Environmental Science and Pollution Research (2023) 30:59249–59261
https://doi.org/10.1007/s11356-023-26430-6

RESEARCH ARTICLE

The response of green finance toward the sustainable environment: the role of renewable energy development and institutional quality

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Received: 9 January 2023 / Accepted: 9 March 2023 / Published online: 31 March 2023

Abstract
The problem for developed and developing economies is achieving sustainable development and cleaner production. Income, institutional regulations, institutional quality, and international trade are the primary factors of environmental externalities. This research looks at 29 provinces in China between 2000 and 2020 to determine the effect of green finance, environmental regulations, income, urbanization, and waste management on renewable energy generation. Similarly, the current study uses the CUP-FM and CUP-BC for the empirical estimation. More precisely, the study shows the positive influences of environmental taxes, green finance index, income, urbanization, and waste management in renewable energy investment. However, the different measures of green finance, such as financial depth, financial stability, and financial efficiency, also positively contribute to renewable energy investment. Therefore, it can be considered the best solution to environmental sustainability. However, imperative policy implications are given to attain the peak of renewable energy investment.

Keywords Renewable energy development · Green finance index · Environmental regulations · China

Introduction

Global warming is one of the greatest threats to human survival and political stability. Rising CO_2 is the main cause of climate change. Most of the recent warming during the past 50 years was probably a result of increasing focusses on greenhouse gases generated by human activities like forest degradation and the burning of fossil fuels, following the United Nations' Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) from 2007. The 2013 AR5 Assessment Report strengthened this view even further. Compared to its pre-industrial value of around 280 parts per million (ppm), the atmospheric awareness of CO_2 rose to 391 ppm in 2011. About 400 parts per million were recorded in 2014. For this reason, the world is deeply concerned about the persistent and rising output of carbon emissions (Zhao et al. 2022). In most parts of the world, the development in carbon emissions is driven primarily by the industrial, transportation, and energy supply sectors (Asbahi et al. 2019; Hailiang et al. 2022; Feng et al. 2022; Yumei et al. 2022). However, substantial quantities of carbon dioxide, methane, and other greenhouse gases are also being contributed by the residential and commercial building sectors, the forestry and deforestation sectors, and the agricultural sector. Given the growing dangers to civilization posed by the continued burning of fossil fuels in essentially unrestricted fashion, one of the most important questions that need to be asked by everyone is what are some strategies that are logically sound, economically feasible, and ethically defensible to moderate the trends of global warming, reverse the increases, and adapt to the present and anticipated climate dangers? The approximately 90 papers that are included in this special book cover a wide range of topics that are pertinent to the investigation of methods to examine methods for reducing carbon emissions and mitigating the effects of global warming (Liu et al. 2022a; Li et al. 2023).

In this overview, we first look at how better managing MSW can help reduce Hawaii's carbon emissions (CE). The primary goals of this research were to (1) fill a significant information gap on the effect of carbon emissions due

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to solid waste disposal across China and (2) offer a clear understanding of emission reductions (ERs) that can be gained by optimizing waste management systems. Research has established that there is a dearth of complete and trustworthy information on trash management. This research aims to lay the groundwork for creating a best-practices protocol for local governments to follow when carrying out Clean Development Mechanism (CDM) initiatives. Three to four percent of the world's annual anthropogenic greenhouse gas (GHG) emissions come from methane released by solid waste landfills (Müsgens 2020). The amount of greenhouse gas emissions caused by garbage dumps has been estimated to fall across a wide spectrum (Nam et al. 2020). The researchers in this study hope to take things further by analyzing carbon emissions from all waste management processes and developing a philosophy to encourage long-term emission reductions.

Increases in carbon emission efficiency (CEE), defined as ecologically sensitive productivity with CE as unwanted output, are used to assess the success of low-carbon economies because they indicate a more harmonious relationship between economic expansion and environmental progress (Liu et al. 2018). Thus, reconciling economic growth and carbon neutrality targets requires decision-making insights that can be gained by investigating the nexus between energy transition and CEE (Liu et al. 2022c). Because it influences so many important policy choices, the connection between energy use and sustainable development has generated much debate. Although necessary, traditional fossil energy has many unintended consequences for the environment due to its widespread adoption and use. These include, but are not limited to, a dramatic rise in greenhouse gas emissions (Bertheau 2020). Almost half of all manmade carbon emissions come from the electricity sector, with more than 80% from coal-fired power plants. In order to meet the Paris Agreement's target of keeping global warming below 2.0 °C, the switch to renewable energy sources has become a must. Thus, there are two major reasons why renewable energy development (RED) is so important. One, there is a consistent increase in the need for energy globally due to industrialization. Distributed broadly and with great potential for expansion, renewable energy helps prevent interruptions in the reliability of the nation's energy supply and makes it possible to meet the growing demand for power (Tardy and Lee 2019). Second, the mining and use of fossil fuels release greenhouse gases and put at risk the land, water, and air that humans rely on for survival. Greenhouse gas emissions and other air pollutants are reduced, while energy consumption remains constant when using renewable sources. For these reasons and more, RED has emerged as a crucial tool in the fight against climate change (Liu et al. 2022b; Tong et al. 2022).

The energy transition process is threatened structurally, although renewable energy has significant potential to advance sustainable development. Because of its greater initial capital and technical cost compared to fossil fuels, renewable energy is less competitive. Diverse strategies, such as renewable energy supports and carbon pricing, have been used to indirectly or directly erode the economic benefit of fossil energy in order to facilitate low carbon transition, induce technological maturity, and promote energy freedom. Yet they do not do much good. It should be noted that the cost would be significantly larger (Raghutla et al. 2021). China began phasing down renewable energy subsidies to lighten its budget, and other countries soon followed suit. Furthermore, the USA extracted from the Paris Agreement, resumed its fossil fuel abstraction program, and decontrolled the traditional energy industry, limiting global RED to boost economic growth and employment. Notwithstanding, there has been no global wavering in commitment to the energy transition. By 2020, over 161 countries will have suggested the RED objective and developed related policies (Nguyen et al. 2021).

Over the period between now and 2020, China has set goals for the widespread use of renewable power. Both the projected share of renewable energy in overall electricity generation and the total installed capacity of these goals are quite ambitious. Decoupling expanding fossil energy use from economic expansion over the next several decades is an important goal of renewable energy development in China, intending to reduce CO_2 emissions and dependency on imported energy. The local environment, including air and water quality, also benefits from this decoupling. Between 1995 and 2003, the environmental pollution cost was predicted to be greater than 4% of the GDP (Wu et al. 2021) (Ugwoke et al. 2020). The effects of China's renewable energy objectives on renewable and fossil energy use and the effect on CO_2 emissions are of great interest to policymakers in China and around the world.

The Chinese government has specified a comprehensive set of energy and climate policies until 2020, and renewable energy deployment targets are a key aspect of these plans. Energy and carbon intensity decline targets and targets for the share of primary energy derived from non-fossil sources have been established at the national level. In order to achieve these overarching aims, supplementary measures are put in place to improve the production of certain forms of electricity (in this case, we will be analyzing the effects of these measures on wind, solar, and biomass electricity production). To help shape China's energy and climate policy after 2020, policymakers need a clear picture of how supply-side targets for renewable energy might fit into the bigger picture. We analyze the effects of present renewable energy targets in order to learn how renewable energy could contribute to achieving low-carbon development.

To the best of our awareness, this is the first effort to examine the complex influence of environmental rules on renewable energy production. Data from three important factors were used to arrive at these conclusions, including environmental taxes in the context of 29 industrialized OECD countries. The selection of these 29 provinces in China was based on the fact that China is directly responsible for 7% of all world carbon emissions due to its high fossil fuel use. The economy has grown steadily since 2000, and CO_2 emissions due to energy use have decreased. This is mostly attributable to structural changes in industrial production procedures, advancements in energy supply and energy efficiency, and other forms of innovation. In order to fully understand the potential of renewable energy generation (REG) in this set of provinces, it is necessary to determine the impact of adopted variables. Using these data, we developed three models (described in greater detail below) to isolate the effects of the three relevant factors (green finance financial depth, efficiency, and depth), as mentioned in the "Data and methods" section. Yet other controllable variables were incorporated into each model as needed (as was mentioned above). Therefore, the importance of environmental regulations and taxes on renewable energy production can be emphasized.

The remainder of this study is as follows: Previous research is summarized in the "Literature review" section, data and methods are accessible in the "Data and methods" section, and empirical findings are presented and discussed in the "Results and discussion" section. The paper concludes by restating its key findings. In the final section, several suggestions for practice and policy are developed.

Literature review

A select few academics are interested in topics related to green finance and energy efficiency. Some researchers have demonstrated that the fundamental issues with green finance make it ineffective in many countries. According to research referenced by Fatima et al. (2021) and Hamid et al. (2022), green finance products, such as green bonds, are unsuccessful in emerging or less-developed nations due to a lack of a strong private market and an insufficient financial infrastructure. Tian et al. (2021) conducted an investigation into the link between green bonds and several economic and environmental factors and came to the same conclusion. Hu et al. (2023) found no link between green bonds and sustainable development goals (SDGs) in India due to a lack of rules in India's climate action plan and a financial gap in the private sector. Finally, Guo et al. (2023) analyzed green bonds for renewable energy projects issued by the European Investment Banks in 2015–2018. The research showed that green finance for ecologically friendly initiatives was wasted due to inappropriate distribution of funds.

While some research has concluded that green finance has little or even a negative effect, other research has shown that it can positively affect various macroeconomic features. In the COVID-19 era, for instance, green bonds were proven to be more effective than traditional bonds. Hou et al. (2019b) also examined the association between green bonds and other factors, including clean energy, from 2008 to 2019. They found convincing evidence that green bonds contribute to the expansion of sustainable energy. Green bond markets in various locations were evaluated by Uddin et al. (2021), with special attention paid to Asia and the Pacific. Their research confirmed the greater returns, higher risks, and increased heterogeneity characteristic of green bonds in Asia. Around 60% of all issuances in the Asian green bond market come from the banking sector. They concluded that issuer diversification, with more public sector involvement and de-risking strategies, was an option in the post-COVID-19 period. The findings demonstrated that private investors might be drawn to the green financing market if the state provided help to the banking and financial sectors in creating green financing.

Thus, progress in green financing could help green energy projects grow. According to Bekun (2022) and , long-term green investments benefit greatly from green finance. Yet they did highlight the part that public financial institutions play in enlightening the efficiency of these financing mechanisms. As mentioned by Su et al. (2017), green bonds are an effective tool for green financing since they lessen the risk, boost the yield on investment, and interest investors around the world in green energy projects. According to Yu et al. (2022), the green finance market mechanism and existing market conditions are two key contributors to the favorable correlation between green financing and green energy initiatives. As studied by Pata (2018), green finance has a favorable effect on green energy projects, especially those involving investments in energy infrastructure on a modest scale (Abbas et al. 2020a; Li et al. 2020; Manfren et al. 2021). According to research conducted by Chen et al. (2023), expanding the green energy financing market recovers green projects, increasing the share of green energy in India's total energy basket. According to Bhattacharyya (2018), the financial market procedures and governmental regulations concerning green finance determine the direct and beneficial influence of green finance on renewable energy development. As argued by Iqbal et al. (2021a, b), green economic changes are critical for all nations to increase investment in green energy generation and reduce environmental pollution.

Before the COVID-19 pandemic, there was a significant amount of published material on environmentally responsible finance. In contrast, there is very little published material on the subject during the current COVID-19 period. There are a handful of studies, such as those of Akintande et al. (2020), and Song et al. (2021), that have investigated the relationship between green finance and share and a variety of other environmental, economic, and energy-related factors. Liang et al. (2019) evaluated the part of green investment while researching China's sustainable development and production-based CE from 1998–2017. This study was one of several studies that looked into these topics. In the long run, production-based CO_2 emissions and the factors that determine them are cointegrated, according to a study that used an autoregressive distributed lag (ARDL) cointegration approach. In addition, the findings suggest that production-based CO_2 emissions can be greatly reduced by using green investments and renewable energy sources, whereas trade openness can increase such emissions. So the two latter variables are crucial to China's long-term economic success. But COVID-19 poses a challenge to every industry worldwide, although green investment is linked to sustainable growth. To address this issue, Zheng et al. (2021) looked into green bond markets to analyze the facilitative function of green finance in the post-COVID-19 period. The research examined the Asia–Pacific region using pooled ordinary least squares (OLS) and random effect GLS estimators. According to the data, green bonds carry a larger risk and exhibit greater heterogeneity but produce a better return. Moreover, the survey claimed that financial institutions were responsible for driving 60% of the green bond market. On the other hand, green bonds issued by banks returned far less than typical bonds.

Similarly, Zafar et al. (2021) suggested that banks had a lower capacity to absorb unanticipated risks, lending credence to the prior study's findings. Some COVID-19 banks fail as a result of this, while other (non-bank) financial institutions and marketplaces urgently require assistance. The study concluded that healthy environmental policies should take into account carbon-free and ecologically friendly ways if sustainable environmental goals are to be attained. Green mortgages, bonds, and other forms of "green financing" may help us reach our goal of environmental sustainability. The SDGs and the Paris Agreement on Climate Change all have a hand in ensuring a sustainable environment. For this reason, Liu et al. (2022d) investigated the best way to allocate funds toward SDGs during the COVID-19 pandemic. The research provided a theoretical framework for determining how best to allocate resources toward achieving the SDGs. The research concluded that investors' current SDG allocation depends on different consulting companies, which distorts their investment portfolios. Only by pricing environmental toxins and wastes would it be possible to allocate the necessary portfolio. Nong et al.'s (2019) research examined the environmental challenges of energy recycling, CO_2 emissions, and trash reutilizing and debated that green industrial planning and carbon price could be effective means of addressing these problems. Energy storage, heat pumps, heat and power, and demand reaction were among the cutting-edge technologies that Joof et al. (2022) found to be integral to China's energy system in 2020, yielding substantial increases in energy efficiency and decreases in fuel utilization and annual cost. As a result, decreasing environmental risks and increasing the amount of variable renewable energy result from investment in green projects. After the appearance of COVID-19, however, the economic landscape shifted dramatically. As such, Noureddine and Tan (2021) looked into the current and future impacts of the COVID-19 outbreak on sustainable energy methods, including the difficulties encountered and the potential presented by this pandemic. The authors argued that identifying priority for short-run policy is necessary to mitigate the implications of COVID-19 on renewable energy development strategies. In order to reach our renewable energy goals responsibly and cost-effectively, we must also prepare our intermediate and long-term action programs (Chien et al. 2021; Zhang et al. 2021).

Liu et al. (2020) analyzed the economies of Next-11 and the BRICS countries throughout 2005–2019 and utilized a method called difference in differences (DID). Their study focused on the link between green finance and climate change mitigation. The research found that factors including renewable energy use, population, carbon emissions, inflation, FDI, grants for technical cooperation and research and development, and investments made through private partnerships all have an important impact on fostering green financing and reducing climate change in the regions studied. In addition, Solangi et al. (2020) conducted a study evaluating sustainability and development in the wake of the current epidemic caused by COVID-19. The research concluded that there had been insufficient progress made toward the sustainable development goals before the epidemic and that following the pandemic, there may be fewer financial resources available for the achievement of these SDGs. Abbas et al. (2020b) complement the aforementioned research by examining the role of green financing mechanisms in developing economies, as well as by examining the most effective methods of supporting green economic recovery and inclusive, sustainable investments. Guo et al. (2022) writing about the worldwide clean energy shift in the wake of the COVID-19 pandemic, suggested that the recent contagious pandemic resulted in the steep drop of energy request, which cuts energy prices and subsequently slows down the distribution of renewable energy (RE) projects. Nonetheless, the authors suggested that this presents a chance to make the case for clean energy asset, especially in the electrical sector. COVID-19's effect on the international energy market is detailed, and methods for achieving a more sustainable future energy supply are examined. Evidence from green finance is provided by Li et al. (2021), and Mohsin et al.

(2022). The beneficial effects of these expenditures, though, show an initial uptick, followed by a slow decline.

Studies that simply analyze green finance exist alongside those that use COVID-19; for example, Xia et al. (2022) looked at public expenditure and green economic growth in the BRI region from 2008 to 2018, focusing on the influence of green finance. The study's findings, based on generalized method of moments (GMM) estimations, show that investing in people and research and development for green energy technologies boosts the green and sustainable economy. The outcomes for different countries vary widely, nevertheless, especially those with high GDP per capita. Cusenza et al. (2019) and Soltani et al. (2021) looked at the province data from China from 2010–2017 to determine the effect of green finance on environmental value and economic development. The analyzed data suggested that the effect of green finance on environmental quality is favorable but conditional on the level of economic expansion in the region. Therefore, green finance benefits both environmental health and economic growth.

Data and methods

Relevant indicator data from 2000 to 2020 are used in data selection and processing for establishing China's green finance index (GFI). We use per capita consumer expenditure as a proxy variable for income in China, and the data originate from the statistical yearbooks of different provinces and their annual financial report. After deleting the missing values, we pick the sample data from 29 provinces in China for empirical research.

To assess the progress made in green finance, this research will employ the entropy technique. The green finance development index can be measured with the use of the entropy approach, but it requires a few standard indicators. To achieve sustainable development, as outlined in the United Nations' "2030 Agenda for Sustainable Development," requires resolving issues with green finance's depth of the financial market, efficiency of its operations, and stability in the long run. The quality of economic growth is a sustainable development aim that can be attained through the use of green finance, which works toward this goal by fostering environmental governance. As used to the financial sector, the term "green finance" suggests that environmental protection is prioritized as a core value. Including the possible profits, risks, and costs associated to environmental conditions is essential when making investment and finance decisions. Every day, we direct social economic resources toward fostering sustainable social growth while also protecting the ecological environment and treating environmental damage from our financial company activities. Investment and funding decisions that may have an effect on the environment should factor in the possible benefits, risks, and costs associated with environmental circumstances. Invest more in measures to safeguard the natural world when conducting financial transactions, and use your influence over the economy to steer people toward a brighter future. This study argues that "green finance" refers to the practice, adopted by financial institutions, of incorporating environmental assessment into the process and paying special attention to the growth of green industries and the preservation of the ecological environment while making investments. The primary difference between green finance and conventional finance is the former's focus on helping the planet. Scholars like Bamisile et al. (2021), Halkos and Gkampoura (2021), Pegels (2010), have all argued that we need to do more to save the environment and foster the growth of green finance (Iqbal et al. 2021a). All economic entities are directed to pay attention to natural ecological balance, which they use as a metric for gauging the efficacy of their activities, and they prioritize the environmental conservation and efficient use of resources. Ultimately, it accomplishes sustainable economic and social development by placing an emphasis on the coordinated growth of monetary activities, environmental conservation, and ecological balance. In order to establish a reliable measure of green finance growth, this article uses metrics drawn from financial depth, efficiency, and stability. It combines data availability with the work of past researchers to determine which indicators to use.

Entropy weight method

The entropy weight approach, consisting of the following steps, is chosen to compute green finance in this study since it is objective and so is thought to be superior to subjective weighting methods (Tola and Lonis 2021).

Normalizing the original data

Green finance's original estimation index matrix is defined as X (x_i is the unique value of data), m is the number of assessment samples, and n is the number of estimation pointers. The extreme value standardization method is applied to the raw index in order to generate a uniform evaluation matrix.

Positive indicator: $Z_{ij} = \frac{x_{ij} - x_{ij\min}}{X_{ij\max} - X_{ij\min}}$ and negative indicator:$Z_{ij} = \frac{x_{ij\max} - x_{ij}}{X_{ij\max} - X_{ij\min}}$

Assessing the weight of pointer J:

$$w_j = \frac{(1 - H_j)}{\sum_{j=1}^{n} (1 - H_j)} \text{and } H_j = \frac{1}{\ln m} \sum f_j \ln f_j, \quad (1)$$

where w_j is the weight of pointer $w_j \in [0, 1]$, H_j is the data entropy, and f_j is the indicators' weight. Next is used$p_{ij} = \frac{z_{ij}}{\sum z_{ij}}$ approximating the inclusive green finance of a precise region: $V_i = \sum_{i=1}^{m} w_j p_{ij}$.

Below are the details regarding the elements of this matrix:

$$W_{ij} = \{ \begin{matrix} 0(i = j) \\ 1/d_{ij}(i \neq j) \end{matrix} \tag{2}$$

where d_{ij} represents the spatial separation of the provincial gravitational centers of provinces i and j. In this research, the spatial autocorrelation test index was developed by using Moran's I index. Following is a definition of worldwide Moran's I index:

$$\text{Moran's}I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \times \frac{\sum_{i=1}^{n}\sum_{j\neq 1}^{n} w_{ij}(x_i - x)(\overline{x}_j - \overline{x})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{3}$$

when n indicates the study unit, x_i and x_j denote the green funding and expansion in provinces i and j, and w_{ij} denotes the geographic weight matrix.

Estimation strategy

Cross-sectional dependence

Cross-sectional dependence (CD) must be evaluated first, especially in panel data investigations, before any other relationship assessment technique is carried out. As a result, we employ both the test of Pesaran et al. (2004) and the Lagrange multiplier (LM) test developed by Dong and Pan (2020). The validity of the generated result is the motivation behind employing two tests for the same objective. Furthermore, establishing the CD ensures a trustworthy output, which is why it is so important to do so. Levenda et al.'s (2021) mathematical representation is displayed below:

$$\text{CD} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^{2} \tag{4}$$

In addition, here is Im et al.'s (2003) mathematical illustration of the test:

$$\text{CD} = \sqrt{\frac{2T}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \rho_{ij}} \tag{5}$$

T is a reflection of time, N is a representation of the number of observations in the panel data, and ρ_{ij} is a representation of the coefficient of correlation between the individual observations in the i-th and j-th rows. Both tests' hypothesis statements presume that CD is not present if the null hypothesis is recognized.

Unit root tests

The sequence of integration evaluation must take into account the factors once the CD test assessment has been made. Consequently, evaluating stationarity with tests from the first-generation group, such as Im et al. (2003), is not enough for the dataset with the CD. Since the "cross-sectional augmented IPS" (CIPS) and the "cross-sectional augmented Dickey-Fuller" (CADF) tests fall into the "second-generation" category and are therefore used in the present investigation, it may be concluded that these tests are appropriate. This is a graphical illustration of the test's underlying mathematics:

$$\Delta \text{CA}_{i,t} = \varphi_i + \varphi_i Z_{i,t-1} + \varphi \overline{C}A_{t-1} + \sum_{I=0}{}^{p} \varphi_{il} \Delta C\overline{A}_{t-1} + \sum_{I=0}^{p} \varphi_{il} \Delta \text{CA}_{i,t-1} + \mu_{it} \tag{6}$$

$\overline{C}A_{t-1}$ and $C\overline{A}_{t-1}$ represent the average of cross-sections in Eq. (6) also the CIPS test and its particular statistics have been explained as shown below:

$$C\hat{I}PS = \frac{1}{N} \sum_{i=1}^{n} \text{CDF}_i \tag{7}$$

Cross-sectional augmented Dickey-Fuller is what CDF stands for in (7).

Panel cointegration test

After that, we checked how well the targeted variables were cointegrated. First- and second-generation tests have several restrictions when it comes to determining CD and structural breakdowns (Malik et al. 2019; Musibau et al. 2021; Mngumi et al. 2022). In addition, conventional statistical methods can produce inaccurate results when heteroscedasticity and CD are present in the data (Khan et al. 2021). Due to the restrictions imposed by these analyses, we evaluated the panel's cointegration using Westerlund and Edgerton (2008), who were able to take into account the CD, structural breaks, and autocorrelation. Here are the numbers that were used by Westerlund and Edgerton (2007):

$$\begin{aligned} \text{LM}_\tau &= \frac{\hat{\Phi}_i}{\text{SE}(\hat{\Phi}_i)} \\ \text{LM}_\Phi &= T\hat{\Phi}_i(\frac{\hat{\omega}_i}{\hat{\sigma}_i}) \end{aligned} \tag{8}$$

Considering Eq. (8), $\hat{\Phi}_i$ is the shadow of least square's estimator; the shadow of Φ's SE is $\hat{\sigma}_i$; whereas the shadow of Φ's SE's SE is $\text{SE}(\hat{\Phi}_i)$.

Long-run analysis

OLS, GMM, and "pooled ordinary least squares" are only a few of the alternatives available to researchers for determining the strength of the connection between the targeted variables. Researchers are therefore free to narrow down their options for the most effective technique based on the merits and shortcomings of each, even if such a decision really needs to be guided by the specifics of the dataset itself. All three of these tests cannot detect the CD, so keep that in mind (Li and Sun 2020; Guo and Zhong 2022; Wang et al. 2023). These tests can also be used to mitigate the potential consequences of mixed $I(1)/I(2)$ explanatory variables and produce a rigorous and robust result in the exogenous attribute of the regressors (0). In addition, the presence of endogeneity is not a problem when using these tests because they still produce valid and trustworthy results.

Parameter distribution is halted to a sustained level during outcome generation using Cup-FM testing, but parameters also absorb changes produced by changes in time by stimulating to a convergent level. Also, it is anticipated that the error terms will follow a constant pattern, and the factor model is described below.

$$\hat{\beta}\text{cup}, \hat{F}\text{cup} = \text{argmin}\frac{1}{nT^2}\sum_{i=1}^{n}(y_i - x_i\beta)' M_F (y_i - x_i\beta) \quad (9)$$

In Eq. (9), $M_F = I_T - T^{-2}FF'$, I_T is the demo of the elements, which is "the identity matrix" as represented by T_S', and the error terms are the reflection of "common latent factors." The initial calculation is assigned at the point F, and the operation is repeated until convergence is reached.

Results and discussion

Table 1 provides some introductory information about the variables that will be used in the empirical study. There is little variation between the mean and median for any of the given variables.

Our empirical research began with a check for cross-sectional dependency between nations before we applied the panel unit root test, cointegration, and long-run coefficients. For this purpose, we use the LM, CD_{LM}, CD, and LMadj tests to check for slope homogeneity and the test to check for cross-sectional dependence between nations. In Table 2, we see both sets of results. The results indicate that there is a rejection of the null hypothesis of no cross-sectional dependency at the 1% level of significance. This further substantiates the importance of international and regional cooperation. The null hypothesis that the slope is homogenous is rejected at the 1% level, as shown by the results of the test conducted by Karasoy and Akçay, (2019).

We used the second-generation unit root test (CIPS) established by Sebi and Vernay, (2020) for the cross-sectional dependency based on the results of the cross-sectional dependency and homogeneity tests. The CIPS findings are presented in Table 3. The results show that for level-formatted variables, the unit root cannot be rejected. In contrast, the level and first differenced forms lead to a static situation for all variables.

In addition, the cointegration test outcomes use the recommendations of Hou et al. (2019b). The results have been broken down into three distinct phases: no change, a change in the mean, and a change in the regime (Table 4). The results indicate a 1% long-term correlation between the studied variables. Also, the break estimator model, created by , has been used to defend the cutoff for each of the sated economies that fall within China's provincial jurisdictions. Zhang (2020) pioneered the aforementioned method for investigating cyclical patterns in data. Table 7's results display numerous examples of data with clear structural breaks. For each location, the structural fractures have had an effect on both global and local shocks.

Long-run estimated results

Investment in renewable energy sources has increased significantly due to GFI, which is unexpected. The coefficients for the influence of green financial development on renewable energy investment are 0.456 and 0.658, respectively, indicating that green financial development both raises the volatility of renewable energy investment and

Table 1 Descriptive statistics

	Mean	Median	Std. dev	Minimum	Maximum
LREI	3.226	3.079	1.998	0.745	6.985
GFI	5.965	5.655	1.526	0.012	11.854
LSWM	1.665	1.510	0.999	0.098	5.741
LER	5.902	5.844	1.552	1.010	8.256
LURB	9.562	8.332	1.245	0.124	14.662
LGDP	12.015	11.999	2.548	1.658	21.854

Table 2 CD tests

	LM	CD_{LM}	CD	LM adj
CD test				
LREI	33.542*	5.665*	−3.214*	3.395*
GFI	37.965*	3.521*	−2.965**	3.442*
LSWM	41.652*	8.542*	−4.652*	5.885*
LER	19.332*	6.145*	−5.245*	6.632*
LURB	23.852*	5.354*	−4.389*	3.999*
LGDP	27.999*	9.412*	−3.965	4.758*

Note: *, ** and *** denotes the 1%, 5% and 10% significance level

Table 3 CIPS unit root test

	LREI	GFI	LSWM	LER	LURB	LGDP
Level	−3.856*	−1.632	−2.652	−2.122	−4.625*	−1.542
1st difference	−5.745	−4.856*	−5.965*	−3.999*	−7.526	−3.589*

Note: *, ** and *** denotes the 1%, 5% and 10% significance level

Table 4 Results of Westerlund and Edgert on cointegration test

	No shift		Mean shift		Regime shift	
	Statistics	*P*-value	Statistics	*P*-value	Statistics	*P*-value
LM τ	−3.456	0.000	−3.245	0.000	−4.965	0.000
LM φ	−4.665	0.000	−6.114	0.000	−5.264	0.000

boosts the efficiency of renewable energy investment. The coefficient of green financial development also shows that during the study period, green financial development acted as a brake on the research institutions' ability to participate in renewable energy businesses. As was noted in the theoretical analysis, renewable energy enterprises face financing constraints in the early stages of their development, and these constraints may mitigate any positive impact the "green" attribute of green financial development has on the efficiency of renewable energy investments (Liu et al. 2021; Lin et al. 2022; Wang et al. 2022).

Reducing China's dependency on imports is one of the many benefits of achieving RE through material recycling in important GDP-influencing sectors in China. Materials can be recycled multiple times throughout the construction value chain, including throughout the production, planning, and decommissioning phases, as stated by Inês et al. (2020). With over 95% trash recovery and low environmental impacts, integrated wet recycling is a viable option for C&D WM in a country that ranks second globally in construction and demolition (C&D) waste production. Recycling aluminum, a key material in both manufacturing and APE, saves over 94.89% of primary and secondary energy needs, as pointed out by Abumunshar et al. (2020). Another field with promising applications in CE is the blue economy (BE), which is "the sustainable acquisition of marine resources achieved through decoupling economic activities and environmental degradation." Hence, GF practices must be adopted if the country's economy is to thrive in the long run.

In place of environmental taxes, we found that a rise of 1% point in the policy stringency index improved renewable energy investment (REI) by 3.44 and 2.85 percentage points, respectively. Similarly, despite modest variations in coefficient values, the relationship between GDP and urban population remained the same and had a highly significant impact. Trade openness typically has a negative effect on the REI variable, but in this case, it actually had a positive effect. In a similar vein, bureaucratic quality was negatively, but not significantly, related to the outcome variable. Finally, non-resident patents showed the same negative and statistically significant results, with a 1% rise in non-resident patents causing a loss of 0.188% in REG.

Table 5 Long-run results by CUP-FM and CUP-BC

Variable	CUP-FM		CUP-BC	
	Coefficient	*T*-value	Coefficient	*T*-value
GFI	0.456*	3.745	0.658*	3.569
LSWM	0.256*	1.524	0.966**	3.415
LER	3.444*	1.996	2.854*	1.096
LURB	2.965*	0.548	2.996*	0.964
LGDP	1.352*	0.254	2.745**	0.445

Note: *, ** and *** denotes the 1%, 5% and 10% significance level

At the 1% level of significance, the panel's GDP coefficient value was positive. Based on the coefficient value for GDP growth, we can deduce that an increase of 1% point leads to an increase of 1.352% and 2.745% in renewable energy generation (Human et al. 2021). It showed that a 3% and a 2.96% rise in the dependent variable resulted from a 3% and a 1% increase in the urban population, respectively. Similarly, despite modest variations in coefficient values, the relationship between GDP and urban population remained the same and had a highly significant impact. This study's findings are consistent with those of previous research, confirming the beneficial influence of GDP and urbanization on REI, but contradicting the conclusions drawn by other researchers about the impact of urbanization on renewable energy consumption. In particular, greener energy generation and consumption can be attributed to rising per capita GDP and urbanization (Tables 5 and 6).

Robust check

The coefficients of green finance by financial depth on investment are all significant. The effect is 1.856% of the total effect. Specifically, green finance increases loans for renewable energy enterprises, while bank loans have a positive and significant effect on renewable energy investment. Therefore, green finance can increase investment

Table 6 Robust check by CUP-FM

Variable	Model 1		Model 2		Model 3	
	Coefficient	*T*-value	Coefficient	*T*-value	Coefficient	*T*-value
LSWM	0.116*	1.089	0.589**	2.555	0.589*	1.224
LER	4.365*	1.347	1.333*	0.687	0.647**	1.652
LURB	1.654*	0.965	3.542*	0.654	2.965*	0.569
LGDP	1.385*	0.141	2.781**	0.357	3.564*	0.660
LFD	1.856*	0.745	–	–	–	–
LFE	–	–	0.896	0.351	–	–
LFS	–	–	–	–	0.665*	1.845

Note: *, ** and *** denotes the 1%, 5% and 10% significance level

of renewable energy. The coefficients of green finance by financial efficiency were significant, which indicates the financial efficiency effect of long-run results and found the positive impact. Green finance has a positive effect on the investment shortage by reducing the long-term loan amount of renewable energy enterprises. Specifically, the effect of green finance on renewable energy investment is less than its financial depth, similarly, the role of financial stability that it also significantly contributes to. Also, the coefficient for the beneficial impact of green finance's dominance in the renewable energy sector is 0.6655. This demonstrates that green finance growth has a multiplicative effect on investment in renewable energy. In addition, as the field of green finance evolves, more and more money is made available for the long-term financing of renewable energy businesses.

Conclusion and policy recommendations

This paper measures the degree of green finance index and the renewable energy investment in China's 29 provinces. The results show that within the study period, green finance index increases renewable energy enterprises and has a positive influence on renewable energy investment. Besides, for renewable energy investment, there has seen the positive contribution of waste management, environmental regulations, urbanization, and GDP to renewable energy investment. However, it is found that there is a positive contribution from financial depth, financial efficiency, and financial stability to renewable energy investment.

Similarly, this study has the following policy implications. First, the government, financial institutions, and businesses all need to work together to increase the beneficial promotion effect of green financial on investment in renewable energy. The most important thing is to let green finance serve as the compass by which resources are allocated. The government must complete the green financial system and actively support its growth. With law, on the one hand, a green financial system can be established; through financial, monetary, and environmental policies or green funds; on the other, the green economy can be supported and promoted. In order to encourage the growth of renewable energy businesses, financial institutions should provide novel green financial solutions. Green bonds, green insurance, and other tailored financing options for renewable energy businesses should be extensively developed alongside green credit. Policy financial institutions, meanwhile, should maximize the contribution they make to the growth of renewable energy businesses. To enhance investment efficiency, businesses working in the renewable energy sector should work to fortify their internal management and become more competitive in the financing market.

Reduced overall institutions of offshore wind power and improved profitability of projects can be achieved through the use of green finance policies such as carbon pricing, tradable green certificate, and green credit, which can increase future cash flows or reduce financial cost during the project lifetime. Yet because China's green finance policy structure is still in its formative stages, a single policy instrument may not be sufficient to encourage offshore wind power investment right now or in the near future. Thus, the policy mix that combines the two or three of them together may be important in the near future to guarantee the effectiveness and practicality of green finance policies. Furthermore, the GFI has been falling over the past few years, and the government can slow down the rate of reduction to ensure that offshore wind power investment remains lucrative during the COVID-19 epidemic.

As a result, renewable energy generation will increase worldwide as economies rise and cities expand. The adoption of stringent policies at the international or national level in the environmental domain and the use of clean environment-related technologies will amplify their beneficial effects. Even if there were brief periods of increasing costs following the financial crisis, overall investment in renewable energy capabilities has steadily expanded, surpassing investments in conventional energy capacities, and their cost has greatly fallen. Though several nations have committed to increasing their use of renewable energy, they will need to implement coordinated policies in order to achieve so. Large-scale adoption of clean technologies is predicted by several models and scenarios. Whether through tax incentives, loan guarantees, subsidizing research and development (despite a recent decline in R&D spending on the energy sector), or stringent environmental restrictions, governments can encourage investment in RE capacities. Nonetheless, there has been a recent surge in public support for green technologies. A highly competitive framework in the energy and environmental tax field, as well as the absence of major benefits in the near run, means that environmental tax alone does not constitute a strategy for increasing renewable energy generation or consumption. The findings allow us to advocate for the ongoing implementation of national and international environmental legislation that promote the use of renewable energy sources and safeguard the environment. Polluters should bear the costs of their misconduct. As a result of loose restrictions, export sectors in these nations have become highly specialized in economic sectors based on conventional energy-intensive items. With time, the efficiency and reliability of institutions' bureaucratic operations should increase.

The usage of renewable energy sources should expand beyond the electric power sector if sustainable development goals are to be met. Countries with access to abundant renewable energy sources should increase their spending in this sector to guarantee universal, low-cost consumption. Fair and affordable access to renewable energy sources will open up new opportunities for economic growth, boost employment rates, and improve people's health and the economy as a whole. The environmental benefits of laws as a whole suggest that OECD countries can pool their resources to advance the use of renewable and sustainable energy. The SDGs can be further advanced with this method. In a similar vein, OECD nations might set aside a certain sum of money to fund research and development into, and advocacy for, greener technology and greater environmental sustainability. Together, these kinds of efforts might be effective in lowering GHG emissions and solving energy security problems. Our research suggests that, in the same vein, administrative decision-making regarding energy mix and general economic strategies should be coordinated and efficient. Lawmakers and policymakers should exercise caution and guarantee that environmental regulations are carried out correctly. There needs to be a carbon price mechanism, for example, to prevent the market for coal and oil from being disrupted, and there should be policies that subsidize the transition to renewable energy.

The sample size of nations used in the analysis and the number of explanatory factors used in the analysis both represent limitations of this study. The production and utilization of renewable energy are multifaceted processes that are affected by numerous variables. Since developing countries depend on mostly on traditional energy sources and have significant financial constraints, studying them in the perspective of renewable energy generation could represent further investigation. Additional investigation could focus on incorporating additional descriptive components into the inquiry, such as exploitation or other official quality aspects, government public expenditures or R&D payments for environmental resolutions, FDI, and the energy prices index or it could employ a different methodology.

Author contribution Lianfeng Xia: conceptualization, data curation, and methodology; Yujia Liu: writing (original draft), data curation, and visualization; Xu Yang: supervision, editing, writing (review and editing), and software.

Availability of data and materials The data can be available on request.

Declarations

Ethics approval and consent to participate We declare that we have no human participants, human data, or human tissues.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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