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The Role of Natural Resource, Carbon Finance, FinTech, Financial Inclusion in Advancing Energy Efficiency: Does the Synergy Promise a Greener Future?

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There has been a substantial body of research examining the relationship between resource growth and resource finance; limited attention has been devoted to the resource-energy interface. This gap has motivated the current study, which examines the relationship between resources, finance, and energy in the context of China. However, China has undertaken extensive efforts to diversify its energy portfolio; coal remains a dominant source of energy to meet national demand. China has been actively pursuing alternative pathways for achieving its target of carbon neutrality by 2060. Drawing attention towards an extensive literature review, this research has posited that natural resources, eco-financing, fintech, and financial inclusion are key determinants of energy efficiency. Using annual data spanning 2000 to 2023, the study employs the Quantile Autoregressive Distributed Lag (QARDL) model to examine the heterogeneous impacts of these determinants across the distribution of energy efficiency. Empirical findings reveal that fintech consistently enhances energy efficiency in both the short- and long-run across multiple quantiles. On the other hand, financial inclusion and natural resource availability negatively affect energy efficiency, suggesting the presence of structural and behavioural inefficiencies. Moreover, carbon finance is found to have no statistically significant effect on energy efficiency across all quantiles and time horizons. Based on these insights, the study proposes targeted policy recommendations to advance China's transition toward a more sustainable, energy-efficient economy.

Keywords: *Fintech; Financial Inclusion; Energy Efficiency; Natural Resources; Carbon Financing.*

Introduction

Higher levels of pollution and the rapid expansion of modern economies have intensified globally, driving demand for energy resources to support domestic and industrial activities (Dorahaki *et al.,* 2018; Fengsheng *et al.,* 2023). Continuity of extraction and consumption of non-renewable energy sources such as coal, oil, gas, and petroleum has accelerated resource depletion and heightened environmental risks, including greenhouse gas (GHG) emissions, chemical waste, and ecological degradation. These environmental harms would not only undermine human health but also weaken the quality, availability, and resilience of natural resources. In response, efficient energy use has emerged as a key tool for mitigating these challenges. Energy efficiency involves using less energy for delivering the same output while reducing waste, conserving resources, and protecting environmental quality (Nizetic *et al.,* 2019; Tan *et al.,* 2022; Zhao *et al.,* 2021). The improvements in energy efficiency contribute to climate change mitigation, lower air pollution, enhanced energy security, reduced price volatility, and improved overall productivity (Fengsheng *et al.,* 2023;

Shove, 2018). Examples include enhancing building insulation, adopting energy-efficient lighting, and implementing smart infrastructure, which reduce energy loss (Nyangon & Byrne, 2021). There has been a wider range of strategies that could enhance energy efficiency, including technological innovation, improved industrial processes, reduced transmission and distribution losses, and increased use of renewable energy sources (Moslehpour *et al.*, 2021; Tronchin *et al.*, 2018). Renewable energy has originated from resources that can be renewed, recycled, and naturally replenished, which has become central to this transmission (Al Mamun *et al.*, 2021; Gyamfi *et al.*, 2018). Wind and solar energy, for instance, could provide lower-cost, lower-maintenance alternatives which produce negligible post-production waste (Ode & Ayavoo, 2020; Royston *et al.*, 2018). Renewable energy has been proven effective for reducing carbon emissions, mitigating water and thermal pollution, and securing sustainable resources for future generations (Moslehpour *et al.*, 2022; Trotta, 2018; Iris *et al.*, 2019). Global momentum towards sustainable development has been supported by frameworks such as SDG-7, which impacts access to affordable, reliable and sustainable energy, motivating economies to maximise the utility of existing resources (Kwong *et al.*, 2023). Sustainable development is commonly conceptualised around three pillars: economic development, redistribution of resources to improve the quality of life, and intergenerational equity (Cheba *et al.*, 2020; Munoz & Cohen, 2017; Zemlickiene *et al.*, 2025). To achieve these goals, nations need to adopt models such as the sharing economy (SE) and circular resource use, which promote efficiency, reduced costs, and minimal environmental externalities (Geissinger *et al.*, 2019; Farmaki *et al.*, 2025; Lestari & Soewarno, 2024). Scholars have increasingly focused on the critical role of financial mechanisms in achieving energy efficiency. Many economies are struggling to generate sufficient fiscal space to invest in energy-efficient technologies due to monetary constraints, heavy fiscal burdens, and limited economic resilience (Liu *et al.*, 2022a). To address these challenges, emerging financial tools such as eco-financing, fintech, and financial inclusion have attracted attention for their potential to expand green investment and support energy transitions. In all these mechanisms, eco-financing has been identified as particularly effective for improving energy efficiency (Lee *et al.*, 2023). In contrast, differences in the structure of financial institutions' funding flows and technological support frameworks often hinder the contributions of fintech, financial inclusion, and natural resource rents to energy efficiency (Vikas et al., 2022). Global concerns, particularly climate change, have prompted countries to adopt financial regulatory measures to reduce energy consumption and strengthen low-carbon development pathways (Alquliti, 2022). Green finance has emerged as a pivotal tool for this process, promoting environmentally responsible investments and enabling firms to achieve lower carbon footprints from sustainable business practices (Jaiwant & Kureethara, 2023). Larger-scale greening initiatives, supported by national nature reserve laws and afforestation programs, have shown contributions to improved ecological conditions, from urbanisation, which remains a mixed factor with both harmful and restorative environmental effects (Feng *et al.*, 2021; Muganyi, Yan & Sun, 2021; Nenavath & Mishra, 2023; Hsu, 2024). The outcome of optimisation alignment between industrial structure and green development has become significant for ensuring ecological sustainability (Zhao *et al.*, 2025). Financial inclusion and financial innovation have also played a significant role in supporting sustainable development and economic growth. Recent studies have shown that fintech, digital finance, and digital financial inclusion have positively influenced green energy adoption; however, digital finance enhances the overall effectiveness of financial systems (Qin *et al.*, 2024; Nguyen *et al.*, 2023; Lulaj & Mekaniwati, 2025; Zeng *et al.*, 2025). These financial instruments could increase access to capital, enhance green technological adoption, and help regulators formulate targeted policies to strengthen green transitions. China has represented a compelling context for studying these dynamics, being the world's largest industrial producer. China is also facing major structural challenges, including declining energy efficiency, heightened environmental pressures, rising production costs, and weaker innovation capacity (Lei & Kocoglu, 2025; Yan *et al.*, 2025; Dong *et al.*, 2024). The government's "Made in China 2025" strategy focuses on transforming its manufacturing sector by shifting from resource-intensive growth to environmentally sustainable production models (Huang & Ge, 2025). Although Covid-19-related disruptions and output declines affected different industries, China is aiming to revive its industrial growth through production, renewable energy expansion, and technological modernisation (Bilan *et al.*, 2020; Moslehpour *et al.*, 2022a; Nar, 2025; Li *et al.*, 2024). However, as industrial output declines and the sector's contribution to GDP decreases, the need to improve energy efficiency becomes even more critical. However, the current literature offers significant body of work that examine the interactions between natural resources and economic growth (Gylfason & Nganou, 2025) as well the relationship between financial development and resource utilization (Tekin & Shahbaz, 2025), there has been a crucial gap which remains in understanding of integrated resource-finance-energy nexus, specifically within the context of major emerging economies such as China. Previously studies analyse these relationships in isolation such as the effect of financial development on energy consumption (Zhang & Zhou, 2021), the impact of natural resources on environmental outcomes (Ahmed *et al.*, 2020), and role of green finance in driving sustainability transitions (Wang *et al.*, 2022; Bartuseviciene *et al.*, 2025) without sufficient consideration of how these dimensions interact to shape national energy efficiency. Additionally, China's aggressive renewable energy expansion and carbon neutrality commitments mean that the country will continue to rely on coal to meet growing energy demand, thereby intensifying the strategic significance of identifying financial and technological mechanisms to enhance energy efficiency (Li & Lin, 2023). While scholars have begun to explore the impact of fintech (Huang & Qiu, 2022; Yang *et al.*, 2024), eco-financing instruments (Gong *et al.*, 2021), and financial inclusion (Xu & Xiao, 2021) on various aspects of economic and environmental performance, the empirical literature still lacks a coordinated examination of how these financial innovations collectively influence energy efficiency when interacting with natural resource dynamics. Most existing studies adopt symmetric modelling frameworks that fail to capture distributional heterogeneity across different levels of energy efficiency, thereby limiting our understanding of how financial and resource-related factors behave under varying economic conditions (Nasir *et al.*, 2022). Moreover, research focusing specifically on China has not yet incorporated a quantile-based methodological approach capable of identifying nonlinear, asymmetric, and quantile-dependent effects within this multidimensional nexus. This omission is particularly significant given China's structural transformation, rapid financial digitalisation, and evolving energy policy landscape, all of which suggest that the effects of fintech development, financial inclusion, carbon finance, and natural resource dependence may vary substantially across different energy-efficiency regimes. Taken together, these gaps underscore an urgent need for a comprehensive, methodologically robust investigation into the resource–finance–energy nexus, one that integrates natural resources, eco-financing, fintech, and financial inclusion into a unified empirical framework and evaluates their heterogeneous impacts on China's energy efficiency across multiple quantiles and time horizons. The primary aim of this study is to empirically investigate the multidimensional relationships among natural resources, eco-financing, fintech development, and financial inclusion, and their combined impact on energy efficiency in China, using the Quantile Autoregressive Distributed Lag (QARDL) model over the period 2000–2023. Specifically, the study seeks to uncover both short-run and long-run quantile-dependent effects within the resource–finance–energy nexus, thereby providing a deeper, more nuanced understanding of how financial innovations and resource dynamics interact across different levels of energy-efficiency performance. This approach enables the study to generate evidence-based insights and policy recommendations that support China's transition toward a more energy-efficient and carbon-neutral economic structure.

Literature Review

The goal of green finance theory is to attract private capital through financial services such as bonds, shares, insurance, and private equity funds into green sectors, including renewable energy, environmental protection, and energy conservation. (Sharma *et al.*, 2022). Green bonds are fixed-income instruments issued to finance conservation efforts. These bonds often offer various tax benefits to increase adoption and bridge the green finance gap. (Wen, 2021). Green investments are expected to be financed by private capital to the tune of 85–90 %, with government funding making up the remaining 10-15 %. The current pricing system fails to accurately reflect the positive externalities of green efforts, making it difficult to direct private capital into green industries. The theory supports the study by influencing green finance to Greening China's Energy Landscape through the interconnected linkage of indicators, Eco-Financing, FinTech, Financial Inclusion, and Natural Resource Rents for Enhanced Energy Efficiency, which ultimately promotes greener growth.

Greening China's Energy Landscape by exploring the Synergy between Eco-Financing, FinTech, Financial Inclusion, and Natural Resource Rents to increase the Energy Efficiency of the linked dynamics, the research gap highlights a dearth of knowledge on the greener growth in China. Previous studies have not evaluated the combined influence of these variables in analysing the impact of sustainable growth in China, as the literature has focused on individual components. It suggests a lack of empirical knowledge about interactions among various determinants, which might yield more extensive and nuanced insights in the context of China. This study is more integrated, with an interconnected specific methodology and a context-specific approach, to bridge the literature gap and develop effective solutions. Research on the potential contributions of energy efficiency and financial inclusion to a sustainable environment is scarce. Policy makers will provide a holistic examination of comprehensive strategies for a greener Chinese landscape.

The depletion of fossil fuel supplies, heightened rivalry, and the emergence of resource-hungry nations are all transforming the global energy environment. Moreover, the militarisation of energy policy is triggered by the growing energy competition. Energy security has thus been elevated to an important foreign policy goal. (Yoneva, 2021). China's efforts to address its domestic energy challenges and adapt to new conditions are changing perceptions of the nation abroad. It explores the fundamentals of China's efforts to enhance energy efficiency and promote green growth, while accounting for current events.

Natural resources, eco-financing, economic growth, and industrialisation all help meet the objective of carbon neutrality set by the COP26 resolution and enhance the production of renewable energy. It is advised that Asian economies with this empirical foundation take advantage of eco-financing opportunities to achieve carbon neutrality (Chau *et al.*, 2023). It implies that eco-finance decreases CO2 emissions while accelerating energy transition, which can assist ASEAN governments in upholding COP26 resolutions. Policymakers in the chosen economies should urge the banking industry to embrace eco-financing practices to achieve long-term environmental sustainability (Dinh *et al.*, 2022). Vietnam's SE transition was positively and significantly correlated with green financial innovation, eco-financing, carbon taxes, economic openness, inflation, and industrialisation. These results aid policymakers in creating fresh approaches to the SE transition (Lam *et al.*, 2023). Green financing, technological advancement, REO, REC, industrialisation, and population growth are all favourably associated with sustainable development. It assists regulators in developing legislation on sustainable development through green finance, energy, and technology (Moslehpour *et al.*, 2023). China has made significant progress towards achieving its carbon-neutrality objectives and improving environmental quality thanks to both initiatives. Additionally, they provide nations with a solid foundation for economic sustainability, enabling them to address environmental degradation and climate change. It highlights the input-output structure and uses negative yield in environmental quality and green growth. The results highlight the significance of clean energy and environmentally friendly financing for a nation's long-term prosperity, which may drive green economic growth (Qing *et al.*, 2023).

A study showed that funding strategies significantly affect energy efficiency. Out of the three funding options, green finance is the most suitable and encouraging for energy efficiency. The main causes of the diminished participation of FinTech and financial inclusion in energy efficiency include differences in attributes, funding sources, money transfer systems, transition systems, and types of financial institution support. To attain energy efficiency, however, theorists need to revisit FinTech transaction structures and features of financial inclusion, including green bonds. (Liu *et al.*, 2022a). In OECD countries, fintech directly increases energy efficiency. Additionally, it increases the use of renewable energy sources and environmental management patents, which tangentially increases energy efficiency. Energy-focused fintech companies with North American headquarters can contribute more to energy efficiency. (Teng & Shen, 2023a). Fintech's impact on energy intensity is more noticeable in western China. However, the influence of finance on fossil energy consumption clearly follows a hierarchical pattern, with eastern regions outnumbering their central and western counterparts. Fintech has little effect on energy intensity in the low-level fintech group, but it increases fossil energy consumption in the high-level fintech group. While lowering energy intensity, increased marketisation can help mitigate the effects of fintech on energy usage. (Zhu *et al.*, 2024; Zhang, 2024). Fintech can directly and significantly improve carbon efficiency at the city level and above, up to and including the prefecture level. The mechanism analysis indicates that by funding green innovation or financial science, fintech might improve carbon efficiency. The heterogeneity analysis suggests that fintech has a substantial effect on carbon efficiency in the eastern parts and cities with the largest market potential. Economic distance or inverse distance matrices used in spatial regression models demonstrate the spatially substantial impact that fintech has on enhancing urban carbon efficiency (Teng & Shen, 2023b). A study demonstrated that fintech has a positive effect on the energy transition of middle-income countries. The study also discovered that the transition to renewable energy is positively impacted by government efficacy. Furthermore, it demonstrated the significant potential impact of economic growth, industrial value addition, urbanisation, and foreign direct investment on the energy transition within the selected population. Achieving net-zero carbon emissions and developing energy transition plans for policymakers are practical implications that are outlined in the research analysis. (Udeagha & Ngepah, 2023).

A study demonstrates that financial inclusion significantly raises energy efficiency. An approximate 6.5% boost in energy efficiency would come from a unit rise in financial inclusion. The estimates support the main findings that one of the main paths to financial inclusion for improving energy efficiency is marketisation. (Yu & Tang, 2023). A study found that funding strategies significantly affect energy efficiency. Out of the three funding options, green finance is the most suitable and encouraging for energy efficiency. The main causes of the diminished participation of FinTech and financial inclusion in energy efficiency include differences in attributes, funding sources, money transfer systems, transition systems, and types of financial institution support. To attain energy efficiency, however, theorists need to revisit FinTech transaction structures and features of financial inclusion, including green bonds. (Liu *et al.*, 2022a). All socioeconomic metrics improve with financial inclusion, except employment in developing nations. Compared with having access to financial services, using them has less influence. However, the impact of energy efficiency differs significantly across nation-states and socioeconomic categories, with a nation's economic growth determining the outcome. All things considered, the impact of energy efficiency is highest in developed nations, but it is negligible in growing and developing economies (Oyewole *et al.*, CO2 emissions are influenced by financial inclusion, import volume, and GDP, but energy efficiency and the magnitude of exports lower CO2 emissions. To achieve sustainability and reduce pollution, we need to increase financial inclusion. In light of these details, public-sector initiatives must be in line with environmental and energy-efficiency standards in order to attain financial inclusion (Tufail, Song, Umut, Ismailova, & Kuldasheva, 2022). Energy efficiency also benefits from political risk, human capital, and green innovation. Nevertheless, the early effects of political risk improvement are negative before they become advantageous later. Improving financial inclusion through the growth of green innovation and human capital is essential to enhancing energy efficiency in terms of the policy consequences. In the meantime, it is important to investigate ways to enhance the political risk profile in order to establish a stable financial system and boost energy efficiency (Khan *et al.*, 2023b).

The adoption of greener technologies and increased energy efficiency in E-7 economies significantly reduces carbon emissions by boosting energy productivity. GDP statistics show a positive correlation with emissions; however, the use of renewable energy has a negative effect, underscoring the need to promote clean energy. To mitigate climate change and stimulate economic growth, policymakers in the E-7 economies may enhance institutional quality, raise energy productivity, and use natural resource rents to support sustainable resource management (Chen *et al.*, 2023). A study's empirical results suggest three strategies for fostering economic activity and achieving sustainable development in the area: increased investment in technology and energy efficiency, remittance controls, and sustainable resource use (Khan et al., 2023a). Empirical evidence indicates that natural resources influence sustainable development differently. Forest rents have the opposite effect on sustainable development compared to mineral and natural gas rentals. While environmental technology development has a positive but small effect on global sustainable development, energy productivity is a crucial component of sustainable development (Fu & Liu, 2023). Rents from natural resources are among the major factors that degrade the environment. World leaders have convened since the previous global climate meeting to advance the objectives of the Paris Agreement. It demonstrated a positive correlation between carbon and methane emissions and natural resource rents, suggesting a negative correlation between natural resource rents and the environmental goals of the COP26 (Sadiq *et al.*, 2023).

Theoretical Underpinnings

The theoretical basis for this study consisted of an integrated framework that draws on Green Finance Theory, the Sharing Economy Theory, and broader principles of Resource Efficiency and Sustainable Development. These theories provide a clear explanation of how eco-financing, fintech development, financial inclusion, and natural resource dynamics interact to shape China's energy-efficiency trajectory. Green Finance Theory has argued that targeted financial instruments, such as green bonds, green lending, insurance products, and equity-based green funds, could attract private capital to environmentally beneficial activities, internalise positive environmental externalities, and reduce financing barriers (Sharma *et al.,* 2022). This theory suggests that well-designed green financial markets can lower the cost of capital for renewable energy, environmental protection, and energy-shaving technologies. Although market pricing mechanisms often fail to account for environmental benefits, private investors are less incentivised to support green sectors without clear financial signals and policy interventions (Wen, 2021). Within the context of China, this theory has provided a basis for understanding how eco-financing mechanisms such as carbon finance, green credit, and green bonds can facilitate the shift from fossil-fuel-driven economic structures to energy-efficient models aligned with China's 2060 carbon neutrality target. The integration of eco-financing into the national financing architecture is therefore theoretically associated with improvements in energy efficiency, the stimulation of green technological progress, and the reduction of capital constraints associated with low-carbon investments.

Complementing the green-finance theory, the Sharing Economy Theory offers an additional conceptual lens to focus on the optimisation of resources, collaborative consumption, and digital-platform-enabled transactions (Pouri, 2025). The sharing Economy Model assumes technological innovation, specifically in digital platforms for data analytics and peer-to-peer financial systems, enabling more efficient resource use by reducing waste, lowering transaction costs, and minimising unnecessary production (Xiong *et al.,* 2025). It has been closely aligned with the rise of fintech, which leverages digital infrastructure, big data, blockchain, and AI-driven tools to expand access to financial services and support greener investment behaviour. The Sharing Economy Model motivates the development of socio-technological solutions to maximise energy efficiency and reduce environmental footprints (Moslehpour *et al.*, 2022b).

The resource efficiency framework additionally underpins the research by linking natural resource rents with sustainable economic development. The Resource efficiency theory focuses on economic systems that should minimise input use while maximising output value to preserve resources for future generations. The literature indicates that natural resource exploitation has frequently led to environmental degradation, reduced energy availability, and increased pollution when economies become overly dependent on extractive industries (Fu & Liu, 2023; Sadiq *et al.,* 2023). Efficient resource management, renewable energy adoption, and technological innovation could break the cycle of resource-led environmental decline. From this perspective, natural resource rents could either hinder or enhance energy efficiency, depending on whether they are used to support fossil-fuel-based energy systems and redirected toward energy expansion and environmental technologies (Chen *et al.*, 2023).

Theoretical underpinnings integrate wider Sustainable Development Theory, which emphasises that energy efficiency plays a crucial role in achieving sustainable economic progress, environmental protection and social welfare (Hussein *et al.*, 2025). The sustainable development literature establishes that improvements in energy efficiency reduce environmental pollution, support the penetration of renewable energy, and enhance national productivity (Zhang *et al.*, 2025). Empirical studies further highlight the essential role of financial inclusion and fintech in achieving sustainability goals, arguing that inclusive financial systems stimulate investments in clean energy technologies and enable households and firms to adopt energy-efficient solutions (Yu & Tang, 2023; Oyewole *et al.*, 2023). China's alignment with the Paris Agreement and the SDGs positions energy efficiency as a cornerstone of long-term climate and economic strategies, reinforcing the theoretical significance of examining the linkage among green, digital, and natural resource finance.

Research Methodology

Research Design and Data Collection

The present study aims to estimate the energy efficiency in China. For this purpose, the energy efficiency has been assessed through financial inclusion, Fintech, carbon finance, total natural resources and economic growth. Considering the research focus and its aims and objectives, secondary data spanning the period from 2000 to 2022 is selected due to data availability. The researcher has implemented different statistical techniques to analyse the data. The basic model of the study for empirical estimation is specified as follows:

$$EEF_t = \beta_0 + \beta_1 FI_t + \beta_2 CF_t + \beta_3 FINTECH_t + \beta_4 TNR_t + \beta_5 EG_t + \varepsilon_t \qquad (1)$$

Where, EEF= energy efficiency
FI = Financial inclusion
FINTECH= Fintech
TNR = Total natural resources
EG = Economic growth

Description of Variables

There are variables in this study. The description of these variables is present sequentially below:

- ***Energy Efficiency (Dependent Variable)***

Energy efficiency is the utilisation of less energy for the performance of a similar task or the formation of similar results (Saunders et al., 2021). In this study, this variable was used as the dependent variable. To measure energy efficiency, the energy intensity level of primary energy (MJ$/2017 GDP) is used.

- ***Financial Inclusion (Independent Variable)***

Financial inclusion refers to access to financial services that aid in building wealth, such as credit, loans, savings, equity, and insurance. (Ozili, 2021). In the present research, this variable has been studied as an independent variable. Following the study of Van, Vo, Nguyen, and Vo (2021)We measure financial inclusion using Domestic credit to the private sector (% of GDP).

- ***Fintech (Independent Variable)***

Fintech refers to the financial technology, which is used to explain new technology that aims to improve and automate the provision and utilisation of financial services (Vives, 2017). In this study, Fintech is also studied as the independent variable. We developed a composite FINTECH index using three indicators: internet users (% of population), fixed-telephone subscriptions, and fixed-broadband subscriptions, all per 100 people.

- ***Economic Growth (Independent Variable)***

Economic growth is the standard measure of the value added resulting from the manufacturing of goods or services in a country during a specific time period (Kira, 2013). This study has taken GDP (constant 2015 US$) as the independent variable.

- ***Carbon Finance (Independent Variable)***

All financial services related to reducing greenhouse gas emissions are referred to as "carbon finance," including bank loans, financing, direct investment and the exchange of carbon credits (Kaifeng & Chuanzhe, 2011). Carbon finance is measured as international financial flows to developing countries for research and development and the generation of renewable energy. The researcher has considered this variable as the independent construct in this study.

- ***Total Natural Resource Rents (Independent Variable)***

The total natural resources rent is the sum of natural gas rents, the sum of oil rents, coal rents (soft and hard), forest and mineral rents (Ampofo et al., 2020). This construct is the independent variable of this study. Total natural resource rents (% of GDP) are used as a measure of natural resource rents in the present study.

Statistical Techniques

In the present study, the researcher used various tests. The researcher first conducted the descriptive test to obtain summary statistics for the data. This test enables the researcher to understand the characteristics of the data, which inform subsequent tests. In the second step, the researcher conducted a unit root test to assess the dataset's stationarity.

Unit Root Test

There are many unit root tests to assess the stationarity of time-series data. In the present study, the statistical test named the Augmented Dickey-Fuller (ADF) test was proposed by (Dickey & Fuller, 1979) and the Phillips-Perron (PP) test proposed by Phillips and Perron (1988) are used to identify the stationarity or non-stationarity of a time series dataset, which is a modified form of the Dickey-Fuller Test, and the Dickey–Fuller equation is augmented by the lagged values of the dependent variable in this test, which ensures that the error term is not correlated (Murshed, 2019). ADF test's null hypothesis is $\rho = 1$, which suggests the existence of a unit root and non-stationarity. The alternative hypothesis is that $\rho < 1$, implying stationarity. We can reject the null hypothesis and conclude that the time series is stationary if the test statistic is less than the critical value. On the other hand, if the test statistic is greater than the critical value, the time series is not stationary, and there is not enough data to reject the null hypothesis.

QARDL Approach

We employ the QARDL estimation technique to examine the short- and long-run relationships between the dependent and independent variables. The QARDL method is applied for the following reasons. First, according to Cho, Kim, and Shin (2015) This approach takes into consideration the locational asymmetry. The QARDL estimates depend on the position of the dependent variable within the conditional distribution, which in turn depends on the locational asymmetry. Second, the QARDL model considers both the long- and short-term behaviour of the dependent variable across changes in the conditional quantiles of its distribution. Third, the linear ARDL model generally does not account for the impact of variables over time. The QARDL approach considers this estimation, as it measures changes in relationships across different quantiles. Last, this method is superior to other non-linear and linear methods, such as non-linear and linear ARDL models, which explain non-linearity by dropping the magnitude to zero. In contrast to these methods, the QARDL is a data-driven approach. Thus, the QARDL method enables us to test the long-run equilibrium effects of independent variables on the dependent variable at conditional quantiles (Shahzad, Orsi, & Sharma, 2024). Therefore, based on these reasons, the QARDL method is the most appropriate for understanding the asymmetric relationship between variables. The QARDL model in its simple form can be represented as follows:

$$EEF_t = \alpha + \sum_i^p \beta_1 EEF_{t-i} + \sum_i^q \beta_2\, FINTECH_{t-i} + \sum_i^r \beta_3 CF_{t-i} + \sum_i^s \beta_4 FI_{t-i} + \sum_i^u \beta_5\, TNR_{t-i} + \sum_i^v \beta_6\, EG_{t-i} + \sum_i^g \beta_7\, URB_{t-i} + \epsilon_t \quad (2)$$

Where, α is the intercept and ϵ shows the error or disturbance term. βThese are the parameters that capture the relationship between the independent and dependent variables. The lag order selected based on the SIC criterion is shown by p, q, r, u, g, v and s. The equation in quantile form is written as follows:

$$QEEF_t = \alpha(\tau) + \sum_i^p \beta_1(\tau) EEF_{t-i} + \sum_i^q \beta_2(\tau) FINTECH_{t-i} + \sum_i^r \beta_3(\tau)\, CF_{t-i} + \sum_i^s \beta_4(\tau) FI_{t-i} + \sum_i^u \beta_5(\tau) TNR_{t-i} + \sum_i^v \beta_6(\tau) EG_{t-i} + \sum_i^g \beta_5(\tau) URB_{t-i} + \varepsilon_t(\tau) \quad (3)$$

In the above equation, $\varepsilon t(\tau)$ denotes the error term, and (τ) shows the conditional quantile level.

Findings and Discussion

Summary Statistics

Summary statistics show the maximum and minimum values of the variables under observation. In addition, the summary statistics table displays the mean, median, standard deviation, skewness, kurtosis, and the Jarque-Bera (J-B) test. The normality of data series is assessed using skewness, kurtosis, and the J-B normality test. The J-B test statistic is statistically significant, indicating that the data series is not normally distributed.

Table 1

Summary Statistics

	EI	FI	FINTECH	CF	TNRR	GDP
Mean	8.441	135.77	-3.33000	212000	3.346	92212000
Median	8.605	125.62	0.1167	131000	2.451	87712000
Maximum	10.91	189.60	1.561	140000	9.648	17613000
Minimum	6.298	100.4	-1.378	2481000	0.863	28312000
Std. Dev.	1.75	26.979	1.000	2760008	2.360	47612000
Skewness	0.041	0.568	0.027	3.443	1.087	0.2483
Kurtosis	1.45	2.076	1.638	15.402	3.338	1.7609
Jarque-Bera	2.36	2.145	1.856	201.25***	4.847***	1.781
Probability	0.30	0.342	0.395	0.0000	0.088	0.410
Observations	24	24	24	24	24	24

After that, we check the stationarity properties of the series using unit root tests. To test the stationarity properties, we applied two tests, the ADF test proposed by Dickey and Fuller (1979) and the PP test proposed by (Phillips & Perron, 1988) to check the stationary properties. The findings of both tests are given in Table 3. All variables are found to have mixed orders of integration, except for CF. All variables are stationary at the first difference.

Table 2

Unit Root Tests

Variables	ADF		PP	
	Level	**First difference**	**Level**	**First difference**
EI	-0.600	-3.8399**	-0.736	-3.479*
FI	0.631	-4.542**	1.338	-4.543**
FINTECH	-0.741	-2.863**	0.356	-4.503***
CF	-3.808**	--------	-3.797**	---------
TNR	-1.898	-6.226***	-1.788	-6.207***
EG	3.478	-3.295**	4.331	-4.071**

*Where *, **, and *** represent significance at 10, 5 and 1 per cent, respectively.*

Long Run and Short Run effects

The findings in Table 5 determine the long-term effects. The results suggest that a 1-unit increase in financial inclusion is associated with a 1.18-unit increase in Energy efficiency. Similarly, a 1-unit increase in FINTECH will result in a 0.06-unit increase in EEF. If we increase Renewable energy consumption by 1 unit, there will be a 0.01-unit increase in Energy efficiency. The 1 unit increase in total natural resource rents will result in a -0.04 unit decrease in Energy efficiency. If we increase GDP by 1 unit, there will be a 0.04-unit increase in Energy efficiency.

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Table 6 presents the short-run effects and highlights the effects of the regressors. An increase in financial inclusion is associated with increased energy efficiency. All the other indicators, agricultural Fintech, GDP, Renewable energy consumption and total natural resource rents, also contribute to the increment in the Energy efficiency

Table 3

Findings of QARDL Estimation

Quantiles	**Constant**	**ECM**	**Long Run Estimation**					**Short Run Estimation**					
(τ)	**$\alpha_*(\tau)$**	**$\rho_*(\tau)$**	**βFINTECH(τ)**	**$\beta_{CF}(\tau)$**	**$\beta_{FI}(\tau)$**	**βTNR (τ)**	**βEG (τ)**	**$\varphi_1(\tau)$**	**$\Omega_{FINTECH}(\tau)$**	**$\Lambda_{CF}(\tau)$**	**$\Theta_{FI}(\tau)$**	**$\Theta_{TNR}(\tau)$**	**$\Theta_{EG}(\tau)$**
0.10	-3.876	0.602	0.756	0.006	0.016	0.037 (0.942)	0.004 (0.902)	-0.380 (0.922)	-0.484	0.000	0.021	0.0436 (0.971)	0.000 (0.859)
	(0.889)	(0.986)	(0.856)	(0.958)	(0.881)				(0.990)	(0.985)	(0.906)		
0.20	-0.446	0.055 (0.960)	0.0137	0.0001	0.0211	0.069 (0.855)	0.004 (0.357)	-0.454	-1.335	0.0000	0.033	0.056 (0.479)	0.000 (0.773)
	(0.962)		(0.997)	(0.997)	(0.791)			(0.670)	(0.584)	(0.945)	(0.259)		
0.30	0.018	0.107 (0.815)	-0.54819	-0.006	0.040*	0.108 (0.301)	0.000** (0.017)	0.454*** (0.000)	-1.335 (0.354)	0.000 (0.847)	0.033** (0.047)	0.056 (0.345)	0.000 (0.564)
	(0.004)		(0.212)	(0.894)	(0.058)								
0.40	0.363	0.308 (0.621)	-0.529	0.000	0.042*	0.122 (0.269)	0.000* (0.050)	-0.483* (0.072)	-0.009 (0.995)	0.000 (0.868)	0.027 (0.143)	0.079 (0.182)	0.000 (0.713)
	(0.915)		(0.377)	(0.882)	(0.059)								
0.50	0.561		-0.460	0.000	0.0215	0.047 (0.679)	0.000 (0.357)	0.379 (0.194)	0.055 (0.968)	0.000 (0.762)		0.082* (0.079)	0.000 (0.571)
	(0.904)	-0.035 (0.947)	(0.244)	(0.920)	(0.344)						0.022 (0.178)		
0.60	3.010	0.247 (0.659)	-0.130	0.000	0.037*	0.0519 (0.608)	0.000** (0.001)					0.062** (0.046)	0.000 (0.691)
	(0.523)		(0.718)	(0.845)	(0.075)			-0.010 (0.976)	-0.871 (0.517)	0.000 (0.756)	0.019 (0.203)		
0.70	2.721	0.410 (0.466)	-0.811*	0.000	0.026	0.039 (0.583)	0.000* (0.050	0.049 (0.883)		0.000 (0.738)	0.018 (0.253)	0.059 (0.560)	0.000 (0.551)
	(0.501)		(0.071)	(0.822)	(0.100)				-1.030 (0.363)				
0.80	2.698	0.284 (0.678)	-0.759*	0.000	0.027	0.0403 (0.8801)	0.0000 (0.510)	0.086 (0.822)	-2.426 (0.207)	0.000 (0.783)	0.029 (0.235)	0.079 (0.554)	0.000 (0.821)
	(0.221)		(0.0014)	(0.753)	(0.505)								

Discussion on Findings

Researching China's energy ecosystem, focusing on the linkages between FinTech, natural asset rents, eco-finance, and financial access, has yielded some interesting results. The current hypotheses examine how natural assets, rents, FINTECH, and eco-financing can contribute to improved energy efficiency. H1 is clearly rejected by the results, which show that CF positively affects energy efficiency. The statistically insignificant, positive impact of CF on EEF is found in both the short- and long-run at all quantiles. This implies that CF hurts EEF. This negative impact of CF on EEF is in line with Cai and Zhang (2024) and Y. Yang (2023) who argued that CF hurts EEF in different provinces in China. This effect can be justified by the fact that China's current economic growth still depends on regional resource development, which is further aggravated by the large capital required for CF development, ultimately leading to a reduction in EEF. The finding suggests that China should change the present mode of development, support the green industries and technological innovation, promote green financial innovation, and support environmental civilisation construction (Yang, 2023).

Secondly, FI has a significant and positive impact on energy intensity in both the short- and long-run across different quantiles. This means that FI leads to a decrease in EEF both in the long and short run. This outcome is in line with Zaidi et al. (2024a) and Zaidi et al. (2024b). Financial inclusion disrupts the financial sector rapidly, providing consumers with banking services, credit, and products. As new financial opportunities become available, economic activity will increase as people interested in business use financial services to achieve better results. The increase in economic activities results in higher energy demand. Moreover, the additional revenue can be used in energy-intensive sectors or systems that rely heavily on fossil fuels. Therefore, energy intensity would increase with greater financial inclusion. (Zaidi et al., 2024).

Likewise, H2 states that FinTech enhances energy efficiency; the results support this argument. The results indicate that FINTECH hurts energy intensity in both the short- and long-run. However, the impact is statistically insignificant in the short run but significant only at extremely high quantiles (0.7 and 0.8). This expected positive impact of FINTECH on EEF is consistent with the earlier studies of Al-Kasasbeh et al. (2024), Liu et al., (2022b) and Teng & Shen (2023a). There are several justifications for this positive impact of FINTECH on EEF. Firstly, FINTECH drives financial innovation by connecting the power of artificial intelligence, digital technology and big data. Secondly, these technologies empower financial institutions to address obstacles to green finance adoption among micro and small enterprises and to alleviate information asymmetry. Moreover, it technically supports the environmental risk assessments and therefore fosters EEF from a multifaceted perspective (Kong & Xu, 2023). Integration of FINTECH in the energy sector enables more efficient, productive processes, improving resource allocation and reducing waste. Finally, FinTech developments, such as smart grids and digital payment systems, help modernise the energy industry by promoting sustainability and efficiency.

Strikingly, the results of this study disprove H4, which posits that investment in natural asset rents could enhance energy efficiency, as the coefficient on TNR is statistically insignificant in the long run; however, it is statistically significant only in the short run at the 5^{th} and 6^{th} quantiles. The positive impact of TNR on energy intensity implies that TNR reduces energy efficiency. The insignificant impact suggests that energy efficiency can be improved by managing natural resources ethically and sustainably. The energy landscape would eventually benefit from investments under prudent application of resource rents, which, in one way, can finance construction and green technologies. This outcome is consistent with Kwakwa, Alhassan, and Adu (2020) and (Yasmeen *et al.*, 2023).

Lastly, the analysis reveals that EG has no significant impact on energy intensity in the short run, but a positive and significant impact over 0.3 to 0.7 quantiles. In other words, EG leads to a reduction in EEF in China. This finding is consistent with Sener and Karakas (2019) and Bu and Ren (2023). This may be because EG leads to increased industrialisation, which requires intensive energy use and therefore causes a decline in EEF. (Sadorsky, 2013).

Conclusion and Policy Recommendations

The main purpose of the present study was to analyse the impact of natural resources, fintech, financial inclusion and carbon finance on energy efficiency in China over the 2000 to 2023 period. To assess these relationships empirically, the QARDL estimation approach is applied, which provides both short and long-run estimation across different quantiles. The findings indicate that financial inclusion and natural resource use decrease, but FinTech increases energy efficiency across quantiles. However, carbon finance has no significant impact on energy efficiency, both in the short and the long run. Overall, this study provided an overview of the dynamics in China's energy space to understand how eco-financing, Fintech, financial inclusion, and natural asset rents can collaborate to enhance efficiency. The results provided enlightening insights into how these variables affected the country's energy sustainability. The development of FinTech is a positive factor that significantly boosts energy efficiency, and the findings support the role of radical technological innovation in improving the distribution and use of energy.

When it comes to implementing sustainable practices, this study has several highly relevant practical applications for policymakers and fiscal institutions, as well as other players in China's energy industry. To begin with, recognising the advantages of FinTech in energy efficiency requires governments to support and facilitate integration between environmentally friendly financing schemes and technological innovations in the energy sector. These findings can help financial institutions design and sell digital solutions that increase energy efficiency while focusing on environmentally responsible products. Simultaneously, awareness of the negative relationship between financial inclusion and energy efficiency enables policymakers to develop targeted solutions. Furthermore, countries with resource endowments must ensure that sustainable energy practices are implemented through efficient governance frameworks, as natural asset rents help stimulate increased expenditure as an incentive for more efficient use.

Theoretical Implications

The theoretical implications of this study are explained below. This study makes a significant contribution to the theoretical understanding of China's energy environment. The correlation between eco-funding and energy efficiency informs the basis for sustainable finance models. The paper provides important new insights into how eco-financing mechanisms determine energy efficiency levels by analysing the relationship between financial instruments and investors' behaviour. The confirmation of FinTech's positive effects on energy efficiency also contributes to the growing literature on tech-driven solutions that improve energy performance. This theoretical factor focuses on the applicability of digital breakthroughs in energy resource use and the potential synergy between environmental sustainability and financial technology innovations. It also rejects the idea that financial inclusion leads to improved energy efficiency. This denial opens the door to an in-depth discussion of the complex nature of financial access and environmental outcomes by questioning the assumed direct link between financial inclusion policies and energy efficiency. Besides, the understanding that asset rents lead to negative energy efficiency helps one understand how countries dependent on natural resources might align their financial systems with environmental goals. This awareness underscores the importance of investing in renewable energy projects through natural resource revenues. It also contributes to the all-encompassing framework that employs environmentally sound financial policies in resource-rich countries.

Limitations

This research has some limitations despite its significance. Firstly, the results are context-specific to China and therefore may not be generalizable. Moreover, the complexity of the relationship between financial inclusion and energy efficiency has not been fully realised due to variations in the measures used to assess financial inclusion. Additionally, no possible mediating or moderating variables are considered that could affect the studied relationships. Moreover, the time frame of this study may limit its ability to capture emerging trends and policy changes in evolving domains such as energy efficiency, financial inclusion, FinTech, and eco-financing. Besides, the unintended consequences or spillovers associated with the use of eco-financing, FinTech techniques, and financial inclusion are not fully discussed in this study.

Future Research Directions

Future studies should apply a variety of methods to deepen understanding of the complex interrelationships revealed by this study. Longitudinal studies may shed light on meaningful changes in FinTech and other variables, such as natural asset rents, financial inclusion, and eco-financing that support energy productivity. Besides, examining temporal dynamics would provide researchers with a better understanding of how changing market conditions, driven by policy changes and technological advancements, affect sustainable energy practices. In addition, to address the quantitative findings, deeper qualitative research is necessary. To illuminate the contextual factors that influence whether financial and technical actions aimed at boosting energy efficiency are successful, qualitative research helps us understand how various stakeholders interpret the complex perspectives of such interventions. Another interesting avenue is to study the unintended outcomes and spillover effects of FinTech, financial inclusion initiatives, and green financing campaigns. Understanding the potential ripple effects of these actions outside energy, as well as identifying possible trade-offs or synergies, can enhance multi-dimensional policy design. Furthermore, future research should investigate the governance mechanisms used to regulate rents from natural assets to achieve sustainable energy goals. Writing about how institutional processes and regulatory systems determine resource income allocation could help identify solutions for newly independent nations struggling to balance environmental conservation and economic development. Finally, regarding the extent to which the world's commodity markets are intertwined, future research could examine what has been done elsewhere and compare other countries' approaches to achieving energy efficiency through technical and financial solutions.

Declaration of generative AI and AI-assisted technologies:

During the preparation of this work, the author(s) used Grammarly and its AI-based features to improve the English language and grammar of the paper.

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