economic and renewable energy systems. A literature review raises the following questions: Can renewable energy in China be developed economically, financially, and environmentally? No answer to this question exists in the existing literature. China's specific conditions are not considered in the majority of these studies (cross-country/panel data).

Studies mostly focus on demand or supply but do not model a market as a whole. China needs to update its energy structure, so this study follows a systematic approach. The study provides important information to Chinese policymakers and bridges the gap in the literature.

3 Model and data

This study explores the impact of globalization, environmental quality, and financial development on renewable energy consumption whereby taking human

TABLE 1 Literature review table.

Authors and year	Methods	Topic
Frankel and Romer (1999)	Correlation and Ordinary Least-Squares Estimates	The correlation between trade, income and geographic characteristics
Antweiler et al. (2001)	Model theoretical specification highlighting scale, technique, and composition effects	The association of trade Goods for the Environmental degradations
Dasgupta et al. (2001)	Review of Literature and Commentory	environmental and resource economics
Dreher, (2006)	economic integration, social integration, and political integration	KOF Index of Globalization
Jalil and Mahmud (2009)	Auto regressive distributed lag (ARDL) methodology	The influences of FDI and trade on carbon emissions and energy consumption
Kayhan et al. (2010)		The influence of economic growth on CO_2 emissions
Sadorsky (2011)	GMM estimation approach	The influence of Financial development on energy consumption
Saboori et al. (2012)	The Granger Causality test based on the Vector Error Correction Model (VECM)	The influences of FDI and trade on environmental degradations
Shahbaz et al. (2013)	Bounds testing approach to cointegration between the variables	The influences of FDI and trade on environmental degradations
Çoban and Topcu (2013)	GMM model	The impact of financial development on energy consumption in the EU
Shahbaz et al. (2013)	ARDL bounds testing approach	The links between energy consumption, economic growth, financial development and trade
Lau et al. (2014)	The bounds testing approach and Granger causality methodology	Identify the relationship between economic growth and CO2 emissions for Malaysia
Farhani et al. (2014)	The ARDL methodology	The influences of carbon dioxide (CO2) emissions, output (GDP) on energy consumption
Potrafke, 2015	KOF indices of globalisation	KOF Index of Globalization
Charfeddine and Khediri (2016)	Unit root tests with multiple structural breaks and regime-switching cointegration techniques	The influence of financial growth and use of energy on environmental degradations
Abbasi and Riaz (2016)	ARDL approach	The influence of CO_2 emissions and financial development on environmental degradations
Shahbaz et al. (2016)	Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT)	The association of urbanization and CO_2 emissions
Shahbaz et al. (2015)	The ARDL methodology	Impact of Carbon emissions, energy consumption and economic growth on environmental degradations
Sekantsi et al. (2016)	Autoregressive distributed lag-bounds testing and Granger causality tests	The influence of Electricity consumption–economic growth on CO_2 emissions
Solarin et al., 2017a	Autoregressive distributed lag (ARDL)	The association of hydroelectricity consumption, urbanisation and environmental degradations
You and Lv (2018)	Spatial panel method	The spatial effects of economic globalization on CO_2 emissions and environmental degradations
Khan et al. (2020)	System-generalized method of moments (GMM)	The carbon emissions, poverty, economic growth, and logistics operations
Gygli, Haelg, Potrafke, and Sturm, (2019)	Updated the Dreher et al. (2008) KOF, The new index is based on 43 instead of 23 variables in the previous version	KOF Globalisation Index—revisited
Dauda et al. (2020)	panel fully modified ordinary least square (FMOLS) and panel dynamic ordinary least square (DOLS)	The effects of economic growth and innovation on CO_2 emissions

capital and economic growth as control variables. In this research annual time series data from 1970 to 2016 were utilized for the case of China. Table 2 explained the detailed description of each variable used in this study. Data for CO2, FD, GDP, HC, and RE were collected from WDI (World Bank, 2022) and data for the economic globalization index was taken from the study of Dreher (2006) KOF Index of Globalization (Dreher, 2006; Gygli et al., 2019). The following model expresses the determinants of renewable energy consumption:

$$\ln RE = f(\ln G, \ln FD, \ln GDP, \ln HC, \ln CO2) \quad (1)$$

where RE stands for renewable energy consumption, G denotes globalization, HC represents human capital, FD stands for financial development and CO2 represents carbon emissions. We have taken a natural log of all the variables to reduce the

TABLE 2 Variables for ARDL model.

Symbol	Variables description	Definition	Units of measurement
RE	Renewable energy consumption	The energy produced from hydro, solar, wind and bio	billion-kilowatt hours
CO_2	Carbon dioxide emissions	Emissions released from using coal, oil, gas and other solid and liquid fuels	Metric tons *per capita*
G	Globalization	Dreher (2006) measured the Economic globalization index is with the trade flow with other countries, FDI and portfolio investment and restrictions on these inflows and outflows	Index
FD	Financial development	Domestic credit provided by financial sector (%of GDP)	% of GDP
HC	Human Capital	Human capital refers to the standard of living of the people by measuring their education, training, knowledge, health, and skills in any country	Index
GDP	GDP *per capita*	Constant 2010 US $	GDP *per capita* (constant 2010 US $)

Data of all variables were taken from World Development Indicators (World Bank, 2022) except globalization index data which is sought from the study of (Dreher, 2006; Gygli et al., 2019).

sharpness in the time series data. Log-linear models offer empirically consistent and efficient results compared to simple linear models. The augmented multivariate production function for the linear log model can be seen below:

$$RE_t = \beta_0 + \beta_1 \ln G_t + \beta_2 \ln FD_t + \beta_3 \ln GDP_t + \beta_4 \mathrm{lnHC}_t + \beta_5 \mathrm{lnCO}_{2t} + \varepsilon_t \quad (2)$$

where β is the slope coefficient, whereas t shows the period (1990–2016), and ε is the residual. Moreover, β_1, β_2, β_3, and β_4, are the coefficients of G, FD, GDP, HC, and CO_2 which reveal globalization, financial development, *per capita* GDP, human capital, and carbon emissions respectively.

4 Econometric strategy

Pesaran et al. (2001) first introduced the ARDL approach in 2001, the basic idea behind this innovative approach is to find the dynamic relationships between short-run and long-run variables (Pesaran et al., 2001). We tested co-integration between existing variables of this study using the ARDL technique (Pesaran et al., 2001). Many researchers used diverse types of co-integration methods to check the relationships between variables, for example (R. Engle and Granger, 1991; R. F. Engle and Granger, 1987; Hansen and Phillips, 1990; Johansen and Juselius, 1990), but many techniques failed to incorporate the sequence of integration and structural breaks in these stated variables (Shahbaz et al., 2013). Therefore, this study uses the ARDL technique which has many advantages over current econometric methods: (i) There is no difference when the variables are stable at the I (0) level, only when the variables are mixed. (ii) ARDL-based result assessments are robust in the calculation of small sample sizes, which are ideal for the research setting (Harris and Sollis, 2003). (iii) Researchers will be able to obtain a dynamic control error correction model (UECM) using the ARDL method. In order to achieve more robust results,

TABLE 3 Correlation matrix.

	lnRE	lnGDP	lnG	lnHC	lnFD	$\mathrm{lnCO_2}$
lnRE	1					
lnGDP	0.984963	1				
lnG	0.909701	0.96425	1			
lnHC	0.956977	0.970644	0.939569	1		
lnFD	0.922224	0.949795	0.948911	0.900135	1	
lnCO2	0.981414	0.981013	0.911873	0.950124	0.892778	1

ARDL boundary testing is recommended when converting lag orders. This analysis brings together long-term and short-term dynamics. When time series data are used, ARDL solves inflection and serial correlation problems (Pesaran et al., 2001). This study used the following ARDL testing equation:

$$\Delta \mathrm{lnRE} = c_0 + \sum_{i=1}^{p} \beta_1 \Delta RE_{t-r} + \sum_{i=0}^{q} \beta_2 \Delta \mathrm{lnG}_{t-r} + \sum_{i=0}^{q} \beta_3 \Delta \ln CO2_{t-r} + \sum_{i=0}^{q} \beta_4 \Delta \mathrm{lnHC}_{t-r} + \sum_{i=0}^{q} \beta_5 \Delta \mathrm{lnFD}_{t-r} + \sum_{i=0}^{q} \beta_6 \Delta \mathrm{lnGDP}_{t-r} \quad (3)$$

where Δ is the 1st difference operator, p shows the lag length, and β represents the coefficients. From Eq. 2 we make two kinds of assumptions that refer to long-term associations, the first of which is the null hypothesis that there is no co-ordination (H_0: $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = 0$) which is checked against the alternative hypothesis (H_1: $\lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq 0$).

5 Results and discussion

Preliminary, we have tested the correlation among all study variables. Table 3 shows the correlation matrix results, which indicate a strong correlation among variables.

TABLE 4 Unit Root tests results.

	Augmented dickey-fuller test statistic		Phillips–Perron test statistic	
	Level	First difference	Level	First difference
lnRE	−0.779874	−3.953696**	0.165664	−3.583732**
lnGDP	−3.075116	−4.991571***	−2.189215	4.28369***
lnG	0.207132	−6.763782***	0.444850	−6.763049***
lnHC	−0.949831	−4.665045***	−2.810289	−4.363373***
lnFD	−2.573712	−5.563423***	−2.553775	−5.561801***
lnCO2	−2.618486	−4.108626***	−1.811053	−2.957711**

The significance level at10% *, 5% ** and 1% ***.

TABLE 5 VAR Lag Order Selection Criteria results.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	191.57	NA	1.00E-12	−10.604	−10.3374	−10.512
1	495.0225	485.5239	2.38E-19	−25.887	−24.02058*	−25.2427
2	550.1774	69.33759*	9.65e-20*	−26.9816	−23.5154	−25.78503*
3	593.4815	39.59229	1.11E-19	−27.39894*	−22.333	−25.6502

LR: LR, test statistic for sequential modified (each test at a 5% level). FPE: final prediction error. AIC: akaike information criterion. SC: schwarz information criterion. HQ: Hannan-Quinn information criterion. *Shows the lag order selection through criterion.

TABLE 6 Results of ARDL bounding test approach.

Model	$\text{lnRE} = f(\ln GDP, \ln G, \text{lnHC}, \ln FD, \text{lnCO2})$
Bound test-F-statistics	16.54606
Significance	1%***
Lower 1 (0) Bound	3.06
Upper 1 (1) Bound	4.15

The significance level at 1% ***.

A prerequisite of ARDL is checking the level of data integration, which will ensure that the overall serial number is integrated and connected with the maximum difference level, and at the second difference level, there is no variable fixed. The series can be stable at the second difference level, then the F values for ARDL cannot be very reliable (Ouattara, 2004). For unit root testing, we used Phillips-Perron (PP) and Augmented Dickey-Fuller (ADF). The results reveal that at the I (0) level, the series of variables RE, GDP, G, HC, FD, and CO2 are non-stationary (see Table 4), but at the first difference level, these series become stationary. The tested results approve that the ARDL model can be used in the order of I (0) and I (I).

After analyzing the sequence of all the rows of the combination, we see the appropriate regression of the data series before using the ARDL boundary-check approach for integration. Table 5 shows the lag selection criteria based on the VAR model results for LR, FPE, AIC, SC, and HQ tests. SC results show lag one is suitable according to AIC, SC, and HQ tests. HQ presents lag two as appropriate, while the AIC indicates that lag three is ideal for the model. We applied the lag selection information criterion provided by the SC test which means demonstrates that the lag one model is suitable for this study.

We have next calculated the long-run cointegration between renewable energy and other independent variables of this study. In order to examine whether there is an association between the variables under investigation, the ARDL Bounds test is used. Presented in Table 6 are the findings of this bounds test. In this study, the estimated F-statistic value is significant at a 1% level of

TABLE 7 Johansen cointegration results.

Hypothesis	Trace statistics	Maximum eigen value
$R = O$	163.7869***	67.06418***
$R \leq 1$	96.7227***	39.06393***
$R \leq 2$	57.65876***	27.84862**
$R \leq 3$	29.81014**	20.07672*

The significance level at 10% *, 5% ** and 1% ***.

TABLE 8 Long and Short Runs Estimations Dependent variable = Renewable Energy.

Long-run estimations lag order (1, 1, 0, 0,1, 0)

	Coefficient	Std. Error	t-Statistic	Prob
LnG	−2.278727	0.476743	−4.779783	0.0001
LnFD	0.860595	0.382236	2.251477	0.0544
lnCO2	1.133856	0.406843	2.786960	0.0237
LnHC	1.133694	0.438014	2.588260	0.0147
LnGDP	1.319456	0.377942	3.491156	0.0016
C	−1.839477	0.828596	−2.219993	0.0347
Short-run estimations				
D (lnG)	−0.017731	0.053921	−0.328835	0.7451
D (lnFD)	0.191468	0.026668	7.179682	0.000
D ($lnCO_2$)	−0.220897	0.124420	−1.795407	0.0885
D (lnHC)	−0.082442	0.083526	−0.987022	0.3321
D (lnlnGDP)	0.590234	0.098651	5.983047	0.000
CointEq (−1)	−0.269771	0.039723	−6.791250	0.0000
Sensitivity analysis	F-statistics	*p*-value		
RESET Test	1.708377	0.2015		
LM	0.965795	0.3339		
Breusch-Pagan-Godfrey	1.355720	0.2643		
R-square	0.9997			
Adj- R-Square	0.9994			
F-statistics	91.8305			
DW	1.8508			

The significance level at 10% *, 5% ** and 1% ***.

significance since its value is very high in comparison to lower and upper bounds, which indicates that the variables have long-run relationships with each other.

The ARDL Bounds test approach ensures that in terms of longitudinal correlation, there is a positive relationship between the variables. The Johansen cointegration test was used to verify and validate the strength of these results. Table 7 shows the trace statistics and Eigenvalues which have confirmed the cointegration among globalization, carbon emissions CO_2, human capital, financial development, and long-term, renewable energy will contribute to both the gross domestic product and the gross domestic product.

5.1 Long and short-run dynamics

After cointegration confirmation between all the variables, the long-run and short-run dynamics were estimated for the renewable energy for this study as a dependent variable. Table 8 shows the results of these estimations.

The estimated coefficient of globalization concerning renewable energy is, Globalization decreases renewable energy by -2.28 percent for every 1 percent increase in globalization. This result shows that globalization brings innovative technologies and innovations, reduces energy intensity, replaces energy-intensive products with energy-efficient products, and reduces environmental pollution by increasing the role of renewable energy production. Globalization improves knowledge, skills, and technological advancement in the energy sector. These results match with the study of (Huang and Wang, 2016; Lv and Xu, 2018; You and Lv, 2018; Zaidi et al., 2019a; C. Zhang and Lin, 2012; Ibrahim et al., 2021; Usman, Muhammad, et al., 2022).

Renewable energy and FD are statistically significant and positively correlated. For example, if there is 1 percent increase in FD it will cause a 0.861 percent increase in renewable energy. These indicated results are consistent with these studies (Lee, 2013; Liu et al., 2011; Paramati et al., 2016; Shahbaz et al., 2013; D. Zhang et al., 2016; Usman et al., 2021a) and the FD affects economic growth, carbon emissions, energy consumption, and particularly renewable energy consumption. Hence, including the FD as a variable in this study was justified through these positive results (Zaidi et al., 2019b).

Financial development relates positively to renewable energy, the results show. Renewable energy increases by 0.861% when financial development increases by 1%. A strong financial system increases the accessibility of loans and results in increased purchasing power of the peoples in buying electronic appliance and vehicles, which lead to more energy consumption. These results are in line with (Lee, 2013; Shahbaz et al., 2013; United Nations Environment Programme et al., 2014; Chang et al., 2016; Danish et al., 2018).

Carbon emissions are also significantly correlated with renewable energy, such that a 1 percent increase in CO_2 results in a 1.134 percent increase in RE. China's rising GDP is contributing to a greater demand for renewable energy, as the coefficient of CO_2 emissions is significantly smaller than the coefficient of economic growth. At the same time, the rise in the GDP of China has also raised the level of CO_2 emissions in the country. The primary reason for environmental degradation is non-renewable energy consumption because China depends heavily on traditional fossil fuels for example coal, oil, and gas. The country's massive increase in the use of traditional energy sources is adversely affecting environmental degradation. However, the government is fighting hard to curb rising emissions by increasing the share of renewable energy (Ozcan and Temiz. 2022).

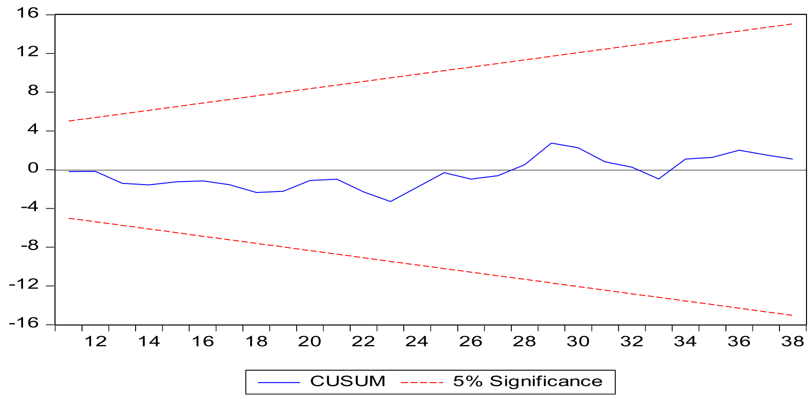

FIGURE 1
CUSUM plot.

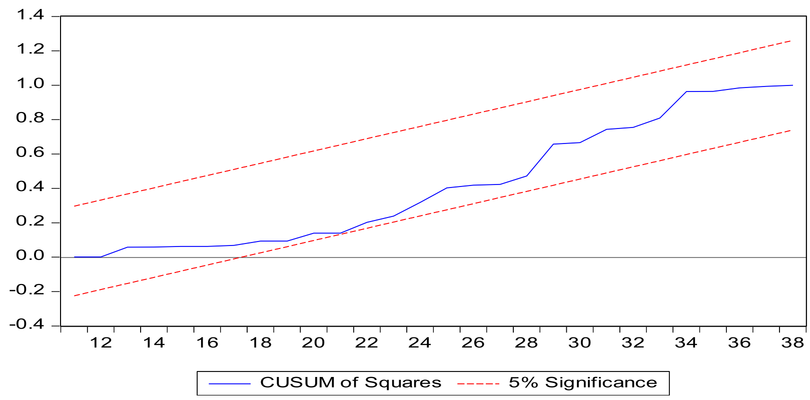

FIGURE 2
Squares of CUSUM plot.

Human capital shows a significant and statistically positive relationship with renewable energy; for instance, if human capital increases by 1 point, renewable energy increases by 1.134 points. These results indicate that when there is a positive role in the country's human capital that will help to increase the demand for environmental quality, people will consume energy with the planning to improve their environmental standards, for example using new innovative technologies to improve the quality of their environment. In China, the demand for domestic and international labor is increasing (in human capital). Improved availability of human capital supports the government to increase investment in renewable projects. The results of this study match with those of (Martínez-Zarzoso and Maruotti, 2011; Wang S et al., 2016; Zaidi et al., 2019a; Zaidi et al., 2019b; Usman et al., 2021a; Usman et al., 2022).

The coefficient of economic growth related to renewable energy is significant and statistically positive for example, if there is 1 percent increase in economic growth, renewable energy will increase by 1.319 percent. This result showed that the Chinese government is massively developing all the sectors of economies, which helps China to use renewable energy sources to perform these economic activities. This finding not only justifies the inclusion of GDP as a control variable in renewable energy activity but also overall confirms that economic growth has a long-term effect on renewable energy (Xu, L, et al., 2022; Raihan et al., 2022c). The indicated results of the short-run dynamics report a statistically positive and significant relationship between renewable energy and economic growth. Financial development impacts renewable energy in the short run also. Furthermore, globalization, carbon emissions, and human capital bear negative relationships with renewable energy (Sheraz et al., 2021). Table 8 is also elaborating on the sensitivity analysis that reflects the robustness of the ARDL model. Similarly, to check the reliability of the coefficient, this study utilized the CUSUM value and the square of

TABLE 9 VECM granger causality results.

	ΔlnRE	ΔlnGDP	ΔlnG	ΔlnHC	ΔlnFD	ΔlnCO2	ECT-1
ΔlnRE	= = = = = =	2.31856	0.73548	4.02764*	4.22017**	0.15534	−0.1870*
		(0.1371)	(0.3971)	(0.0528)	(0.0477)	(0.6959)	(−1.869)
ΔlnGDP	3.54566*	= = = = =	9.31471***	2.49378	0.14989	0.03575	−0.3362***
	(0.0683)		(0.0044)	(0.1236)	(0.7011)	(0.8512)	(−3.2417)
ΔlnG	1.67871	1.51968	= = = = =	0.65691	1.90606	3.42663*	−0.3912**
	(0.2038)	(0.2261)		(0.4233)	(0.1764)	(0.0729)	(−2.222)
ΔlnHC	2.77275	32.1851***	44.5400***	= = = = = =	18.8079***	8.94684***	−0.6092***
	(0.1051)	(0.000)	(0.000)		(0.0001)	(0.0051)	(−4.946)
ΔlnFD	0.62874	5.07399**	0.72169	1.80273	= = = = = = =	2.54212	−0.3601***
	(0.4333)	(0.0309)	(0.4015)	(0.1883)		(0.1201)	(−3.240)
ΔlnCO2	12.4984***	1.33030	5.04789**	0.03255	1.04457	= = = = = = =	−0.1411
	(0.0012)	(0.2568)	(0.0313)	(0.8579)	(0.3140)		(−1.1681)

Note, in this table the first difference is indicated by Δ, The significance level at10% *, 5% ** and 1% ***, in brackets t-values are mentioned, and in parenthesis the *p*-values are mentioned.

CUSUM. Figure 1, 2 show overall CUSUM values and squares of CUSUM values.

The Residual values represent the blue line and the red line is the confidence level. These graphs show that the ARDL model is consistent and stable because the estimated values of the residues are within the 5% significance level within the confidence interval.

The overall ARDL results provide information on long-term and short-term dynamics but don't give many details about variable relationship direction, which are very important to generate some policy recommendations and implications (Yu, Yang, et al., 2022). Therefore, we use the Granger causal analysis based on the Vector Error Correction Model (VECM) to verify the variable relationship direction. These analyzes reveal the long-term causality between short-term and variable. First, with the help of the test, we calculate the short-term cause; We create the long-term cause through VECM. Long-term causes confirm if there is a negative sign for the error correction period, and this is statistically significant. The VECM Granger module is designed using the following equation:

$$\begin{bmatrix} \Delta \text{lnRE}_t \\ \Delta \text{lnGDP}_t \\ \Delta \text{lnCO2}_{t-p} \\ \Delta \ln G_t \\ \Delta \text{lnHC}_t \\ \Delta \text{lnFD}_t \end{bmatrix} = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \\ \delta_6 \end{bmatrix} + \sum_{p-1}^{q} \begin{bmatrix} \theta_{11p} & \theta_{12p} & \theta_{13p} & \theta_{14p} & \theta_{16p} & \theta_{17p} \\ \theta_{21p} & \theta_{22p} & \theta_{23p} & \theta_{24p} & \theta_{25p} & \theta_{26p} \\ \theta_{31p} & \theta_{32p} & \theta_{33p} & \theta_{34p} & \theta_{35p} & \theta_{36p} \\ \theta_{41p} & \theta_{42p} & \theta_{43p} & \theta_{44p} & \theta_{45p} & \theta_{46p} \\ \theta_{51p} & \theta_{52p} & \theta_{53p} & \theta_{54p} & \theta_{55p} & \theta_{56p} \\ \theta_{61p} & \theta_{62p} & \theta_{63p} & \theta_{64p} & \theta_{65p} & \theta_{66p} \end{bmatrix} \times \begin{bmatrix} \Delta \text{lnRE}_{t-p} \\ \Delta \text{lnGDP}_{t-p} \\ \Delta \text{lnCO2}_{t-p} \\ \Delta \text{lnG}_{t-p} \\ \Delta \ln HC_{t-p} \\ \Delta \text{lnFD}_{t-p} \end{bmatrix} + \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \end{bmatrix} ECT_{it-1} + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \\ \mu_{3t} \\ \mu_{4t} \\ \mu_{5t} \\ \mu_{6t} \end{bmatrix} \tag{4}$$

Eq. 3, μ is representing the error term where the Δ, and p are showing the lag length and the first difference operator.

Based on the VECM Granger causality (see Table 9), the long-run results indicate bidirectional causality between renewable energy and globalization, financial development and renewable energy, human capital and renewable energy, and economic growth and renewable energy. In the long run, there was no causal link between carbon emissions and renewable energy (Sheraz et al., 2021; Ahmad et al., 2022). Human capital is closely related to renewable energy, as is economic growth. Granger notes that renewable energy creates economic growth and lowers carbon dioxide emissions in the short term. According to this conclusion, renewable energy reduces carbon emissions and increases economic growth (Saud et al., 2020).

6 Conclusion and recommendations

The study explores the nexus between renewable energy, economic globalization, environmental quality, financial development, human capital, economic growth, and carbon emission in China. An ARDL model can predict changes in the independent variables and their impact on the dependent variables. Using the LDF test, each variable was checked for consistency and stationarity. A causal analysis was also used to determine the direction of the relationship using the Granger test.

This is the first study to investigate the role of renewable energy as a dependent variable in globalization, financial development, and environmental quality. The results clarify the role of globalization, financial development, and environmental quality in the renewable energy sector in China. There was a long-run cointegration between studied variables, based on ARDL bound tests and Johansen cointegration tests. Through ARDL, the long- and short-run dynamics of globalization are found to be negative. In addition, financial development, human capital, carbon emissions, and economic growth are positively correlated with renewable energy. Long-run VECM Granger causality results show bidirectional causality relationships with globalization and renewable energy, with financial development and renewable energy, with renewable energy and human capital, and with renewable energy and economic growth. Renewable energy, on the other hand, has no causal link with carbon emissions in the long.

We recommend that the Chinese government continue its current policies toward globalization. The negative relationship between globalization and renewable energy suggests that non-renewable energy consumption is increasing due to increased exports from China. As a result of increased exports, China's economy grew rapidly, but at the same time, fossil fuel use increased carbon emissions. With the help of improved imported technology, we expect the country to have a higher share of renewable energy and less pollution. Future studies could study the non-linear relationship of globalization with renewable energy to support this argument. China can also increase trade activities, foreign direct investment (FDI), and financial investment activities in the process of globalization. Also, China's direct environmental policy on energy consumption helps to overcome globalization and achieve a sustainable environment. Economic growth has a positive effect on renewable energy consumption. The Chinese government should develop such policies that provide a foundation for strong economic growth and financial institutions. Funding is needed to develop clean energy and energy-efficient technology. Such a project can reduce energy consumption and increase efficiency if strong financial institutions and a healthy economic development framework are in place.

Globalization and economic growth are impossible without quality human capital. Therefore, good health and education services are essential for the development of human capital for successful economic growth. As a financially developed economy, China is now in a position to invest heavily in education and health facilities, thereby increasing the amount of human capital in the country. The Chinese government should invest in professional training and encourage the management of skilled and educated immigrants from abroad. Through their efforts, China can promote economic growth, technology, and foreign direct investment.

This study has some limitations too which can be overcome in future studies. This study only discusses the linear relationships among globalization, financial development, carbon emissions, human capital, environmental quality, and renewable energy. New studies may include innovation, technology, and institutional quality as determinants of renewable energy. Another econometric methodology considering the quantiles and non-linearities can be considered in future studies. Lastly this study focus only on China, in new studies other developing countries might be included to verify the stated results.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author.

Author contributions

MA: Original draft preparation, Conceptualization, Methodology. LM and MZ: Supervision and Reviewing. RU: Theoretical Framework. MU: Modeling, and Software. IK: Revision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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