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Research article

Impact of sustainable energy, fossil fuels and green finance on ecosystem: Evidence from China

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ABSTRACT

The adoption of sustainable energy has increased as a substitute for petroleum derivatives due to growing concerns about environmental degradation caused by pollution and non-renewable energy sources. This study aims to investigate the impact of sustainable energy, green finance, and fossil fuels on the ecology of China. Instead of using traditional intermediaries like CO2 and EF, we employed the ecosystem habitat index to evaluate the conservation of terrestrial ecosystems. This index measures the extent of habitat destruction, deterioration, and fragmentation. The research demonstrated that implementing ecological power and green finance in China has enhanced the country's ability to safeguard and enhance its ecosystem in the short and long term. Furthermore, the findings suggest that using non-renewable energy sources in China has heightened the risk to biodiversity and the ecosystem. The analysis indicates that prioritizing green funding and renewable energy sources is crucial for policymakers, legislators, and investors to safeguard and enhance ecosystem diversity.

1. Introduction

The energy industry is the most important contributor to worldwide carbon emissions. Decarbonizing the energy sector is crucial to keeping abnormal weather change below 2 °C, which agrees with the Paris Agreement's aims. This calls for extensive preparation to establish sustainable energy sources. The perspective-shifting guide for net-zero projects is that the Global Energy Organisation predicts that the contribution of renewable sources to global power will rise from 29 % to 88 % by the year 2050. However, renewable power has several risks to preserving biodiversity and the ecosystem. For example, according to a report published not too long ago, arranged hydro, wind, and sunlight-based power plants correspond with many significant regions for preservation. These regions include safeguarded areas, Key Biodiversity Regions, and wild regions. As a result, these power plants posed a risk to the biodiversity and ecosystem in these areas [1].

The correlation between energy use, economic growth, and environmental sustainability has been a central focus of scholarly investigation for many years [2–4]. [5] conducted fundamental research on the complex relationships between energy usage and economic progress, emphasising the substantial influence of energy consumption on the state of the environment. In addition, a study conducted by Grossman and Krueger (1995) introduced the hypothesis of the Environmental Kuznets Curve (EKC), which proposes that economic growth initially contributes to environmental deterioration. However, once a certain level of income is reached, the trend reverses, and further growth actually enhances ecological conditions. These influential studies established the foundation for

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comprehending how energy policies and economic strategies may be harmonized to promote sustainable development. Recent research conducted by Ref. [6] has delved deeper into the significance of renewable energy in reducing environmental effects and fostering economic development. Our study seeks to contribute to the ongoing discussion by investigating the impact of sustainable energy, fossil fuels, and green financing on China's ecosystem. We will use the ecosystem habitat index as a new way to analyze the environment.

Because hydropower is the most significant source of environmentally friendly energy globally (accounting for 47 % of the overall capacity for ecologically friendly power), it deserves particular attention even though all renewables are related to biodiversity risks. In addition, hydropower is anticipated to play a significant part in net-zero energy development. Its capacity is expected to quadruple by the year 2050 since it is a controllable energy innovation that does not rely on weather patterns. Both the construction of hydroelectric dams and their continued operation pose a threat to aquatic and terrestrial ecosystems. The world's 10,000 or more big hydroelectric dams (more than 15 m in level) are primarily responsible for the depletion of free-flowing streams and the loss of the species that depend on them. Nearly 66 percent of streams over 1000 km long currently have inaccessible portions. More than one-third of the natural landscape of the Earth, which encompasses more than 340,000 square kilometres (about the size of Germany), has been impounded by repository impoundment [7]. Because of the potential for these buildings and the surrounding foundation to have significant creature funding-related consequences inside riverine biological systems, hydropower's critics sometimes call it red energy. In addition to the impacts on the species composition and the connectedness of the ecosystem, there is another one. Mass fish death and injury are known to be caused by a variety of factors, including collisions with and entrapment in machinery such as generators, monitors, bars, and sluiceways; tension and stroke brought on by attraction (i.e., the limited admission of occupant fish to problematic regions); and attraction-related tension and stroke. Even if fish-friendly enhancements may be put to dams, the consequent decrease in fish mortality is insignificant. Considering the cumulative nature of the consequences of hydroelectric dams is essential. When many barriers are operated near one another, the impacts of each dam build up over distance and time, resulting in cumulative effects that are both stronger and more intricate. Fig. 1 represents the sources of renewable energy.

China is highly dependent on petroleum derivatives, which are the primary source of ozone-depleting components since their proportion of total energy consumption in 2025 will be 82.72 percent. According to Ref. [9], non-renewable energies kick off a chain reaction of environmental concerns, including mining, building, transportation, and non-renewable energy sources. These drills directly and significantly impact significant results (in mines, oil fields, streets, and ships). However, the CO2 emissions from using petroleum derivatives pose the most critical risk of drastically altering the environment. CO2 is a significant ozone-depleting substance, with almost 30 % of its total fixation in recent years [10]. This presents a substantial challenge to the preservation of the

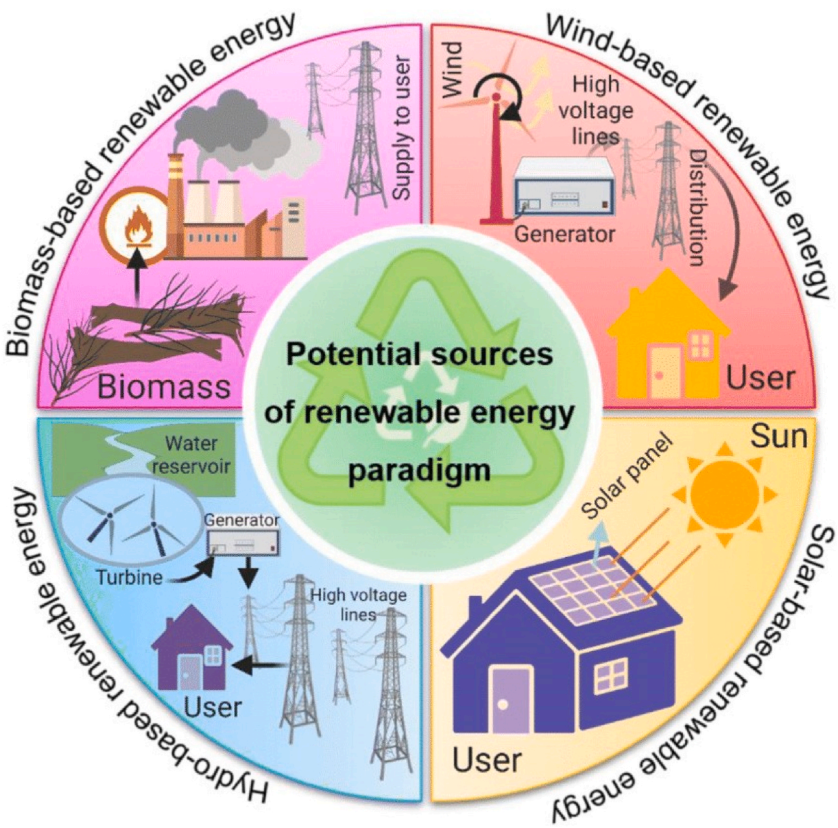

Fig. 1. Sources of renewable energy [8].

environment. Increasing CO2 levels negatively impact plants and contribute to temperature rises of one to 6 °C [11]. Unless CO2 emissions are cut by 80 %, this trend will continue. This feature can potentially trigger global extinction since an aberrant change in climate may start a chain of calamities that might wipe out whole species, such as heat waves, disease transmission, increasing sea levels, coastal floods, flooding, dry seasons, and fires. As a result, natural catastrophes can potentially eradicate a sizeable percentage of an ecosystem and its inhabitants, ultimately resulting in biodiversity loss. In addition [12], have shown that an increase in temperature has already altered the ranges of different species.

There is also the possibility that the "economic complexes" (EC) were developed by Hidalgo and Hausmann (2009) to determine the extent to which an economy is dependent on a centralized trade system, which may have repercussions for biodiversity. By including newly transported items in its database, the EC file can accurately portray the economic development of nations in connection to trade. The EC determines "the efficiency result of an economy that requests refined abilities and information." If this theory is correct, the financial complexity of a nation may affect the biodiversity of that country. One of the primary contributors to high CO2 emissions and the accompanying loss of biodiversity in nations with low EC is an increase in the demand for energy brought on by producing a wider variety of commodities at higher production volumes. However, the economy's complexity may assist in buffering biodiversity loss by integrating research, development, and clean technology into the production cycle. This will limit the usage of compounds that deplete the ozone layer and strengthen the biodiversity's resistance to the effects of these substances. Fig. 2 shows sources of renewable energy and their socio-economic impact.

According to Ref. [10], the primary focus of the United Nations' Sustainable Development aim is to end starvation while also fulfilling the objective of ensuring that everyone receives an appropriate amount of nourishment. Extension and bolstering of rural land has become an overarching peculiarity in the face of rapidly increasing crop curiosity [14]. This is because specialized constraints [15] and negative cooperative energies from expanding yield [16] thwart the technique to increase output and then spar-kilometers in the wild nature. The method aims to increase yield and then spare land for wild nature. According to Ref. [11], urban growth changes how land is used and has far-reaching, detrimental repercussions on the natural environment. The only exception to this rule is agriculture. According to Ref. [17], expanding land use authority and growing contributions of resources (such as water, pesticides, and manure) for agriculture would result in the destruction, fragmentation, and pollution of natural ecosystems [18], which would continue the decline of world biodiversity. According to Ref. [12], an increase in human perception would have a significant negative impact on the abundance of species.

According to Ref. [19], the worldwide practical result of this scenario is contingent on the ability to satisfy the need for food while preserving biodiversity [19]. found that successful preservation and restoration activities are critical for conserving species diversity. This is particularly true for initiatives that target species and habitats that cannot adapt to future environmental change. According to [20], it is crucial to highlight the possible conflict zones between the protection of biodiversity and the security of food supplies. Studies incorporating and examining species abundance in many distinct taxonomic categories may ignore conflict hotspots critical for a single, unambiguous type [21]. These findings were published in Ref. [21]. The majority of the assessments that did take into

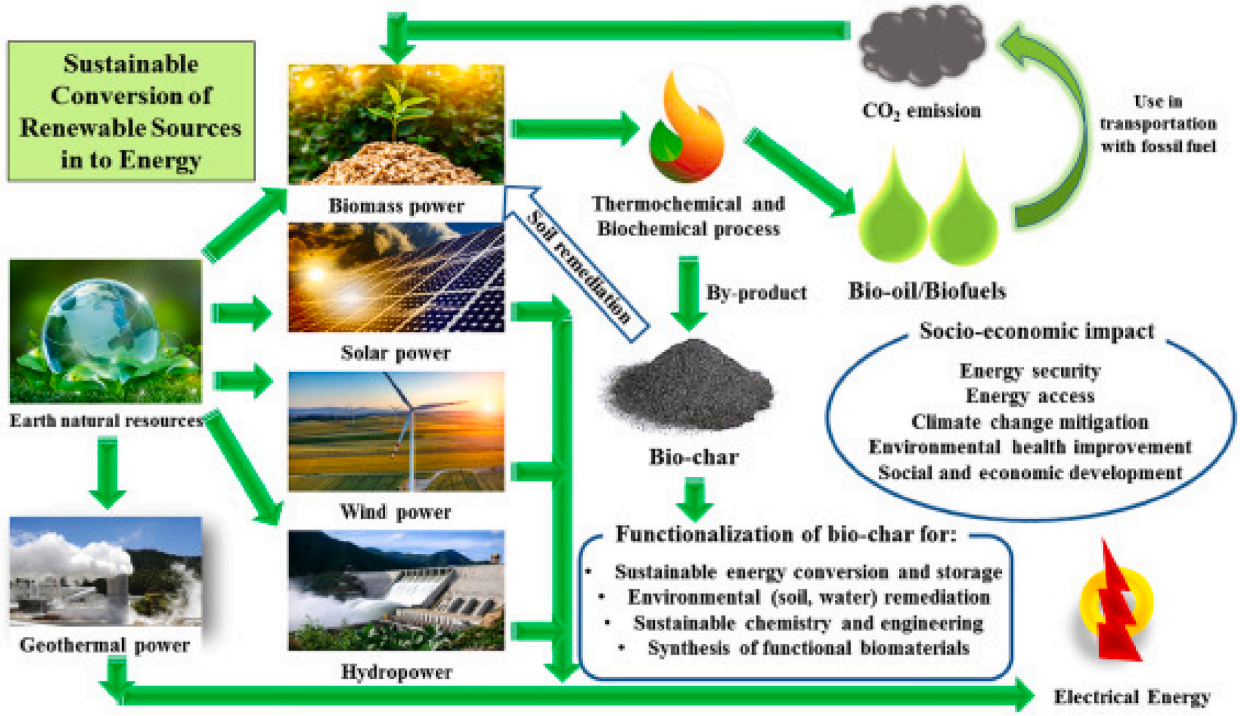

Fig. 2. Sources of renewable energy and their socio-economic impact [13].

consideration various directed classes [22] concentrated on the relationship between changes in land use linked with farming and biodiversity. However, these reviews ignored the possible psychological implications of urban growth on the natural environment.

The research contributions can be summarised as follows: This study is the inaugural examination of the correlation between China's ecosystem, renewable energies, non-renewable energy, and green finance. As per the findings of [20], human-induced carbon dioxide emissions are a major factor in driving environmental change. China has the highest carbon dioxide (CO2) generation rate among all countries. From 1990 to 2022, China has had the largest environmental impact, accounting for 28.5 % of global output. In addition, the researchers have been endeavouring to analyze the influence of non-renewable energy on numerous aspects, such as CO2 emissions and pollution that adversely affect the ecosystem. Access to these goods could have been improved. To tackle this problem, we examine the ecosystem habitat index, which quantifies the changes in the population of organisms from various sources, such as terrestrial, marine, and other aquatic ecosystems, and the physical structures that make up their environment. This includes the diversity within species, the differences between species, and the variations in biological systems. A biodiversity living space score of 100 indicates that a nation has not experienced any environmental calamities or instances of corruption.

Conversely, 0 represents a complete and extensive loss of territorial control (Stahlschmidt et al., 2012). An increase in the index indicates a positive change in the environment. The Biodiversity Heritage Index developed this record. This study employed the Bootstrap ARDL methodology to produce more reliable and conclusive results and notions that would demonstrate the significance of the technology.

The rest of this paper proceeds as follows. Section 2 presents a literature review; Section 3 discusses methodology and data; Section 4 presents results and discussions; and Section 5 concludes the paper and presents policy implications.

2. Literature review

Little effort has been made to investigate the potential connection between energy complexity (EC), renewable energy [23] and biodiversity (BD) [24]. examined the impacts of EC, biodiversity and REC on the ecosystems of sixteen of the world's most important trading nations. The study showed that the complexity of the monetary system affects the biological quality. In addition, the impact of EC on the climate was analyzed by considering 88 different worldwide instances. They discovered that higher concentrations of EC resulted in an improvement in the overall performance of the environment [25]. used the "quantile board relapse model" to data from 55 nations for every three pay periods between 1971 and 2014 to investigate the consequences of CO2 emissions. They claim that EC improves air quality in "major league salary nations" while lowering CO2 emissions in "low-and-center pay nations." OECD members investigated the "variety of commodity items on carbon force" using the "GMM and the quantile model" [26]; they worked as analysts for the "Normal Corresponded Mean Gathering (CCEMG), Cross-sectionally Expanded Autoregressive Dispersed Slack (CS-ARDL), and Increased Mean Gathering (AMG) assessor on the Relationship of Southeast Asian Countries (ASEAN)" between the years 1960 and 2016. The data indicate that an increase in monetary complexity leads to a rise in CO2 and EF. In addition, it was shown that the adverse effects of EC were far more pronounced in Indonesia than in Singapore. The shift from financially complicated environments to EF was seen as a potential causal factor. The investigation of forty-eight intricate economies using FMOLS and DOLS [27]. Found that there is a favourable association between effective communication and bio-impression.

Ongoing research has investigated the possibility of testing the EKC theory using monetary complexity rather than payment [28]. used the "cross-sectional autoregressive disseminated slacks" statistical method. The relationship between EC and EF seems to be a modified U when viewed in light of the data. It was also discovered that the intelligence level of an institution (its institutional character) improves the natural supportability of a situation and influences the link between EC and EF. A study that followed a similar pattern [29] investigated the impact that the European Community, Foreign Direct Investment, Renewable Energy [23], and Urbanisation had on CO2 discharges in the PIIGS countries [30] between the years 1990 and 2019, with a particular emphasis on FMOLS and DOLS. The findings demonstrated a deformed N and U-shaped pattern. So, these pieces do not use the EF to protect themselves from the erosion caused by natural processes. Given the above, our article may be seen as a perceptually astute report.

To explain this link, other articles adopt a different approach by concentrating on country-specific characteristics. For instance Ref. [31], employed the QARDL model to investigate the relationship between EC, petroleum derivatives, and EF in the United States. They concluded that EC and goods derived from petroleum contribute to a rise in EF in the United States [32]. investigated how EC, REC, non-REC, and globalization have all contributed to the problem of air pollution in the United States. He asserted that the U-shaped connection between EC and pollution was more accurately described as a C. In addition, the ARDL method was utilized in China to investigate EC's impact on EF. The analysis exposes both the current and future energy needs, and EC is also responsible for the construction of EF in China [33]. India evaluated the influence of EC, REC, non-REC, and globalization on EF. They utilized ARDL and VECM to assess data from 1990 to 2022, and their findings were similar to those of the previous study. Because of the impact, it can be concluded that CE, globalization, and REC all reduce the inherent weaknesses. The results of the VECM also suggest that there is a long-term causal connection between EF and EC.

Using board experiments and time series examination, scholars have looked at how human consumption of energy affects the natural world [34]. Using the NARDL, the researchers "researched the effect of the protection market and environmental change and sustainable power on biodiversity in BRICS" and found that the REC further developed a biodiversity file [35]. did a literature analysis on the subject, and one of the things they found was that the influence of energy on biodiversity might be either direct or indirect? In addition, he emphasized how dirty powers kick off a chain reaction of stressors that directly harm biodiversity. These stresses include the mining of minerals, the construction of infrastructure, the movement of goods, and the use of energy sources that are not renewable. Certain restrictions come with this kind of writing. We investigated the network between several biochemical and energy-based intermediates using this technique (Brown et al., 2020b). researched how the usage of energy and routine assets influenced the EF, carbon impression [36], and CO2 output of OECD nations. They emphasized that not using RE was detrimental to the environment while using REC was beneficial to the climate. He highlighted the prospect of EKC becoming present in countries that are still economically developing [37]. Employed MG, AMG, and DCCE for their research on emerging countries. According to the study, non-REC is responsible for a decline in environmental quality, while RE contributes to its improvement. According to Ref. [38], the countries of "Bangladesh, India, Pakistan, and Sri Lanka" (BIPS) supported comparable conclusions. It was also shown that REC improves people's overall quality of life.

[32] performed a study to understand better how REC, urbanization, and EF are related in different countries. According to the data, REC contributes to the expansion of EF, but non-REC and urbanization have the reverse effect [39]. analyzed the link between tourist visits, energy consumption, financial system vulnerability, and environmental footprint (EF). The findings indicated that energy was a factor that worked against EF in these countries. A vector autoregression was investigated by Ref. [40] between 1976 and 2016 in countries such as Mexico, Indonesia, Nigeria, and Turkey. In addition, FMOLS and DOLS were used to carry out the cointegration analysis. According to the research findings, the use of primary energy results in the destruction of EF [41]. In their study [42], "dissected the relationship between human resources, trade enhancement, economic development, and CO2" by applying the PMG to MINT nations between 1975 and 2010. According to their results, energy use has a detrimental effect on the surrounding ecosystem.

Alternately [43], found that EF was brought on in ASEAN countries by factors other than RE, but RE had no impact on EF. In addition [44], discovered data that corroborated the findings in MENA countries. In light of the results of this research, advances in REC may not always have to be accompanied by a comparable downfall in EF [45]. used the "NARDL in Pakistan and certified that main unfavourable shocks significantly affect EFs" as their source. Based on Algeria [46], evaluated the influence of acceptable energy on EF. Data collected over a prolonged period revealed an unmistakable link between REC, CO2 emissions, and EF. In addition, we found that REC, CO2, and EF all had a positive association with one another. Additionally, it shows that EF was a contributor to REC.

Researchers from various fields are starting to investigate the consequences of marine biodiversity depletion on the tourist industry [47]. This is due to the multidisciplinary character of environmental change. For instance, research focuses on the connections between anomalous alterations in common marine species' physiology, biochemistry, and genetics [48]. Researchers in this group evaluated the combined effects of environmental threats (such as seawater warming) and anthropogenic influences (also known as human stressors) (such as sewage releases), and they made substantial recommendations to sea and beachfront administration as a result [22].

[49] have pointed out how the behaviour of tourists concerning shoreline issues may change if the natural character of marine and seaside regions is adversely affected. According to Refs. [50,51], the negative impacts on the environment (such as coral bleaching, dead seagrass, water turbidity, and so on) may have a substantial influence on the economics of business and other 'personal happiness' elements of beachfront tourism. This is especially true for beachfront resorts.

In conclusion, it is essential to emphasize that most research has been done on coral reefs. This is because corals are foundational species that offer structural support for ecosystems that are very susceptible to changes in seawater temperature and salinity, in addition to acidification and harsh weather events [52]. Both as a barrier that stops the erosion of beaches and as a significant tourist attraction in their own right, they play an essential role in protecting the environment. On the other hand, other establishing species in the EU Mediterranean and Atlantic Ocean bowls, such as the phanerogam knolls from the classes, have been less intensively investigated [53].

An essential component of environmental risk assessment is the prediction of future threats (i.e., actual events) and the physical, social, ecological, and monetary deficiencies of the exposed components, as well as the capacity of networks to adapt to, endure and recover from unfavourable effects [54]. No one method can be used to analyze all of the potential dangers to the environment. Many studies have used data on environmental restrictions, often revealing that issues linked with transparency, vulnerability, and readiness are either driven by human activities or are not entirely addressed by human actions. Therefore, the prolonged danger results from networks' incapacity to react to an environmental threat by requiring strain reduction, moderation, or diversity [52]. Alongside this traditional portrayal of luck is a more fundamental approach focusing on the causes of faults [55]. These reasons may include the unsaid circumstances and political attitudes that give birth to unfair and biased economic situations.

The environmental impact chain is a solution that Eurac Exploration created in response to the need for unified strategies. Another idea was offered by Refs. [22,56], and the German collaboration (GIZ) 'catalyzed' its adoption in the Weakness Sourcebook [57]. Since then, a variety of industries, such as the economy, national security, aviation, fishing, farming, the urban cycle, food production, and consumption, have progressively embraced the impact chain framework for environmental risk assessment [52]. Currently, an ISO Norm known as ISO/DIS 14091 is being developed to encourage more widespread use of the impact chain. This is because the impact chain is considered a helpful tool for examining the effects of environmental change and does so in a way compatible with a practical strategy plan developed by leaders.

The IPCC first presented the Impact Chain Approach in its Fifth Assessment Report (AR5) in 2015. The creation of this tool was also beneficial to the IPCC SROCC report [58] and the IPCC AR6 report (IPCC, 2022). The most recent notion developed by the Intergovernmental Panel on Climate Change (IPCC AR6) defines 'risk' as a possible adverse effect of environmental change for human and financial institutions [58]. The impact of ecological change and how people have responded to it have entirely flipped the script on the idea of danger. According to this theory, risk is a multi-dimensional phenomenon that may take the form of threats or vulnerabilities and the exposed character of both conventional and financial systems [47,48,59].

3. Data and methodology

The dataset used in this study includes a wide range of variables to investigate the complex connection between sustainable energy, fossil fuel usage, green finance, and ecosystem health in China from 1990 to 2022.

- **Economic Complexity index**

In addition, the country's productive composition appearance, as determined by the Atlas of Economic Complexity index, provides a comprehensive representation of the range of goods that China exports. This reflects several characteristics of the country's economic structure that could impact environmental results.

- **Energy Consumption Data**

Moreover, the dataset contains information about both energy use and production. The World Bank's data from 2022 provides information on the proportion of various energy sources used in China's energy mix as a percentage of total final energy consumption. The BP-stats-review (2022) comprehensively analyses China's dependence on fossil fuels and its impact on energy security and environmental sustainability, specifically focusing on oil consumption measured in Exajoules. These variables allow for a detailed analysis of the shift towards sustainable energy sources and the difficulties presented by China's reliance on fossil fuels in its energy sector.

The dataset combines several sources of information to offer a full knowledge of the complex relationship between sustainable energy practices, fossil fuel usage, green finance initiatives, and ecosystem health in China. The study intends to utilize this extensive dataset to reveal empirical evidence concerning the influence of these elements on China's ecological resilience. The findings will then be used to guide policy initiatives that aim to promote sustainable development paths.

- **The Biodiversity Habitat Index**

The Biodiversity Habitat Index is a crucial measure to assess this study's environmental quality level. The index, obtained from the Yale Centre for Environmental Law & Policy, combines information on the abundance of habitats, variety of species, and ability of ecosystems to withstand disturbances in the Chinese ecological environment. It offers a comprehensive assessment of the overall state of biodiversity.

The Biodiversity Habitat Index (BHI) quantifies the effects of habitat fragmentation, degradation, and loss on terrestrial biodiversity. It combines species abundance data, habitat diversity, and ecosystem health status to address disturbances. The BHI score for a region is calculated using statistical models that predict ecological similarities based on abiotic and geographical factors. The similarity measure is represented on an ordinal scale, where 0 indicates no species in common, and 1 indicates that all species are in common. The BHI score for a certain cell is obtained by calculating the habitat condition of biologically similar places and then taking the average. Next, this metric is multiplied by the ecological distinctiveness of each grid cell to calculate a nation's BHI score, which indicates the country's capacity to preserve its various species even in the worst settings.

This assessment uses the biodiversity habitat index as a proxy for the environmental quality from 1990 to 2022.

$$\mathrm{lnBD}_{it} = \beta_0 + \beta_1 \mathrm{InEC}_{it} + \beta_2 \mathrm{InREC}_{it} + \beta_3 \mathrm{InNREC}_{it} + \varepsilon_t \quad (1)$$

Equation (1) depicts China's biodiversity and ecosystem, represents the economy's complexity, symbolizes renewable energy, and means fossil fuels. Table 1 contains a summary of the series.

3.1. Development of the biodiversity habitat index

The BHI "gauges the impacts of natural surroundings loss, debasement, and fracture on the normal maintenance of earthbound biodiversity" [60]. The SPI featured that the "BHI estimates how the spatial circulation of natural surroundings misfortune, corruption, and discontinuity influences collections of species. It likewise gauges the outcomes of neighbourhood level misfortune debasement on the worldwide variety of networks and environments". The BHI is registered utilizing factual strategies to anticipate the biological similitudes among regions given abiotic and geological environmental elements. The natural correspondences produced by the models range somewhere between 0 and 1, where 0 shows no species in like manner while 1 is all species. The natural comparability information is joined with the terrain alteration information by the Region Logical and Modern Exploration Association. In this manner, the "BHI score for a given cell rises to the typical natural surroundings state of all biologically comparative cells" [61]. The "BHI score for a nation rises to the weighted mathematical mean for all cells inside the nation, weighted by every cell's biological uniqueness;

Table 1
Variables description and sources of data.

Variables	***Description***
InBDit	*Biodiversity Habitat Index*
InECit	*The diversity and quantity of exports from an entity might provide insight into the nation's economic makeup.*
InRECit	*% of total final energy consumption*
InNRECit	*Oil : usage – Exajoules*

hence, this score addresses a country's corresponding maintenance of territory supporting unmistakable collections of species across the full scope of conditions" [60].

3.2. Examinations of stationarity and cointegration

Traditional methods of evaluating unit roots, such as the extended ADF tests, do not consider the actual date of the breakdown; accordingly, the continuing study uses [62] and Perron and [63] appraisals to detect primary breaks. The underlying unit root valuations that were used wholly ignored any asymmetry. Both unit root tests fail due to spurious assumptions, indicating that the time series is not stationary. In contrast to this hypothesis, the option shows that all analyzed components have a single break date. There exists a need between the involved members to determine cointegration. The BARDL test [64] was used in the review. The t and f tests' power has been increased by the BARDL testing, a more advanced form of the ARDL model. This model was presented by Ref. [65] using the "Monte Carlo recreations" and indicated that this project had a sensible scale. The fundamental features of the earlier ARDL limits models were obtained only for F and T subordinate evaluations. The updated model differentiates between two savage scenarios based on the one fully slack factor and dependent and free elements. In the most extreme instance, the F-test is the only determinant of all neglected significance levels in the standard ARDL model.

T-tests are also employed on the dependence's slack to assess the network between series. A new F-test was presented on the deficiency of standard ARDL's illustrative pointers (RT, MF et al., n. d.). Therefore, the BARDL method keeps track of the overall series of F-test, *t*-test, and F-test gaps. He acknowledges using these tests to identify "cointegration, non-cointegration, and declined" events. Two cracked situations prove the series mixture is unsound. "The first savage circumstance happens when the slacked level ward variable is immaterial, while the second ruffian case happens when autonomous factors are insignificant."

Additionally, this econometric approach is preferable to accurate models with a few investigated elements. If the benefits are more than the CV of the bootstrap method, then the cointegration between the series will be acknowledged. The following factors combine to produce the ARDL model:

$$\Delta\ln BD_{it} = \alpha_0 + \sum_{i=1}^{r}\beta_1\Delta\ln BD_{t-j} + \sum_{i=1}^{r}\beta_2\Delta\ln EC_{t-j} + \sum_{i=1}^{r}\beta_3\Delta\ln REC_{t-j} + \sum_{i=1}^{r}\beta_4\Delta\ln NREC_{t-j} + analyze\gamma_1\ln BD_{t-j} + \gamma_2\ln EC_{2t-j} + \gamma_3\ln REC_{t-1} + \gamma_4\ln NREC_{t-1} + \omega ECT_{t-1} + \varepsilon_{1t} \quad (2)$$

Equation (2): indicates white noise; represents the "first difference process operator"; is the "constant term"; designates coefficients of the evaluated variables shortly; means factors of the variables being assessed over a long period.

Error correction phrase relating to the rate at which a system reaches equilibrium; denoted by the symbol s. However, we apply the "Ramsey RESET test; " and the "ARCH test, normality test, Brush-Pagan-Godfrey heteroscedasticity test" to confirm the validity of the scientific procedure used in this study. In addition, "CUSUM and CUSUM-square" are used to test the model's reliability. To further understand the connection between the designated research variables, the "Granger causality technique" is also used. This method shows "the speed of adjustment of variables from long-term equilibrium." ECM Equations: (3–6)

$$\Delta\ln BD_{it} = \alpha_0 + \sum_{i=1}^{p}\beta_1\Delta\ln BD_{t-j} + \sum_{i=1}^{q}\beta_2\Delta\ln EC_{t-j} + \sum_{i=1}^{q}\beta_3\Delta\ln REC_{t-j}\sum_{i=1}^{q}\beta_4\Delta\ln NREC_{t-j} + \omega ECT_{t-1} + \varepsilon_{1t} \quad (3)$$

$$four\Delta\ln rEC_{it} = \alpha_0 + \sum_{i=1}^{p}\beta_1\Delta\ln EC_{it-J} + \sum_{i=1}^{q}\beta_2\Delta\ln BD_{it-J} + \sum_{i=1}^{q}\beta_3\Delta\ln REC_{t-j} + \sum_{i=1}^{q}\beta_4\Delta\ln NREC_{t-j} + \omega ECT_{t-1} + \varepsilon_{1t} \quad (4)$$

$$\Delta\ln rREC_{it} = \alpha_0\sum_{i=1}^{p}\beta_1\Delta\ln REC_{it-J} + \sum_{i=1}^{q}\beta_2\Delta\ln BD_{it-J} + \sum_{i=1}^{q}\beta_3\Delta\ln EC_{t-j} + \sum_{i=1}^{q}\beta_4\Delta\ln NREC_{t-j} + \omega ECT_{t-1} + \varepsilon_{1t} \quad (5)$$

$$\Delta\ln rNREC_{it} = \alpha_0 + \sum_{i=1}^{p}\beta_1\Delta\ln NREU_{it-J} + \sum_{i=1}^{q}\beta_2\Delta\ln BD_{it-J} + \sum_{i=1}^{q}\beta_3\Delta\ln EC_{t-j} + \sum_{i=1}^{q}\beta_4\Delta\ln REC_{t-j} + \omega ECT_{t-1} + \varepsilon_{1t} \quad (6)$$

In this case, (delayed ECT) stands for the initial variance. The "Wald test statistics (F)" determine the causal relationship between variables over the long term. Finally, we used the "Canonical cointegration regression (CCR)," "fully modified least squares (FMOLS)," and "Dynamic least squares (DOLS)" statistical models to ensure the stability of our research.

Table 2
Correlation matrix analysis findings.

	BD	EC	NREC	REC
BD	1	0.686684	−0.48686	0.62206
EC		1	−0.66064	0.621664
NREC			1	−0.62868
REC				1

4. Experimental results

Table 2 illustrates the connection, and the results demonstrated that the relationship factor "r2" is not precisely the CV, which signifies that the utilized model does not have multicollinearity. Therefore, it is often assumed that the employed model is not multicollinear. Table 3 demonstrates I(1) coordination between InBD, InREC, InNRE, and InEC by fixing them at the primary contrast. This test's findings corroborate the claims that the values exceed BARDL CVs. Therefore, this confirms significant cointegration among the tested series, providing evidence for cointegration among them. We can observe subtle variations and similarities when comparing China's correlation matrix analysis findings with those of other countries like Germany and Brazil. China demonstrates a significant positive correlation between biodiversity (BD) and economic growth (EC), as well as a moderate negative relationship between non-renewable energy consumption (NREC) and both BD and EC.

On the other hand, Germany shows slightly higher correlations between BD and EC, suggesting a stronger connection between economic growth and efforts to conserve biodiversity. Germany has a stronger and more noticeable inverse relationship between NREC, BD, and EC, indicating a more assertive approach to reducing dependence on non-renewable energy sources than China. Furthermore, the strong relationship between renewable energy consumption (REC) and both biomass consumption (BD) and (EC) in Germany indicates the need for a more comprehensive strategy for embracing renewable energy. However, Brazil might display stronger links with China because they are either at similar stages of growth or have similar governmental approaches. The findings in this study are consistent with prior research, which emphasises the significance of sustainable energy transitions and green financing initiatives in promoting biodiversity conservation and economic development [66]. Analyzing these relationships within the framework of various nations' strategies for sustainable development can offer significant insights for policymakers seeking to advance biodiversity conservation and economic growth concurrently.

The correlation matrix analysis results are consistent with earlier research that emphasises the substantial influence of economic complexity and renewable energy usage on biodiversity [5,67]. highlighted the significant impact of energy use on environmental results, endorsing the established beneficial relationship between economic complexity and biodiversity. This study presents a detailed explanation by demonstrating the clear opposite connection between the usage of non-renewable energy and biodiversity, supporting the findings of [68] regarding the harmful environmental effects of fossil fuels. This model effectively integrates the economic complexity index to accurately represent the diverse array of knowledge and skills that contribute to sustainable development.

Table 3 displays the outcomes of unit root examinations for different variables at the original level and after taking the first differences, together with the Zivot-Andrews (ZA) test. All variables at this level display t-statistics below the crucial levels, suggesting non-stationarity. Nevertheless, upon applying differencing, all variables exhibit t-statistics that surpass the critical values, indicating the presence of stationarity. This indicates that the variables are integrated of order one, or I(1), which suggests a long-term link between them. Analyzing these results about data from other countries, such as Germany and Brazil, could uncover comparable trends of non-stationarity and integration, particularly in variables associated with economic growth and energy use. Such commonalities highlight the worldwide scope of difficulties and shifts in sustainable development. Prior research corroborates these explanations, underscoring the importance of unit root tests in comprehending the stationarity of time series data and guiding econometric analysis [69]. Furthermore, these discoveries establish an essential basis for additional examination, such as cointegration tests, to investigate the enduring connections between variables and direct policy interventions to foster sustainable development.

The findings of stationarity and cointegration support the stability of the relationships between the variables, which is in line with the conclusions of [70,71]. These studies also found stable long-term relationships between energy consumption, economic growth, and environmental quality. This study's adoption of the Bootstrap ARDL method is new and yields more robust and accurate results. It is particularly effective in detecting unit roots and structural fractures, hence improving accuracy compared to traditional ADF and ZA tests.

The findings of the ARDL cointegration approach in Table 4 are consistent with the earlier study conducted by Ref. [72], which highlighted the significant influence of economic complexity on enhancing environmental performance. This study expands upon these insights by showcasing the enduring beneficial effects of utilizing renewable energy on biodiversity in China. As a result, it offers empirical information that supplements previous discoveries and underscores the significance of green finance programmes.

The findings of the testing model are accounted for in Tables 5 and 6. The results of this framework indicated that using non-sustainable forms of energy had a negative correlation with biodiversity at both the 5 percent and 1 percent levels of significance.

Table 3
Unit root tests.

PV test	At Level		At Δ 1st Differences		
Variables	t.stat	SBD1	Variables	t.stat	SBD1
lnBDt	−1.650	1996	ΔlnBDt	−9.790 **	2012
lnRECt	−1.965	1998	ΔlnRECt	−8.543**	2011
lnNRECt	−2.706	2002	ΔlnNRECt	−6.468 **	2004
lnECt	−2.031	2009	ΔlnECt	−9.651 **	2014
ZA test					
lnBDt	−2.451	2013	ΔlnBDt	−7.445**	2017
lnRECt	−2.851	2008	ΔlnRECt	−8.551**	2019
lnNRECt	−1.436	2006	ΔlnNRECt	−8.9651**	2004
lnECt	−2.851	2007	ΔlnECt	−7.112**	2015

Table 4
ARDL cointegration approach results.

Bootstrap ARDL and Diagnostic test findings						
Model(0,0,0,1)	F.statistic−OV	t.statistic−DV	F.statistic−IDV	X^{-Rrt}	x−Not	x−Bbgh
(BD,REC, NREC,EC)	4.950 **	−4.120 **	6.102 **	2.37^{FS}	0.979^{FS}	0.506^{FS}
Bootstrap-based table CV 5 %	4.818	−3.761	5.711	0.154^{pv}	0.616^{pv}	0.870^{pv}

China's ecology declined by 0.175 % across relatively short distances and by 0.632 % over rather long distances for every "1 %" increase in NREC. The ARDL findings provide empirical support for Grossman and Krueger's (1995) Environmental Kuznets Curve concept, demonstrating that economic growth initially leads to a decline in environmental quality but later leads to its improvement. This work contributes to the ongoing topic by using quantitative methods to demonstrate the immediate detrimental and long-term positive impacts of renewable energy consumption on biodiversity. This research enhances our comprehension of the complex relationship between these factors.

The inverse relationship between the use of non-sustainable energy sources and biodiversity can be understood from two perspectives: directly through transformation and indirectly through deterioration of the natural environment at petroleum derivative extraction sites, contamination, and debasement [73]. In addition, "after extraction, the dispersion, refinement, and utilization of non-renewable energy sources again influence biodiversity straightforwardly through environment obliteration related with framework improvement and contamination. Increases in global average temperature caused by the emission of greenhouse gases and other ozone-depleting pollutants from NREC are also harmful to biodiversity (IPCC, 2014). When dirty energies are used, other stresses are triggered, such as those associated with mining, construction, transportation, and non-renewable energy sources [14]. To put it another way, "expanding access for lumberjacks, ranchers, trackers, and settlements" [74] details the effects on terrestrial, aquatic, and marine biological systems.

However, REC had a beneficial effect on BHI in China. This indicates that a one percent increase in REC increases China's capacity to manage its biodiversity by 0.887 % in the near term and by 0.791 % in the long time. REC's popularity as an alternative to petroleum derivatives has increased in response to mounting concerns about the health and biological disasters of fog pollution.

The experimental results also suggested that a 1 % crucial increase in financial complexity significantly influences biodiversity in China, decreasing it by 0.366 % and increasing it by 1.321 % in the short run and long run, respectively. This is because of how EC processes a country's creation of knowledge, information, and natural abilities. There is little doubt that in advanced economies like China's, more varied products are developed using a wider breadth of knowledge and skills. Financial complexity may mitigate biodiversity risk, and it can centralize research and development, clean innovation, and the skills necessary to produce ecologically responsive goods.

The results obtained from the FMOLS and CCR analyses support a previous study conducted by Ref. [75] about the harmful impact of non-renewable energy on environmental quality and the advantages of renewable energy. The incorporation of economic complexity and green financing as variables in this study offers a fresh viewpoint that emphasises the various factors that contribute to biodiversity enhancements, emphasising the significance of combining economic and environmental policy.

The data indicates the rate of change is 27.7 %. The CUSUM and CUSUM represent the models' stability, as shown in Fig. 3. Table 4 provides an overview of the resulting symptoms. Homoscedasticity and independence from autocorrelation are shown using the "Breusch-Agnostic Godfrey heteroscedasticity test" for the model under study. In addition, the Ramsey RESET test shows that the model is correct and stable, and the ordinariness test confirms that the model in question is widely disseminated.

Table 6 presents the results of FMOLS and CCR investigations, which show the negative impact of REC on biodiversity in China. Please refer to Fig. 4 for further details. Table 6 shows that a flood in REC resulted in a biodiversity increase of 0.589 % in FMOLS testing, but in CCR testing, the increase was just 0.261 %. The findings of these investigations demonstrated that the utilization of non-sustainable power impacts China's biodiversity. The results showed that an increase in the use of non-environmentally friendly power led to a decrease in biodiversity by 0.004 % and 0.172 % in the FMOLS and CCR testing models, respectively. The results from the FMOLS and CCR models indicate that the level of economic complexity significantly impacts China's variety ratio. The findings indicated that in the FMOLS and CCR analyses, the BHI experienced growth of 0.375 % and 0.111 %, respectively, following an EC flood.

This study used the Granger causality evaluation to investigate the series' causal relationship. Table 7 and Fig. 5 reveals the results of the analysis. The findings of the F-measures confirmed a unidirectional causal relationship between the examined components—consequently, the leading causes of China's degrees.

Table 7 displays the results of the Granger causality analysis, presenting the test statistics for the associations between the variables

Table 5
ARDL results.

Variable	Coefficient	t.stat	p.value
ΔlnRECt	0.366**	2.572	0.025
ΔlnNRECt	−0.175*	−2.177	0.052
ΔlnECt	0.162 *	2.846	0.091
ECTt−1	−0.277 ***	−8.179	0.000

Table 6
FMOLS, CCR, ARDL results.

Variable	ARDL	FMOLS	CCR
	Coefficient	Coefficient	Coefficient
lnRECt	1.321***	0.589 ***	0.261 **
lnNRECt	−0.632**	−0.004	−0.172 **
lnECt	0.586 **	0.375 ***	0.111 *

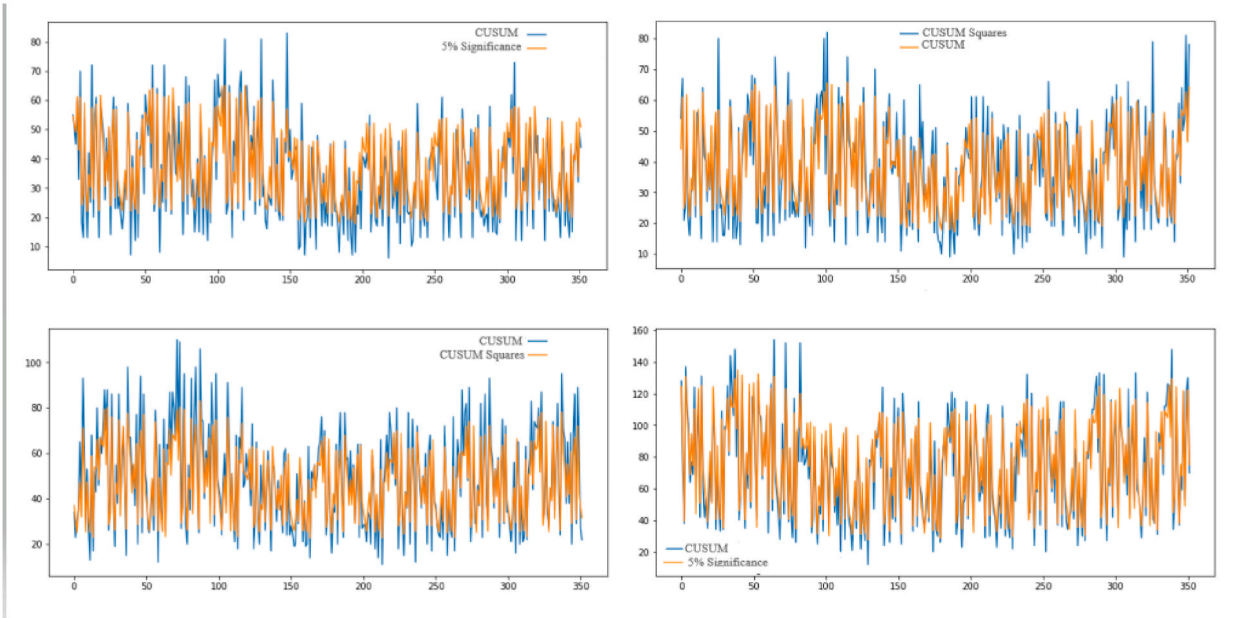

Fig. 3. CUSUM and CUSUM Squares tests (author source).

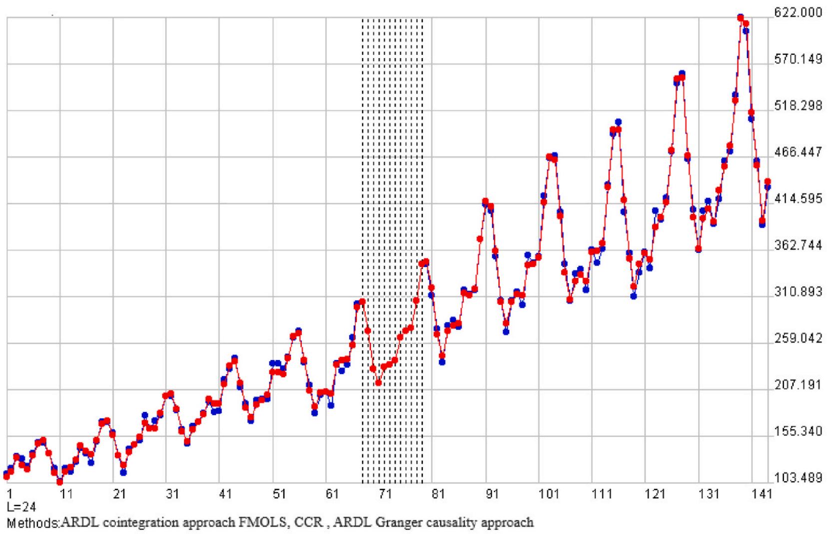

Fig. 4. Time series analysis and forecast (author source).

ΔlnBD, ΔlnEC, ΔlnNREC, and ΔlnREC. There is empirical evidence suggesting that changes in (ΔlnEC) have a causal relationship with changes in (ΔlnBD), changes in (ΔlnREC) have a causal relationship with changes in ΔlnEC, and changes in ΔlnREC have a causal relationship with changes in ΔlnNREC. Statistically significant test statistics support these causal relationships. These findings indicate

Table 7
Findings of the Granger causality approach.

	ΔlnBDt	ΔlnECt	ΔlnNREC	ΔlnRECt
ΔlnBDt	–	2.364 *	0.246	1.140
ΔlnECt	1.349	–	0.438	1.129
ΔlnNRECt	0.485	2.357*	–	1.188
ΔlnRECt	1.189	3.468**	3.219**	

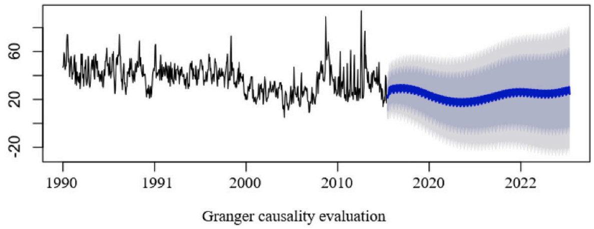

Fig. 5. Findings of the Granger causality approach (author source).

cause-and-effect correlations in specific directions, suggesting that changes in economic growth may affect biodiversity, and changes in renewable energy use may affect non-renewable energy consumption.

Nevertheless, the lack of substantial causation between (ΔlnNREC) and the other variables suggests no clear influence from non-renewable energy consumption on the other variables in the system. Analyzing these findings about those of other nations, such as Germany and Brazil, could offer valuable insights into the distinct dynamics of sustainable development trajectories and their policy implications. Existing literature highlights the significance of utilizing Granger causality analysis to comprehend the chronological order and direction of interactions between variables [1]. These findings enhance our comprehension of the intricate interplay that propels sustainable development and environmental conservation endeavours.

The Granger causality results are consistent with the causative connections identified by Ref. [76] about the linkages between economic complexity, energy use, and environmental impacts. This study contributes to the current body of research by illustrating the one-way relationship between the consumption of renewable energy and both economic complexity and biodiversity. It emphasises the possibility of implementing specific policy interventions to foster sustainable development.

5. Conclusion and policy implication

The loss of biodiversity and ecosystem degradation is the strongest warning to the planet, and the world is now facing a widespread vanishing of animals with far-reaching consequences. Using the Bootstrap ARDL, this study examines the dynamics of China's renewable energy sector, monetary complexity, conventional energy, and biodiversity during 1990–2022. To make a call on whether or not the data was stationary, we relied on the main break unit root tests developed method of diagramming cointegration between series. The short- and long-term correlation was analyzed using the Bootstrap ARDL (BARDL) method developed by Ref. [60]. The unit root tests and cointegration findings reveal that all components are fixed and cointegrated. BARDL's results showed that more attention to efficient energy use will positively impact China's biodiversity. This evidence implies that increasing the use of green electricity would contribute to the growth of China's biodiversity.

Financial complexity was also shown to be beneficial for biodiversity change. The use of resources that are not renewable is linked to a decrease in overall biological diversity. The finding of causality indicated that the list of biodiversity-rich natural environments was related to either REC or non-REC in just one way. The combined VECM causality also found that NREC, EC, and REC are the overall causes of biodiversity. The CCR and FMOLS for power test also found that economically complex and environmentally friendly power contributes to the development of biodiversity.

This investigation has demonstrated that REC further promotes biodiversity. Chinese experts should invest in greener energy to avoid biological catastrophes. This would bring down biodiversity misfortune and convert into "green' development." However, that does not mean Chinese experts ignore REC's benefits or have not launched initiatives to promote the technology. Recently, China has invested heavily in renewable energy construction (REC) projects. For instance: "In 2016, the BRICS New Improvement Bank, of which China is a member, gave its most memorable round of long haul green credits worth $811 million in April to support clean energy projects for its individuals". "The result is just a spot of good ideas that developments towards efficient power energy may very well be a pointless pursuit all things considered," the authors write, despite all the hopeful predictions.

Given that arrangements are inadequate to achieve green growth without solid installations [77]. Directly via alteration and the disturbing influence of nature at petroleum product extraction sites, pollution and corruption also contribute to the harmful effects of non-sustainable power on biodiversity [78]. In addition, "after extraction, the appropriation, refinement, and utilization of petroleum products again influence biodiversity straightforwardly through natural surroundings obliteration related with foundation improvement and contamination" (Area and collaborators, 2013). The emission of GHG via consumption, including from NREC, is harmful to biodiversity through unnatural weather change (IPCC, 2014). Moreover, this effect will be "in a roundabout way by expanding access for lumberjacks, ranchers, trackers, and settlements," as stated by Ref. [10] all point to the adverse effects of these on terrestrial, aquatic, and marine ecosystems.

In addition, the findings demonstrated that EC promotes biodiversity. As a result, China is among the top 20 most complicated economies, as measured by the Economic Complexity (EC) index. By combining R&D with eco-friendly innovation, we can increase biodiversity while decreasing our reliance on ozone-depleting substances, which in turn helps the planet's diminishing ozone layer.

5.1. Policy implications

The following policy recommendations are suggested:

The correlation between renewable energy consumption and biodiversity highlights the necessity for worldwide policies that encourage the growth and utilization of renewable energy sources. Governments ought to allocate resources towards the development of infrastructure and technology that streamline the shift from fossil fuels to renewable energy sources, minimising the detrimental effects on ecosystems.

The paper emphasises the use of economic complexity as a policy tool to enhance biodiversity. Policymakers should prioritise the diversification of economies through the promotion of industries that employ modern knowledge and technology. This approach can result in the development of more sustainable and environmentally friendly production methods.

The results affirm the efficacy of green finance in advancing sustainable energy and conserving biodiversity. Financial institutions and governments globally should strengthen green finance instruments, such as green bonds and sustainable investment funds, to bolster projects that promote environmental sustainability.

The interdependence of energy use, economic intricacy, and biodiversity necessitates the implementation of integrated policy frameworks. Environmental policies should be coordinated with economic and energy policies to generate mutually beneficial effects that advance sustainable development in several aspects.

5.2. Limitations and future research directions

The current study work is limited by its exclusive focus on China, which may restrict the applicability of its conclusions to other nations or regions with distinct socio-economic and environmental circumstances. Moreover, the dependence on secondary data sources can add biases or inaccuracies in measurement, emphasising the importance of being cautious when interpreting the findings. To overcome these constraints, future research might conduct comparative studies across multiple nations to gain a more thorough knowledge of the interconnections between sustainable energy, economic growth, and biodiversity protection. In addition, including primary data gathering methods, such as surveys or field experiments, has the potential to improve the accuracy and dependability of the results. Moreover, investigating the impact of supplementary variables, such as governance systems or cultural elements, could provide a more profound understanding of the aspects that influence sustainable development. Finally, conducting longitudinal studies that monitor changes over time would enable the analysis of dynamic processes and assess the long-term effectiveness of policy initiatives.

Potential avenues for further investigation in your work involve extending the analysis to encompass a comparative study across multiple countries or areas to comprehend better the intricate interplay between sustainable energy, economic growth, and biodiversity protection. Primary data-gathering methods, such as surveys or field experiments, can improve the comprehensiveness and dependability of research outcomes. Furthermore, exploring the intermediary function of governance structures, policy interventions, and cultural factors could provide a valuable understanding of the mechanisms that propel sustainable development pathways. Conducting longitudinal studies that track changes over time would allow for evaluating the long-term impact of policy initiatives and understanding the dynamic nature of these interactions. Moreover, investigating the possible harmonies and compromises among several sustainability objectives, such as ensuring a stable energy supply, promoting economic growth, and preserving the environment, could provide valuable insights for developing comprehensive and interconnected policy strategies. In summary, these potential research areas could enhance our comprehension of the elements that impact sustainable development paths and inform the creation of more efficient policy measures.

Ethics approval and consent to participate

Not applicable.

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Data availability

We collected relevant data from World Bank open data available at https://data.worldbank.org/. For any further query on data, corresponding author at email address *awangzt945@163.com* may be approached.

CRediT authorship contribution statement

ZuoTeng Wang: Writing – review & editing, Visualization. **Sheng Zeng:** Writing – review & editing, Writing – original draft, Visualization. **Zohan Khan:** Writing – review & editing, Writing – original draft, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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