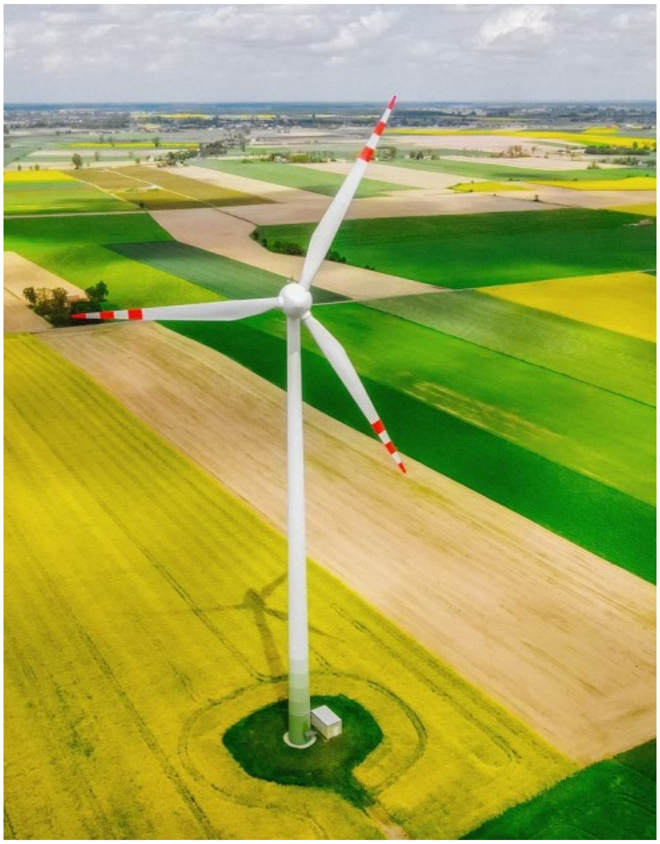


GREEN FINANCE FOR ENERGY TRANSITION, ENERGY POVERTY ALLEVIATION, AND ENERGY SECURITY*

Farhad Taghizadeh-Hesary, PhD.,
Chief Economist, Climate Finance Asia, Tokyo, Japan
Associate Professor, Tokai University, Tokyo, Japan

Lilu Vandercamme,
Assistant Analyst, Climate Finance Asia, Tokyo, Japan
Research Assistant, Tokai University, Japan

ABSTRACT

Energy poverty and security are persistent global challenges affecting developed and developing nations. This study examines the role of green finance in mitigating energy poverty and enhancing energy security within the framework of inclusive financial development. Using panel data from 30 Chinese provinces spanning 2004 to 2017, we employ a fully modified ordinary least squares (FMOLS) regression approach to analyze the impact of energy security and inclusive financial development on energy poverty. The results underscore the importance of integrating green finance into national strategies to promote sustainable energy access and economic growth. Policy recommendations include the development of a national green financial development strategy, the implementation of energy efficiency incentives, and the acceleration of renewable energy deployment. This study provides critical insights for policymakers and stakeholders aiming to advance sustainable energy solutions and enhance energy security through innovative financial mechanisms.

Keywords: green finance; inclusive financial development; energy poverty; energy security, sustainable energy access

* This paper is the preprint of the chapter with the same title, to be published in *The Role of Green and Transition Finance in Achieving Carbon Neutrality and Sustainable Energy*, by Elsevier

1. INTRODUCTION

Energy poverty and security remain significant global challenges impacting developing and developed nations. Hence, an understanding of the multidimensional nuances of energy poverty and energy security is critical in developing effective green finance strategies (Zhao, Wang, and Dong, 2023). The definition of energy poverty varies depending on the country's development level (Al Kez et al., 2024). In developed nations, energy poverty primarily focuses on the affordability of essential energy (Primc, Dominko, and Slabe-Erker, 2021). In developing countries, energy poverty is mainly established as a lack of access to modern energy services, including electricity and clean cooking facilities, severely restricting economic development, health, and quality of life (Igawa and Managi, 2022). According to The International Energy Agency (IEA) report, over 700 million people worldwide continue to live with limited access to electricity, and nearly 2.6 billion rely on traditional biomass for cooking, which leads to significant health and environmental consequences (World Energy Outlook, 2021). Traditional biomass includes wood, charcoal, and animal dung, and polluting fuels that produce harmful smoke, contributing to respiratory illnesses and environmental degradation (Dumga and Goswami, 2023). The reliance on such fuels also burdens women and children, who often spend hours collecting firewood, thus limiting their opportunities for education and economic activities (Chandrasekaran, 2023). Conversely, energy security is determined by how diversified and politically secure a country's energy sources are (Kim, Panton, and Schwerhoff, 2024). In easier words, energy security is defined as the security of energy supplies. That entails that given that all else is equal, there is high energy security if there is a diverse portfolio of suppliers with low political risk. While steady progress is observed in selected regions, many populations, particularly those in developing countries, continue aggravating extremely severe energy poverty and deteriorating social and economic inequalities (Lee, Song, and Lee, 2023).

To tackle energy access issues, inclusive financial development has been highly recognized as a critical instrument (Z. Khan *et al.*, 2023). Inclusive financial development refers to extending financial services focused on underserved populations that promote economic inclusion and reduce poverty (Corrado and Corrado, 2017). Through extending financial services such as facilitating investments in energy infrastructure and technologies to underserved populations, it is recognized as a potent instrument for reducing energy poverty, increasing economic opportunities, and societal inclusion (Anu et al., 2023). However, integrating green finance and financial investments that promote environmentally sustainable projects into this framework offers a promising avenue for further enhancing energy security and reducing energy poverty

(Sachs *et al.*, 2019). Access to credit, savings, insurance, and other financial products allows individuals and communities to invest in productive activities, including energy infrastructure and technologies. Inclusive financial development's role in enhancing energy access and facilitating energy transition has been widely recognized, with numerous studies demonstrating its potential to increase investments in renewable energy projects and energy-efficient technologies (Zheng and Chen, 2023). For instance, Liu et al. (2021) and Han et al (2019) highlight the impact of microfinance institutions and digital financial services in supporting small-scale renewable energy initiatives in rural areas. However, integrating green finance into this framework offers a transformative approach to improve energy access and security further. Green finance includes instruments such as green bonds, green loans, and sustainable investment funds designed to finance projects delivering environmental benefits (Martin, 2023). These initiatives are essential for mobilizing resources for renewable energy projects and efficiency improvements, accelerating the transition to a low-carbon economy, and achieving global sustainability goals (Lee, 2020). Despite its potential, the adoption of green finance remains limited in many regions due to barriers such as lack of awareness, regulatory challenges, and perceived risks (Lv et al., 2021).

China ranks first globally in coal production and consumption, second in petroleum consumption, and third in natural gas consumption. As can be observed in Figure 1, the country's energy mix is heavily reliant on coal, which accounts for 58% of its energy consumption, followed by petroleum (20%), hydropower (8%), natural gas (7%), other renewables (4%), and nuclear (2%) (Global Energy Institute, 2020).

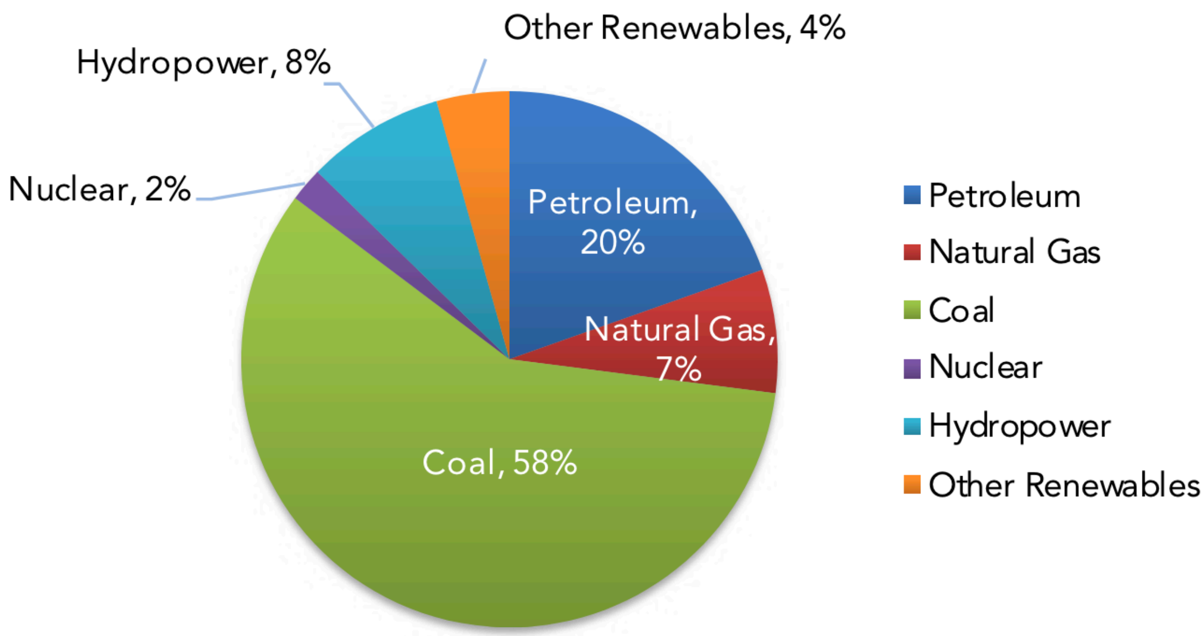
Climate Finance Asia Limited
66/F, The Center, 99 Queen's Road Central, Central, Hong Kong

Climate Finance Asia Inc.
Room 501, Zenken Building 1-4-11, Nishi-shinjuku, Shinjuku-ku, Tokyo, 160-0023, Japan

CFin Asia Pte Limited
133 New Bridge Road Chinatown Point #10-03 Singapore 059413

(852) 2541 5020
info@climatefinanceasia.com
www.climatefinanceasia.com
@Climate Finance Asia

Figure 1. China: Energy Mix



Source: Global Energy Institute (2020), International Index of Energy Security Risk 2020 Edition

Alongside being a world-leading producer, China is a large importer of petroleum, natural gas, and coal, underscoring its vulnerability to international market fluctuations and geopolitical risks (Global Energy Institute, 2020). Improving energy security in China would entail the diversification of energy sources and a reduction in dependence on fossil fuel imports (K. Khan et al., 2023). China must focus on maintaining a diversified portfolio of energy sources, ensuring political stability in supplier countries, investing in robust infrastructure, fostering liquid energy markets, and integrating environmentally sustainable practices. This study recommends green finance policies that can be integrated into China's energy policies and achieve national goals by promoting investments in renewable energy and energy efficiency projects, reducing energy poverty, and enhancing overall energy security. By addressing these dimensions, China can mitigate risks associated with energy supply disruptions, stabilize energy prices, and support sustainable economic growth (Qin and Yong, 2024).

This study aims to assess the determinants of energy poverty by examining the elements of energy security, inclusive financial development, economic growth, and urbanization. The primary objective is to evaluate the impact of energy security and inclusive financial development on energy poverty. By analyzing the interdependence between inclusive financial development, energy poverty, and energy security, this research provides valuable insights into the dynamics and mechanisms determining energy access, offering practical green finance policy implications. This study contributes to understanding energy access challenges and provides evidence-based guidance for policymakers, energy professionals, and financial institutions. It examines how inclusive economic development affects energy poverty and its subsequent impact on energy security. The potential to bridge the existing knowledge gap and create a concrete impact is particularly significant in this study. While the role of inclusive financing in enhancing energy access is increasingly recognized, empirical data and a comprehensive understanding of the multidirectional link between inclusive financial development, energy poverty, and energy security in the context of green finance still need to be developed. This research seeks to fill this gap through rigorous analysis and the application of robust methodologies, aiming to contribute to both theoretical advancements and practical actions in sustainable energy access.

This paper is structured as follows: Section 2 reviews the relevant literature on energy poverty, energy security, inclusive financial development, and green finance. Section 3 outlines the empirical methodology and results, including detailed descriptions of the FMOLS regression approach, the data sources utilized, and the empirical results. Section 4 concludes the study with a summary of key insights and suggestions for future research, underscoring the importance of leveraging green finance to achieve sustainable energy access and security.

Climate Finance Asia Limited
66/F, The Center, 99 Queen's Road Central, Central, Hong Kong

Climate Finance Asia Inc.
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CFin Asia Pte Limited
133 New Bridge Road Chinatown Point #10-03 Singapore 059413

(852) 2541 5020
info@climatefinanceasia.com
www.climatefinanceasia.com
@Climate Finance Asia

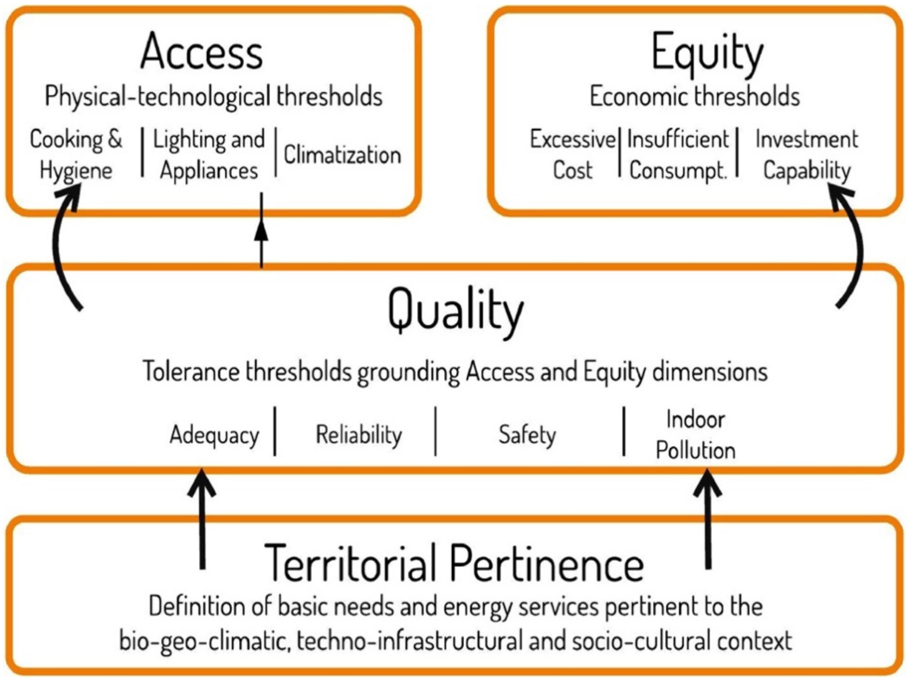
2. LITERATURE REVIEW

2.1 Overview of Energy Poverty and its Dimensions

The impact of fuel poverty is far-reaching and has profound implications for many aspects of human development. In China, for example, fuel poverty hinders educational opportunities, as students struggle to study after dark or lack access to digital learning resources (Niu et al., 2023). In addition, there are health implications as households rely on traditional and inefficient cooking methods that cause indoor air pollution, respiratory disease, and premature death. Economically, poverty perpetuates inequality across China by impeding income-generating activities and hindering the growth of small and medium enterprises (Shen and Lu, 2024). Inadequate power supplies limit productivity, restrict access to markets and financial services, impede economic development, and perpetuate poverty. Moreover, the need for modern energy sources in China often places an unfair burden on women and girls when collecting firewood and doing time-consuming household chores. Hence, fuel poverty is a social issue, especially regarding gender equality. (Chandrasekaran, 2023).

Numerous studies, reports, and frameworks worldwide and in China have enhanced our understanding of fuel poverty and its dimensions. Figure 2 shows a context-sensitive three-dimensional approach to energy poverty.

Figure 2. Context-sensitive three-dimensional approach to energy poverty



Source: Urquiza et al., 2019

This framework brings a new perspective of considering 'quality' as a hidden dimension of energy poverty, specifically in middle-development countries. This suggests that there are multiple ways to assume the dimensions of energy poverty and that the state of a nation's economy plays a prominent role in the dimensions; however, the fact that energy poverty is an issue remains. The United Nations Sustainable Development Goal 7 (SDG 7) aims to ensure access to affordable, reliable, sustainable, and modern energy for all by 2030. In particular, it is related to China's energy poverty problem (United Nations, 2023). The World Bank's Global Tracking Framework provides a comprehensive assessment of energy access and underscores the importance of tackling energy poverty as a top priority (World Bank Group, 2014). Academic research has contributed to understanding the social, economic, and environmental impacts of energy poverty in China. It has highlighted the need for tailored interventions to close the energy access gap and mitigate related challenges.

2.2 Concepts and Indicators Related to Energy Security

Concepts and indicators related to energy security play an important role in understanding and addressing energy access, reliability, and sustainability issues. Energy security includes several aspects: availability, accessibility, affordability, reliability, and resistance to external shocks and disturbances (Kruyt et al., 2009). Furthermore, for a comprehensive energy security analysis, it is essential to consider related concepts and metrics that capture its complexity (Vivoda, 2010). The concept of energy security aims to ensure an adequate and stable supply of energy sources to meet the needs of individuals, communities, and industries. This includes diversifying energy sources to reduce reliance on a single energy source or energy country, thereby minimizing vulnerabilities associated with supply disruptions and price fluctuations (Siksnelyte-Butkiene, 2023). Energy security also includes promoting renewable and sustainable energy sources to reduce environmental impact, increase energy efficiency, and contribute to long-term energy sustainability. According to (Taghizadeh-Hesary et al., 2023), various indicators measure and monitor energy security. One of these indicators is energy self-monitoring. It indicates how much a country depends on domestic energy resources to meet its energy needs. Greater energy autonomy reduces dependence on external resources and increases energy security. Diversifying the energy mix is another indicator that assesses a country's portfolio of energy sources and reduces reliance on a single energy source or technology. It is important to note that diversification helps reduce risks associated with supply disruptions and price fluctuations (Jasiūnas, Lund, and Mikkola, 2021).

Rasoulinezhad et al. (2023) present a framework that this paper will focus on and be the inspiration for the variables used in the empirical analysis. This chapter presents policy implications of reforms in the structure of government and government-affiliated institutions in Asian countries. The framework proposed is the 'Four A's,' which can be seen in Figure 3.

Figure 3. Four As framework and indicators

Dimension	Indicator
Availability	i. Share of imports in oil supply ii. Share of imports in gas supply iii. Share of imports in coal supply iv. Hydro power production
Applicability	i. Energy intensity (agriculture and transport) ii. Energy intensity (industry)
Acceptability	i. Share of renewable energy in power generation ii. Carbon emissions per capita iii. Share of Global CO2 emissions
Affordabiilty	i. Energy supply per capita ii. Gas price iii. Electricity price iv. Gasoline price

Source: Compiled by the authors from Rasoulinezhad et al., 2023; Yao and Chang (2014)

Energy efficiency is an essential indicator of energy security as it measures the ability to provide desired energy services with minimal energy consumption (Rasoulinezhad, Taghizadeh-Hesary, and Vandercamme, 2023). Energy efficiency will improve energy security by reducing overall energy needs and making energy systems more resilient (Chakraborty and Mazzanti, 2020). Infrastructure resilience is another metric that measures an energy infrastructure's ability to withstand natural disasters, cyberattacks, and other disruptions without disrupting energy supplies. Resilient infrastructure helps maintain reliable and uninterrupted energy services (Pahadia et al., 2023). In addition, indicators related to accessibility to modern energy services such as electricity and clean cooking are essential elements of energy security. These indicators measure the percentage of the population with access to affordable and reliable energy services.

They reflect the satisfaction of energy demand and response to the challenge of fuel poverty (Murshed and Ozturk, 2023). Many studies, reports, and frameworks have contributed to our understanding of concepts and indicators related to energy security. For example, the World Energy Council's Global Energy Impossible Triple Index looks at energy security, energy equity, and environmental sustainability, providing a comprehensive assessment of energy systems (World Energy Council, 2024). The International Energy Agency's World Energy Outlook provides an overview of global energy security challenges and policy recommendations to improve energy security (World Energy Outlook, 2021). These resources and academic research have enhanced our knowledge of energy security and influenced policy debates and decision-making.

2.3 Inclusive Financial Development and its Relevance to Energy Access

According to Tan and Peng (2018), financial inclusion is essential in energy access by providing financial services, mechanisms, and resources to underserved populations. This includes the availability and accessibility of financial products such as credit, savings, insurance, and investment opportunities tailored to the needs of individuals, communities, and businesses. Financial inclusion in promoting energy access is critical to addressing energy poverty and promoting sustainable development (Li and Qamruzzaman, 2023).

Liu, He, and Turvey (2021) argues that access to financial resources and is critical to overcoming economic barriers related to energy access. Financial inclusion can allow individuals and communities to finance clean energy solutions such as solar panels, innovative stoves, and energy-efficient appliances. Financial inclusion institutions offer credit programs, microfinance programs, and innovative financing mechanisms to enable households and businesses to invest in energy infrastructure and technology, thereby improving access to energy. Furthermore, financial inclusion empowers individuals and communities by providing them with the tools and resources to engage in energy-related income and business activities (Anu et al., 2023). Access to financial services such as loans and grants allows entrepreneurs to set up energy-related businesses such as renewable energy installation and maintenance services. This leads to job creation, economic development, and poverty reduction in local communities (Han, Wang, and Ma, 2019).

With reference to Zhou et al. (2018), financial inclusion can also help improve energy affordability, especially for low-income households. Financial services such as mobile banking and digital payment platforms will increase transaction efficiency, reduce costs associated with traditional payment methods, and make energy services more affordable and accessible. In addition, financial inclusion institutions can develop innovative financial models such as payment-for-use systems and energy microgrids that allow individuals to pay for energy services in small, manageable batches. Numerous studies and reports highlight the importance of financial inclusion for energy access and sustainable energy development. For example, United Nations Sustainable Development Goal 7 (SDG 7) emphasizes the importance of providing affordable and reliable energy access and recognizes the role of financial institutions in achieving this goal (United Nations, 2023). Academic research has explored the impact of financial inclusion on energy access and the effectiveness of microfinance programs, innovative financial models, and policy frameworks. These studies have demonstrated the positive outcomes of integrated development finance interventions, including improved energy access, enhanced entrepreneurship, energy affordability, and poverty reduction.

2.4 Existing Research on the Relationship Between Inclusive Financial Development, Energy Poverty, and Energy Security

Existing research sheds light on the complex and interrelated relationship between financial inclusion, energy poverty, and energy security. Numerous studies have explored the dynamics and impacts of these aspects, providing valuable insights into the impact of financial inclusion on energy access, poverty reduction, and energy security (Uddin et al., 2014). financial inclusion is important in promoting energy access and addressing energy poverty. The study highlights a positive link between access to financial services and investment in clean energy technology. For example, microfinance programs facilitate financing renewable energy projects and enable households and businesses to adopt sustainable energy solutions. These programs provide individuals with the capital and financing needed to overcome the initial costs of clean energy technologies, thereby improving energy access and reducing energy poverty. Furthermore, Lai et al. (2020) show that financial inclusion positively impacts entrepreneurship and income generation in the energy sector, focusing on digital financial inclusion. Access to financial services and credit systems has enabled individuals and communities to engage in energy-related economic activities, such as installing and maintaining renewable energy systems. This promotes regional economic development and alleviates poverty by creating job opportunities and increasing income levels. We also find that financial inclusion has a mutual impact on energy security. Improved access to financial services will reduce financial risks and barriers to energy investment, facilitating energy infrastructure development and diversification of energy sources. Financial inclusion facilitates the transition to sustainable energy systems and reduces dependence on fossil fuels by facilitating access to finance and investment. This makes the power supply more flexible and reliable, thus contributing to energy security. In addition, Chakravarty and Pal (2013) highlight the importance of policy support and regulatory frameworks to generate positive outcomes for financial inclusion concerning energy access, poverty reduction, and energy security. Effective public policies that promote financial inclusion and create an enabling environment for sustainable energy investment have been shown to improve the effectiveness of financial inclusion policies. Although current studies have contributed significantly to understanding the link between overall financial development, energy poverty, and energy security, there are still areas for further research. For example, more research is needed to assess the long-term viability and scalability of inclusive financial development policies in the energy sector. Longitudinal studies and impact assessments provide insight into the sustainability and effectiveness of these interventions over time. In addition, Acharya and Sadath (2019) delve deeper into the specific mechanisms and pathways through which financial inclusion impacts energy poverty and security. This includes examining the role of financial institutions, microfinance models, innovative financing mechanisms, and policy frameworks in promoting access to sustainable energy and enhancing energy security. The present study indicates a positive association between financial inclusion, energy poverty, and security. Access to services and financing has been shown to facilitate access to energy, entrepreneurship, and income generation, thereby reducing energy poverty. In addition, financial inclusion contributes to energy security by promoting investment in renewable energy, improving the development of energy infrastructure, and diversifying energy sources. Political support and regulatory frameworks are essential in facilitating positive outcomes from financial inclusion interventions. However, more research is needed to investigate long-term sustainability and to delve deeper into the mechanisms underlying these relationships.

3. METHODOLOGY AND EMPIRICAL RESULTS

This section delineates the empirical results derived from the methodological framework employed in this study. The estimation procedure comprises three essential steps. Initially, this study conducted unit root tests on all variables to ascertain their stationarity properties. This is a crucial step to ensure that the variables do not exhibit random walk behavior, which could lead to spurious regression results. For this purpose, the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test are utilized, given their robustness in detecting unit roots under different assumptions of serial correlation and heteroskedasticity (Dickey and Fuller, 1979)(Phillips and Perron, 1988). Subsequently, the Kao residual cointegration test is employed to investigate the presence of the cointegration and the long-run equilibrium relationships between the variables. This test is essential for confirming that the variables move together over the long term, indicating a stable long-run relationship (Kao, 1999). The choice of the Kao test is informed by its suitability for panel data and its ability to account for cross-sectional dependence. Finally, a Fully Modified Ordinary Least Squares (FMOLS) regression analysis is conducted to estimate the long-run coefficients. The FMOLS technique is preferred due to its ability to correct for endogeneity and serial correlation in cointegrated variables, thereby providing unbiased and consistent parameter estimates (Phillips and Hansen, 1990). This methodological approach ensures robust and reliable results, enhancing the validity of the empirical findings. The methodological process in this study draws inspiration from Erdal and Erdal (2020), who employed a similar approach in examining financial development and economic growth. The comprehensive data analysis is meticulously performed using EViews 13.

3.1 Data and variables

In this section, we introduce the data and variables employed in the empirical component of the study. Following this, we present the theoretical background, highlighting the factors identified in the literature and their impact on inclusive financial development. We also discuss the appropriate estimation methods. As outlined earlier in this paper, this study examines the various determinants of energy poverty from an energy security perspective, utilizing panel data from 2004 to 2017 covering 30 Chinese provinces. Hong Kong, Taiwan, Macao, and Tibet are excluded from the analysis due to difficulty in obtaining consistent data.

Secondary data for this study were collected from various external sources and previous literature. The primary data sources include the China Statistical Yearbook and the China Regional Financial Performance Report. Customized data for modified variables were obtained from the article "How to Develop Financial Inclusion to Alleviate Energy Poverty in China? Role of Technological Innovation" (Dong, Taghizadeh-Hesary, and Zhao, 2022). The independent variable, Financial Inclusion Development (IFD), was derived from financial institutions, institutional regulations, and national financial inclusion indicators. The composite energy poverty index (EP) was the dependent variable obtained from energy access surveys, socioeconomic surveys, and official energy poverty reports.

Additionally, control variables were incorporated to provide a comprehensive analysis. These include energy accessibility and efficiency (EAE), clean energy consumption (ECC), and the availability of energy services (ESA). Economic growth was measured by real GDP per capita, adjusted by the previous year's growth index (PGDP). Technological innovation was quantified by the number of national patent applications granted (TEC), and urbanization growth was measured by the ratio of permanent urban residents to the total provincial population (URB) obtained from relevant government and statistical sources. The energy poverty composite index (EP) was used as the dependent variable, in line with Dong, Taghizadeh-Hesary, and Zhao (2022). Data were provided by the China Statistical Yearbooks, a database regularly used by scholars and researchers researching this topic, and hence, reliable. Inclusive financial development was used as the independent variable, in line with Dong, Taghizadeh-Hesary, and Zhao (2022). China's Regional Financial Operation Report, a reliable data source used in wide-scale research, provided the data.

An extensive literature review identified the determinants of energy poverty from an energy security perspective, emphasizing the four A's: Availability, Affordability, Accessibility, and Acceptability. These dimensions are essential for understanding and mitigating the impact of inclusive financial development on energy poverty. To operationalize this framework, six variables were selected: energy affordability and efficiency (EAE), which reflects the cost-effectiveness and efficiency of energy consumption; energy consumption cleanliness (ECC), measuring the environmental sustainability of energy use; energy services availability (ESA), indicating the reliability and accessibility of energy services; economic growth (PGDP), gauged by real GDP per capita adjusted by the previous year's growth index; technical innovation (TEC), represented by the number of domestic patent applications granted; and urbanization evolution (URB), assessed by the proportion of permanent urban residents in the total provincial population. These variables collectively provide a comprehensive understanding of the factors influencing energy poverty from an energy security perspective, facilitating a nuanced analysis of how inclusive financial development can address energy poverty. Description and data sources of variables are presented in Table 1.

Table 1. Description of variables

Notation	Definition	Group	Source
EP	Energy Poverty Composite Index	Dependent	China Statistical Yearbooks
IFD	Inclusive Financial Development	Independent	China's Regional Financial Operation Report
EAE	Energy Affordability and Efficiency	Control	China Statistical Yearbooks
ECC	Energy Consumption Cleanness	Control	China Statistical Yearbooks
ESA	Energy Services Availability	Control	China Statistical Yearbooks
PGDP	Economic Growth Gauged by Real GDP Per Capita Converted by the Growth Index of the Previous Year	Control	China Statistical Yearbooks
TEC	Technical Innovation Measured by the Number of Domestic Patent Applications Granted	Control	China Statistical Yearbooks
URB	Urbanization Evolution Assessed by the Proportion of Permanent Urban Residents in the Total Population of the Province	Control	China Statistical Yearbooks

Source: Authors

3.2 Unit Root Test

Since we are considering relatively long panels, assessing the stationarity of the variables is essential, as outlined by Erdal and Erdal (2020). The purpose of performing unit root tests is to verify the suitability of the time series data employed in this study. Stationarity is critical for reliable statistical inference in a time series analysis, and nonstationary series could lead to spurious regression results where the relationships between variables will appear significant when they are not. Accordingly, a panel unit root test, specifically the Fisher-extended Dickey-

Fuller test (Fisher-ADF), is conducted to test the null hypothesis of nonstationary for all variables. An additional test, the Choi Z-Stat test, is also performed to ensure robustness. The results of the Fisher-ADF and the robustness tests are presented in Table 2. Each test is conducted on the variables' level and first difference.

Table 2. Unit Root Test

Variable	Fisher Chi-square	Choi Z-stat	Stationary
EAE	58.01 [0.55]	-0.036 [0.49]	No
D(EAE)	143.75 [0.00]	-6.50 [0.00]	Yes
ECC	123.09 [0.00]	-4.36 [0.00]	Yes
D(ECC)	217.46 [0.00]	-9.89 [0.00]	Yes
EP	35.22 [0.99]	2.13 [0.98]	No
D(EP)	156.05 [0.00]	-7.03 [0.00]	Yes
ESA	71.39 [0.15]	-1.28 [0.10]	No
D(ESA)	268.99 [0.00]	-11.82 [0.00]	Yes
IFD	96.55 [0.00]	-2.95 [0.00]	Yes
D(IFD)	166.76 [0.00]	-2.95 [0.00]	Yes
PGDP	15.12 [1.00]	8.09 [1.00]	No
D(PGDP)	93.52 [0.00]	-3.40 [0.00]	Yes
TEC	3.57 [1.00]	11.82 [1.00]	No
D(TEC)	122.19 [0.00]	-4.76 [0.00]	Yes
URB	24.07 [1.00]	8.08 [1.00]	No
D(URB)	130.85 [0.00]	-5.19 [0.00]	Yes

Source: Authors

The panel unit root tests indicate that EAE, EP, ESA, PGDP, and URB are nonstationary at levels (indicated by high p-values); however, they become stationary after differencing (indicated by low p-values). For EAE, non-stationarity can be explained by the fact that changes in environmental policies and education often follow a trend over time. For EP, environmental performance metrics improve gradually due to long-term investments and policy changes. For ESA, subsidies and assistance programs typically increase as government support for renewable energy grows. For PGDP, economic growth tends to follow a trend that generally leads to nonstationary behavior in GDP. For URB, it can be explained that there is a gradual upward trend in urbanization, causing non-stationarity. This demonstrates that the dataset is suitable for further analysis and provides valuable insight into the time series properties of the variables, ensuring appropriate model specifications.

3.3 Panel Cointegration Analysis

These series exhibit nonstationary levels (see Table 2) and are integrated of the first order, necessitating an evaluation of cointegration (Erdal et al., 2020). To assess long-term relationships between the variables, a panel cointegration analysis is conducted using the Kao panel cointegration test, as shown in Table 3. This analysis investigates whether a stable relationship exists between the variables over time, indicating a typical long-term equilibrium relationship between inclusive financial development and energy poverty. The panel cointegration analysis accounts for potential cross-sectional dependencies, allowing for robust estimation.

Table 3. Kao Residual Cointegration Test

	t-Statistic	Prob.
ADF	-11.22	0.00
Residual variance	0.00	
HAC variance	0.00	

Source: Authors

Note: Newey-West automatic bandwidth selection and Bartlett kernel; Automatic lag length selection based on AIC with a max lag of 2

The Kao residual cointegration test results indicate the presence of cointegration between the variables, with a p-value of approximately 0.00, rejecting the null hypothesis of no cointegration. Most statistics support the presence of cointegration, which is consistent with the Kao residual cointegration test results. This indicates that the variables exhibit long-term correlations with each other. Given this scenario, using the Fully Modified Ordinary Least Squares (FMOLS) method is strongly recommended instead of vector autoregressive models, as FMOLS allows for combining both short-term and long-term relationships in the analysis.

3.4 Fully Modified Ordinary Least Squares (FMOLS) Regression Analysis

Table 4. Fully modified ordinary least squares (FMOLS) Regression Results

Dependent Variable: EP		
Variable	Coefficient	Prob.
EAE	-0.59	0.00***
ECC	-0.06	0.00***
ESA	-0.23	0.00***
IFD	-0.07	0.08*
PGDP	0.00	0.80
URB	0.04	0.43
R-squared		0.99
Adjusted R-squared		0.99

Source: Author

*Note: ***, * shows significant results in 0.01, and 0.1 . Long-run covariance estimates (Bartlett kernel, Newey-West fixed bandwidth)*

Fully Modified Ordinary Least Squares (FMOLS) regression analysis is employed to estimate the coefficients and assess the significance of the relationships between inclusive financial development, energy poverty, and the control variables, as presented in Table 4. FMOLS effectively addresses the model's potential endogeneity and serial correlations, ensuring consistent and efficient estimates. This method allows for dynamic interactions between variables and controls for potential biases resulting from omitted variables, providing a robust analytical framework (Erdal et al., 2020).

The results of the Fully Modified Ordinary Least Squares (FMOLS) regression analysis provide coefficients, t-statistics, and p-values for each variable, offering valuable insights into the strength and significance of the relationships between inclusive financial development, energy poverty, and the control variables. The findings allow for an evaluation of the impact of inclusive financial development on energy poverty, considering various factors related to energy affordability, acceptability, availability, accessibility, economic growth, and urbanization.

From the FMOLS results, it is evident that Energy Affordability and Efficiency (EAE), Energy Consumption Cleanliness (ECC), Energy Services Availability (ESA), and Inclusive Financial Development (IFD) are significantly negatively associated with the dependent variable, Energy Poverty (EP). Specifically, EAE is significant at the 1% level, indicating a negative relationship with reducing energy poverty (EP). This can be explained by the understanding that making energy affordable and efficient will lower household cost burdens, allowing a more significant allocation of resources and leading to an overall decrease in poverty. ECC is significant at the 1% level, indicating a negative relationship with reducing energy poverty (EP). This can be explained by the understanding that clean energy consumption reduces environmental degradation and health risks, leading to a cleaner environment, lower health costs, and increased economic stability. ESA is significant at the 1% level, indicating a negative relationship with reducing energy poverty (EP). This can explained through the understanding that having reliable and accessible energy services leads to an increase in economic activities such as job creation and improved quality of life, as well as significantly reducing regional disparities. The results indicate that Inclusive Financial Development (IFD) reduces energy poverty, with a significance level of 10%, which aligns with the expected outcome. The coefficient for IFD is calculated to be 0.07. This implies that a 1% increase in China's inclusive financial development is associated with a 0.07% increase in the eradication of fuel poverty. This finding suggests that policies and incentives promoting inclusive financial development can alleviate energy poverty and enhance China's energy security.

To summarize the analysis, the significantly positive coefficients for EAE, ECC, ESA, and IFD indicate that improvements in energy affordability and efficiency, cleaner energy consumption, increased availability of energy services, and advancements in inclusive financial development contribute to reducing energy poverty in China. These results underscore the importance of integrated financial and energy policies in achieving sustainable development and energy security.

Climate Finance Asia Limited
66/F, The Center, 99 Queen's Road Central, Central, Hong Kong

Climate Finance Asia Inc.
Room 501, Zenken Building 1-4-11, Nishi-shinjuku, Shinjuku-ku, Tokyo, 160-0023, Japan

CFin Asia Pte Limited
133 New Bridge Road Chinatown Point #10-03 Singapore 059413

(852) 2541 5020
info@climatefinanceasia.com
www.climatefinanceasia.com
@Climate Finance Asia

4. CONCLUDING REMARKS AND POLICY IMPLICATIONS

This study provides a comprehensive analysis of the determinants of energy poverty from an energy security perspective, focusing on the role of inclusive financial development in China. Utilizing panel data from 30 Chinese provinces from 2004 to 2017, we employed advanced econometric techniques, including unit root tests, cointegration analysis, and Fully Modified Ordinary Least Squares (FMOLS) regression, to elucidate the complex relationships between energy poverty, energy security, and inclusive financial development.

The empirical results reveal significant insights into the relationships between the variables under study. Energy affordability and efficiency (EAE), energy consumption cleanliness (ECC), and energy services availability (ESA) were found to be significant at the 1% level. Inclusive financial development (IFD) was significant at the 10% level. The negative coefficients for these variables indicate that improvements in these areas contribute to reducing energy poverty. The significant negative coefficient for Energy Affordability and Efficiency (EAE) underscores the importance of making energy more affordable and efficient. Enhancing energy affordability and efficiency reduces the cost of energy services, making them more accessible to low-income households. This reduction in energy costs directly lowers the proportion of household income spent on energy, alleviating energy poverty. The significance of Energy Consumption Cleanliness (ECC) highlights the crucial role of clean energy consumption in alleviating energy poverty. Clean energy technologies, such as solar and wind, provide sustainable energy solutions that are environmentally friendly and cost-effective. Energy consumption cleanliness can reduce energy poverty by providing access to affordable and sustainable energy sources, lowering costs for low-income households. Additionally, clean energy initiatives can create jobs and stimulate economic growth, further alleviating poverty. The transition to cleaner energy sources significantly reduces health costs associated with pollution from traditional energy sources, thus improving the overall well-being of communities.

Additionally, the availability of energy services (ESA) is critical for reducing energy poverty. The availability of energy services reduces energy poverty by ensuring that households have reliable access to electricity and modern cooking facilities, improving quality of life and economic opportunities. Access to energy services also enables better education, healthcare, and productivity, further contributing to poverty alleviation.

Furthermore, the negative coefficient for Inclusive Financial Development (IFD), though significant at the 10% level, is particularly noteworthy. It suggests that financial inclusion initiatives provide access to financial services for underserved populations and play a crucial role in reducing energy poverty. Financial inclusion enables households to invest in energy-efficient appliances and renewable energy technologies, thereby improving their energy access and reducing energy poverty.

The relationship between financial inclusion, energy security, and energy poverty is bidirectional and multifaceted. Financial inclusion can enhance energy security by providing the necessary financial resources for investments in energy infrastructure and technologies. Conversely, improved energy security can foster financial inclusion by creating a stable environment for economic activities and financial transactions. Access to credit is a crucial element, as financial inclusion facilitates households and businesses in obtaining credit, which can then be used to invest in energy-efficient technologies and renewable energy systems. These investments reduce energy costs and enhance energy security by ensuring a more stable and affordable supply. Savings and insurance are also vital financial services that protect households from the volatility of energy prices and unforeseen expenses, contributing to energy security and reducing vulnerability to energy poverty. Furthermore, economic growth, supported by financial inclusion, increases incomes, enabling households to afford modern energy services. This increased affordability reduces energy poverty and strengthens energy security. Additionally, financial inclusion fosters technological innovation by funding research and development in energy technologies. Innovative energy solutions improve energy efficiency and reduce costs, enhancing energy security and alleviating poverty. These interconnected mechanisms highlight the importance of a comprehensive approach that leverages financial inclusion to address energy poverty and improve energy security.

Based on the empirical findings, several policy recommendations are proposed to enhance energy security and reduce energy poverty in China and other developing and emerging economies. Emphasizing green finance solutions, policymakers should prioritize promoting green finance initiatives to address energy poverty and enhance energy security. This involves creating a supportive regulatory environment encouraging investments in renewable energy and energy efficiency projects. Specific measures include subsidies and tax incentives for green bonds and loans to fund renewable energy infrastructure and energy-efficient technologies. Additionally, establishing green finance frameworks that standardize green financial products can attract private sector investments and ensure transparency. Policymakers should also facilitate partnerships between financial institutions, government agencies, and renewable energy companies to develop innovative financing models, such as pay-as-you-go solar systems and microfinance schemes for energy access. To ensure the effectiveness of these policies, it is essential to integrate green finance into national energy strategies and development plans, aligning them with broader sustainability goals. By implementing these green finance-focused solutions, China can mobilize the necessary resources to improve energy access, reduce poverty, and enhance overall energy security.

Despite the robust findings, this study has certain limitations. First, due to data unavailability issues, the analysis is limited to data from 30 Chinese provinces, excluding Hong Kong, Taiwan, Macao, and Tibet. Future research could extend the dataset to include these regions for a more comprehensive analysis. Second, the study focuses on a specific period (2004-2017), and future research could explore longer time horizons to assess the long-term impacts of inclusive financial development on energy poverty. Additionally, while this study employs FMOLS regression to address endogeneity and serial correlation, future studies could utilize alternative econometric methods such as Dynamic Ordinary Least Squares (DOLS) or Generalized Method of Moments (GMM) to validate the findings. Further research could also explore the impact of other factors, such as policy interventions and international financial flows, on energy poverty and security.

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Climate Finance Asia Limited
66/F, The Center, 99 Queen's Road Central, Central, Hong Kong

Climate Finance Asia Inc.
Room 501, Zenken Building 1-4-11, Nishi-shinjuku, Shinjuku-ku, Tokyo, 160-0023, Japan

CFin Asia Pte Limited
133 New Bridge Road Chinatown Point #10-03 Singapore 059413

(852) 2541 5020
info@climatefinanceasia.com
www.climatefinanceasia.com
@Climate Finance Asia