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RESEARCH ARTICLE

The nexus between energy consumption, financial development and ICT: A panel data analysis

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Abstract
This study explores the relationship between financial development, energy consumption and information and communication technology (ICT) in a sample of 83 global countries for the period of 1990 to 2020. By employing generalized method of moments, the findings shows that there is a long run co integration financial development, ICT and renewable energy consumption. This study reveals that in standalone, emerging, and developed financial markets, the development of the financial market and its associated factors, encompassing market depth and accessibility, play an important role in promoting the usage of renewable energy. However, in frontier financial economies, a contrasting trend is observed, where financial market efficiency is associated with lower utilization of renewable energy. Furthermore, the non-linear and moderating impacts of financial market growth on renewable energy adoption vary across nations with different financial market development stages. this study further provide important policy suggestions for the sample economies in context of ICT, financial development and renewable energy consumption.

Keywords: Financial development; ICT; financial market development; renewable energy

Introduction

A growing population, industrialization, and rapid technological development contribute to the increased demand for energy in terms of consumption and production. On a global scale, the predominant sources of energy are fossil fuels, such as coal, natural gas, and oil. Since fossil fuels can be produced relatively readily and cheaply, they have been widely used over the last 200 years. The utilization of fossil fuels also upsurges the chances of pollution (YILMAZ, 2012). Nations are increasingly dedicating their endeavours to fostering renewable energy sources and diminishing their reliance on non-renewable energy resources. This shift is propelled by the detrimental environmental consequences and the finite accessibility of fossil fuel reserves. The sources of renewable energy encompass solar power, hydroelectric energy derived from waves and streams, wind power, geothermal energy, biomass energy, and the energy harnessed from ocean waves. These sources are often perceived as sustainable due to their ease of generation, cost-effectiveness, and rapid returns on investment (ÇAKIR, 2010).

In this context, researchers are actively investigating approaches to alleviate the potential economic repercussions linked to environmental pollution caused by the emission of greenhouse gases resulting from the utilization of energy sources derived from fossil fuels. The prevalence of adverse externalities and assorted macroeconomic expenses resulting from worldwide contamination of the environment has focused the focus of academics and policymakers on the effective utilization of renewable energy resources. Renewable energy, compared to non-renewable counterparts, may exhibit a greater dependence on the stability of a robust financial system due to the relatively higher investment requirements associated with renewable energy projects. Enhancements in a nation's financial infrastructure mitigate the investment costs related to renewable energy initiatives, consequently promoting the adoption of environmentally sustainable energy resources. By fostering an environment of reliable environmental investment through advancements in the financial system, projects centred on installing and utilizing renewable energy resources gain enhanced efficacy and efficiency. In the coming years, the continuous establishment of a resilient financial market is poised to significantly bolster the use of renewable energy sources in the long run. It warrants attention that numerous emerging economies predominantly hinge on energy resources, entailing substantial raw material imports, including oil and natural gas, resulting in substantial outflows of foreign exchange. The utilization of renewable energy sources, characteristically heightening both energy consumption and productivity, presents a viable alternative, and could yield considerable foreign exchange savings that could be redirected towards financial markets, fostering their diversification and deepening. Hence, the anticipated foreign exchange savings generated by the usage of renewable energy sources play a substantial role in improving the economic condition of these countries. Additionally, it's important to highlight that financial development supports economic growth, fosters competition, and encourages innovative initiatives, ultimately leading to dynamic improvements in productivity. Numerous investigations in the vast realm of academic literature have delved into the relationship between the utilization of non-renewable energy and financial growth. Yet, it is worth highlighting that within the domain of energy economics, there has been a distinct lack of comprehensive investigations addressing the ramifications of financial advancement on renewable energy use. The present research carries significant weight in addressing this gap within the existing literature by providing a discerning insight into how a nation's financial progress influences the usage of renewable energy. Our research, in particular, emphasizes the expansion of financial markets, acknowledging it as a significant indicator, as affirmed by (Sadorsky, 2010, 2011). It's worth highlighting that limited prior investigations have employed market-oriented financial development measures to examine their implications on adopting renewable energy. Furthermore, the majority of prior studies have relied upon one-dimensional measures to gauge financial market development, despite its inherently multi-faceted nature, as corroborated by (Svirydzenka, 2016). The earlier studies have ignored the effect of ICT and energy consumption in the presence of heterogenous financial market stages and non-linearity of financial market for 83 economies. To fill this gap, we argue that financial market structure is a framework that takes ICT, energy consumption, and environmental risks into account. If the financial market is strong, it can benefit the environment through different ways. The ICT sector can improve the environment by investing in green technologies, smart infrastructure, and advanced environmental monitoring. Collaboration with environmental organizations and responsible e-waste management practices, including recycling, can further contribute to environmental sustainability. The energy sector can improve the environment by using funds from the financial market to invest in renewable energy projects, support clean technology research, and promote energy efficiency initiatives. This helps reduce carbon emissions and advances environmental sustainability. This study adds to the existing body of knowledge in several distinct manners: (i) This research delves into the impact of financial development stages on renewable energy across 83 countries during the timespan from 1990 to 2020. Moreover, the study divides the growth of the financial market into sub-measures, which are; financial market depth, accessibility, and efficiency. These aspects are complicated and warrant a comprehensive examination of their individual effects on the utilization of renewable energy. (ii) Secondly, this research explores the intricate, non-linear impact manifested by the expansion of financial markets on the adoption of renewable energy sources. (iii) Thirdly, this paper delves into the intricate dynamics of how the stages of financial development within countries interact with ICT to shape the consumption of renewable energy. (iv) Fourthly, the study investigates whether the interaction between financial development and energy consumption amplifies or mitigates its influence on the utilization of renewable energy and (v) whether this influence exhibits significant regional variations. In this investigation, the Instrumental Variable Generalized Method of Moments (IV-GMM) is employed as a potent analytical instrument to tackle issues concerning variable bias and endogeneity. The paper's framework is unveiled as follows: Section 2 is the comprehensive review of the existing literature, whereas Section 3 immerses into the details of the methodology and the data utilized. Moving forward, Section 4 encompasses the empirical discoveries and discussion, ultimately culminating in the presentation of conclusions and policy directives.

Literature review

The dynamic relationship between the widespread usage of renewable energy and the growth of financial markets has ignited a passionate discussion, emphasizing the critical imperative to reconfigure our financial systems in alignment with the pursuit of sustainable development. As highlighted by (Eren et al., 2019), the complex landscape of investments in renewable energy initiatives, characterized by formidable obstacles encompassing substantial initial expenditures, ongoing responsibilities for repaying long-term debt, and sustaining investments in research and development. Substantiate the substantial contribution, totalling a remarkable 42.42%, to the critical trajectory of renewable energy development in China, as they clarify the critical importance of financial market expansion in accelerating the advancement of renewable energy integration (Ji & Zhang, 2019). Their analysis underscores the chief importance of the capital market in this framework. Besides, (Le et al., 2020) delved into this symbiotic association by using a comprehensive dataset spanning 55 countries from 2005 to 2014. Their findings parallel those of (Kim & Park, 2016), especially in emphasizing the fundamental role of financial growth in fostering the renewable energy industry within high-income nations. Conversely, its role appears less pronounced in nations with low and moderate-income levels. They explicitly demonstrated that the progress of financial development is crucial in promoting the sustainable expansion of the renewable energy sector in developed nations. In contrast, its significance appears less pronounced in economies with modest or lower incomes. Conversely, (Raza et al., 2020) utilized the panel smooth transition regression (PSTR) method to investigate the intricate relationship between financial progress and the adoption of renewable energy sources in the world's primary energy consumers during the period from 1997 to 2017. Their findings shed light on how various aspects of financial development contribute to adopting renewable energy. (Alsagr & van Hemmen, 2021) examined emerging economies during the period 1996 to 2015. Using the system Generalized Method of Moments (GMM), their investigation unveiled a compelling link between the growing adoption of renewable energy and financial progress. (Shahbaz et al., 2021) they delved into the impact of financial development on the transition to renewable energy in 34 developing countries between 1994 and 2015. Their empirical results show that financial growth serves as a stimulant, promoting the renewable energy demand. (Denisova, 2020) examined the electricity usage in Germany and financial growth. The practical findings of this study shed light on a scenario where both economic growth and the influence of urbanization exert significant consequences on energy usage. In contrast, the influence of the growth of the financial market remains insignificant. In African nations (Sare, 2019) delved into the complex relationship between energy consumption and financial progress was explored in depth. This study revealed the efficacy of financial development by employing threshold estimation and a sample-splitting technique. It was found that energy consumption is encouraged by financial development when the financial development index is below a certain threshold. Nevertheless, as this index surpasses the threshold, the stimulating effect experiences a gradual attenuation.

Research on the intersection of ICT and renewable energy can be classified into two main groupings. The first group addresses the environmental consequences of renewable energy and ICT, as evidenced by studies such as those by (Charfeddine & Kahia, 2021; Hussain & Lee, 2022). The second viewpoint focuses on how information and communication technology (ICT) has an impact on the uptake and production of renewable energy. (Awijen et al., 2022) unveiled that the surge in the proportion of Internet users and ICT adoption is accompanied by raising the use of renewable energy. According to (Yu et al., 2023), ICT is now recognised as a helpful component in facilitating renewable energy utilisation. The complex link between ICT and renewable energy adoption in India and China, using both generalised method of moments and conventional least squares approaches. Their studies revealed that ICT has a considerable favourable influence on the use of renewable energy (Chowdhury et al., 2022). Conversely, (Bano et al., 2022) conveyed findings of an adverse relationship between adopting renewable energy and ICT. In China's shift towards renewable energy, (Li et al., 2023) identified research and development (R&D) and financial advancement as the fundamental driving forces behind the nation's energy transition. As explored in a research (Tzeremes et al., 2023), a comprehensive investigation unfolds, scrutinizing the intricate connections among economic progress, Information and Communication Technology (ICT), the transition towards sustainable energy, and CO_2 emissions within the BRICS nations, ICT emerges as a significant avenue for advancing the energy transition and mitigating environmental challenges. The Information and Communication Technology (ICT) sector is enhancing the adoption of renewable energy in the South Asian region. This observation holds even when the proportion of renewable energy in the overall final energy consumption continues to increase. The research conducted by (Murshed, 2020) delves into the complex non-linear effects of Information and Communication Technology (ICT) development on renewable energy-related trade. (Saidi et al., 2017) extensively analysed data from 67 countries to examine the connection between electricity consumption and Information and Communication Technology (ICT). Their investigation unveiled that ICT significantly contributes to enhancing electrical power usage. Another study (Longo & York, 2015) explored the influence of ICT on energy consumption, and their results shed light on the fact that the widespread prevalence of telephones and mobile phones exerts a considerable influence on power consumption. (Lange et al., 2020) investigate four hypothesised processes by which ICT influences energy use: direct impact, energy utilisation enhancement effect, rebounding impact, and reforming impact. They discover that the direct contributions impact and rebounding impact are presently dominating, and ICT promotes increased usage of energy. Chinese data were used to experimentally assess the presence of direct contributing impacts and rebounding impacts of ICT. They discovered that technical advancement, changes in financial development, industrial structure, and human capital are major avenues via which ICT influences energy use (Ren et al., 2021). The second academic viewpoint is that ICT decreases energy use. Scholars who agree with the thinking that ICT may be effectively incorporated into social and economic endeavours while also contributing to energy waste reduction (Bastida et al., 2019; Collard et al., 2005). Information and Communication Technology (ICT) significantly promotes the growth of internet-based endeavors like remote work, virtual meetings, digital commerce, and electronic transactions. This shift from tangible to virtual operations saves substantial time and transportation cost savings and enhances energy efficiency, as illuminated by the research of (Zhao et al., 2022). ICT growth also helps with the fast growth of environmentally friendly financing, which has become a key policy instrument recently in major countries throughout the globe to lessen greenhouse gas emissions and energy consumption (Lv et al., 2021). This is because environmentally friendly finance necessitates a greater amount of environmental info than conventional financing. ICT serves as a catalyst in disseminating and disclosing environmental information, thereby mitigating the detrimental consequences of information asymmetry on the advancement of eco-friendly finance. Consequently, this leads to decreased energy usage, as explicated by the investigation of (Akomea-Frimpong et al., 2021). The earlier studies have ignored the effect of ICT and energy consumption in the presence of heterogenous financial market stages and non-linearity of financial market for 83 economies. To fill this gap, we argue that financial market structure is a framework that takes ICT, energy consumption, and environmental risks into account. If the financial market is strong, it can benefit the environment through different ways. The ICT sector can improve the environment by investing in green technologies, smart infrastructure, and advanced environmental monitoring. Collaboration with environmental organizations and responsible e-waste management practices, including recycling, can further contribute to environmental sustainability. The energy sector can improve the environment by using funds from the financial market to invest in renewable energy projects, support clean technology research, and promote energy efficiency initiatives. This helps reduce carbon emissions and advances environmental sustainability. How financial development influences renewable energy is likewise unclear. Because the integration of financial development with other industries alters the mode of functioning of social and economic operations, the influence of financial development might extend beyond its direct effects on renewable energy, potentially affecting renewable energy through alternative pathways, which have yet to be investigated by scholars. Therefore, to thoroughly comprehend the complex relationship between renewable energy and financial development across various markets, this study employs models that consider moderating effects to investigate the indirect processes and nonlinear patterns of the association between renewable energy and financial development.

Methodology

Following the model introduced by (Shahbaz et al., 2021), this study is conducted to examine the influence of financial development on renewable energy usage across various financial economies, including standalone, developed, frontier, and emerging markets. For this purpose, data from 83 countries were collected between 1990 and 2020. The complete sample was classified into emerging, developed, standalone, and frontier markets using the stock market categorization of Morgan Stanley Capital International (MSCI). As a result, the study is divided into 23 emerging financial markets, 29 frontier financial markets, 22 established financial markets, and 9 standalone financial markets. Used variables are: renewable energy (RE) was represented by the proportion of renewable energy consumption within the final energy consumption. Gross Domestic Product (GDP) serves as a representation of the growth in GDP per capita, while energy consumption is approximated by kilograms of oil equivalent per capita. The total population was used to estimate population, whereas total urban population was used to represent urbanisation. The dataset utilized for this analysis is drawn from the World Development Indicators provided by the World Bank. Additionally, the International Monetary Fund's (IMF) financial development index is employed in this study. The IMF development of financial market measures ranges from 0 to 1. This dataset outperforms the WDI development of stock market measures in various ways. Firstly, it covers many factors and gives multiple perspectives on financial market development (Svirydzenka, 2016). It also provides sub-measures for the development of the financial market, such as accessibility of the financial market, depth, and efficiency. This research scrutinizes an array of financial market indicators, providing a comprehensive view of financial market development. These encompass the broad spectrum of financial market growth (FD) along with distinct sub-indicators, including financial market efficiency (FEF), accessibility (FAC), and depth (FDE). For analysis purpose, firstly the descriptive statistics is analysed, following by cross sectional dependence (CSD) and slope heterogeneity tests. Further, the CADF and CIPS unit root tests, Pedroni cointegration and Westerlund cointegration and in the last instrumental variable generalized method of moments (IV-GMM) applied to this research data. In this empirical research to examine the linkages between above considered variables, we checked for cross-sectional dependence of the data which is a crucial factor to be determined before carrying out further analysis. Without checking for cross-sectional dependence can lead to inaccurate results. Therefore, we took into account (Pesaran, 2015) CSD test. The CSD equation is given by:

$$\mathrm{CSD} = \sqrt{\left(\frac{2T}{N(N-1)}\right)}\left[\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho_{ij}}\right]$$

Furthermore, we applied (Pesaran & Yamagata, 2008) slope heterogeneity technique for considering problems related to the CSD. The equation of slope heterogeneity is given by:

$$\Delta = (N)^{\frac{1}{2}}(2k)^{-\left(\frac{1}{2}\right)}\left(\frac{1}{N}S - k\right)$$

The equation adjusted for biasness for Δ is given by:

$$\Delta_{Adj} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{-\left(\frac{1}{2}\right)}\left(\frac{1}{N}S - k\right)$$

After confirming these results, we can effectively ascertain the suitability of unit root analysis for our research investigation. Within this investigation, we incorporated (Pesaran, 2004, 2007) unit root test methodology to ascertain the stationarity of the dataset. Among the available methodologies, the choice of Pesaran's unit root test stems from its comprehensive consideration of both slope homogeneity (SH) and cross-sectional dependence (CSD) variables. Furthermore, within this study, (Pedroni, 2004) and (Westerlund, 2005) cointegration analysis emerges as the preferred approach to unravel the intricate connections between energy consumption, information and communication technology, financial market, and renewable energy for 83 economies. This preference is rooted in the limitations of previous methods, such as random and fixed effects, which fail to account for CSD in error terms, potentially leading to misleading test outcomes. In this intricate model the core structure of the model mirrors the framework proposed by (Shahbaz et al., 2021), the adoption of renewable energy (RE) serves as the dependent variable, while the growth of financial markets (FD), energy consumption (EN), the influence of information and communication technology (ICT), and a range of control variables (μ) function as the independent variables. By including fixed broadband subscriptions, fixed telephone subscriptions, the extent of internet utilization by individuals, and mobile cellular subscriptions, we construct an index for ICT in alignment with the methodological approach detailed by (Shehzad et al., 2022); we adopted their prescribed methodology for our study. In addition, we use reduced-form modelling to explore the impact of financial market development on renewable energy use. Therefore, empirical estimations were derived from the logged model as presented in Equation (1).

$$\ln RE_{it} = \beta_0 + \beta_1 \ln EN_{it} + \beta_2 \ln ICT_{it} + \beta_3 \ln FD_{it} + \beta_4 \mu_{it} + \beta_5 i_i + \varepsilon_{it} \quad \ldots\ldots\ldots..(1)$$

As argued by (Shahbaz et al., 2018) and (Acheampong, 2019), financial development may exhibit an intricate, non-linear connection with renewable energy use. This indicates the possibility of a curved, possibly U-shaped, or inverted U-shaped connection between financial growth and the utilization of renewable energy. Therefore, this research extends the work of (Shahbaz et al., 2018) and (Acheampong, 2019) by introducing the financial market growth quadratic term (lnFD2) into Equation (1). This is done to investigate whether the relationship between financial market growth and the use of renewable energy aligns with a U-shaped or inverted U-shaped pattern. We define the renewable energy consumption equation in Equation (2). This equation incorporates the square term of financial growth, facilitating investigating this complex relationship.

$$\ln RE_{it} = \beta_0 + \beta_1 \ln EN_{it} + \beta_2 \ln ICT_{it} + \beta_3 \ln FD_{it} + \beta_4 FD^2 + \beta_5 \mu_{it} + \beta_6 i_i + \varepsilon_{it}$$

(2)

The connection between the growth of financial markets and the utilization of renewable energy sources might display fluctuations instead of consistently uniform. Therefore, if β3>0 and β4<0, the link between renewable energy utilization and financial growth takes on an inverted U-shaped pattern. Conversely, when examining the relationship between financial market development and the adoption of renewable energy, it follows a U-shaped course if β3<0 and β4>0. As per the inverted U-shaped linkage, the initial phases of financial market expansion stimulate the consumption of energy from renewable sources, but at a specific level of financial market growth, renewable energy begins to fall. On the contrary, In the event that the U-shaped connection identified between the advancement of financial markets and the incorporation of renewable energy implies that the initial expansion of financial markets results in a decrease in the usage of renewable energy. However, beyond a certain threshold of financial market development, a subsequent resurgence in renewable energy utilization emerges.
To delve into the moderating effects of ICT and financial market growth (lnFD×lnICT), and energy use and financial market growth (lnFD×lnEN) on the use of renewable energy, we adapt Eq. (2) into Equation (3) and Equation (4). In this manner, we employ Equation (3) to analyse how ICT and the growth of financial markets (lnFD×lnICT) moderate the use of renewable energy. Similarly, we utilize Eq. (4) to investigate the moderating impact of energy use and financial market growth (lnFD×lnEN) in relation to renewable energy.

$$\ln RE_{it} = \beta_0 + \beta_1 \ln EN_{it} + \beta_2 \ln ICT_{it} + \beta_3 \ln FD_{it} + \pi_1 (\ln FD \times \ln ICT) + \beta_4 \mu_{it} + \beta_5 i_i + \varepsilon_{it}$$

(3)

$$\ln RE_{it} = \beta_0 + \beta_1 \ln EN_{it} + \beta_2 \ln ICT_{it} + \beta_3 \ln FD_{it} + \pi_2 (\ln FD \times \ln EN) + \beta_4 \mu_{it} + \beta_5 i_i + \varepsilon_{it}$$

(4)

where i = 1 to N, t = time, β0 is the constant parameter; β1 to B5 is the coefficient to be estimated; π1and π2 symbolize the indirect influence of financial development; ii is the separate influence; error term is denoted by εit; μ show controls includes population (lnPOP) and urbanisation (lnURB) used by (Salim & Shafiei, 2014) which have potential impacts on the use of renewable energy. All these variables are in log form.
Given the potential endogeneity issues connected with the renewable energy usage and financial development relationship modelling Eqs. 1-4 using traditional estimators, for example, fixed effects or Ordinary Least Squares (OLS), may provide inefficient findings. Furthermore, there are several additional factors that may influence renewable energy use; hence, omitted variables bias occurs if failed to account for such variables, providing conflicting and inaccurate findings. It should also be highlighted that based on markets, indicators of financial development undergo evaluation with significant errors, which might lead to weakened bias, leading the fixed effects and OLS estimations to fall.
Hence, the research employs the instrumental variable generalized method of moments (IV-GMM) technique to assess the influence of financial growth on renewable energy utilization. This approach addresses potential issues like inconsistencies, reverse causality, variable omission bias, and endogeneity. Furthermore, IV-GMM, by ensuring the orthogonality prerequisite, offers robustness against concerns such as autocorrelation and

unforeseen heteroscedasticity (Baum et al., 2003). These methodological choices align with the study's goal of examining the impact of financial market growth on renewable energy use, necessitating the inclusion of stock market indicators. According to (Stock et al., 2002), it can be hard to identify suitable exogenous instruments. In this study, a unique methodology was implemented involving the utilization of financial market metrics as lag instruments for the financial market expansion measures under investigation. To ensure the reliability of these instruments, the analysis employs statistical tests, including F-statistics based on the Cragg-Donald and Kleibergen-Paap tests, along with the Hansen J tests. This thorough examination aims to validate the instruments' effectiveness.

Results and discussions

Preliminary tests

The descriptive statistics, definitions of the variables, and correlation matrix has been provided in Table 1A, 1B, 1C in Appendix A accordingly. According to Table 1A, the average renewable energy use is higher in developed markets, and frontier financial economies and lower in standalone markets and then emerging markets. The data also shows that developed markets have high financial market development averages and sub-measures, whereas frontier countries have low averages. Regarding the ICT (information and communication technology) average, emerging markets have the most, then frontier financial countries, while standalone financial markets have the least. The frontier markets have the highest average consumption of energy, which is followed by the emerging market, and standalone markets, while the developed markets have the most minor average usage of energy. These summary statistics give a good picture of the features of emerging, developed, standalone, and frontier markets. At this point in Table 2 the Pesaran CSD and unit root results are given. The cross-sectional dependence status determines the econometric model that will be chosen for the sample used. The CSD test, according to (Pesaran, 2004, 2015), can reduce bias from empirical conclusions derived from econometric techniques. There is a cross-sectional dependence among the panel units, according to the CD test results, which demonstrate the statistical significance at the level of 1%. After checking the CSD results and the values are significant, which means panels are dependent on each other. Similarly in Table 2, the SH test of (Pesaran & Yamagata, 2008) results confirms that all the models are highly significant thus by confirming the heterogeneity in the panels, we applied (Pesaran, 2004, 2007) CADF and CIPS tests given in Table 1 to handle the CSD and SH problems. The SH results for model 1-4 are given in Table 2 The result suggest that the panels are stationary at I(0) and I(1). The results of CSD, CADF, and CIPS are presented in Table 1.

Table 1: Pesaran CSD, CADF, and CIPS tests

Variables	Pesran CSD	CADF		CIPS	
	CD-test(p-value)	Level	t-statistics	Level	t-statistics
lnRE	169.302***	I(1)	-15.070***	I(1)	-4.745***
lnEN	42.922***	I(0)	-16.666***	I(1)	-4.895***
lnGDPC	27.905***	I(0)	-6.708***	I(0)	-3.481***
lnPOPT	.454***	I(0)	-8.312***	I(1)	-2.490***
lnUPOP	165.266***	I(0)	-7.080***	I(1)	-2.193***
lnICT	183.737***	I(1)	-4.901***	I(1)	-3.324***
lnFD	164.798***	I(0)	-4.271***	I(0)	-2.491***
lnFMA	92.647***	I(1)	-15.205***	I(1)	-4.633***
lnFMD	144.976***	I(0)	-2.616**	I(1)	-4.737***
lnFME	30.619***	I(1)	-13.046***	I(1)	-4.509***

Note: ***, ** show 1% and 5% probability

Table 2: Slope heterogeneity results

	M-1	M-2	M-3	M-4
	lnRE lnEN lnGDP lnPOP lnURB ICT FD	lnRE lnEN lnGDP lnPOP lnURB ICT FD FD2	lnRE lnEN lnGDP lnPOP lnURB ICT FD FDICT	lnRE lnEN lnGDP lnPOP lnURB ICT FD FDlnEN
	Statistics	Statistics	Statistics	Statistics
Δ tilde	39.889***	35.613***	20.530***	32.097***
Δ tilde (Adj.)	46.309***	42.274***	28.227***	38.596***

Note: *** is 1% significance

Table 3 shows the outcomes of our cointegration analysis. Both (Pedroni, 2004) and (Westerlund, 2005) cointegration results of Model-1 confirms the long run relationship between lnEN, lnGDP, lnPOP, lnURB, ICT, FD, and lnRE. In Model-2, we have included the non-linear impact of FD on renewable energy which is also significant. In Model-3, we have augmented the impact of interaction term of FD and ICT on renewable energy and confirms the long-run relationship whereas in Model-4, we included the impact of interaction term of FD and lnEN on renewable energy which is highly significant. In all four models, there is a long run relationship between lnEN, lnGDP, lnPOP, lnURB, ICT, FD, FDICT, FDlnEN, and lnRE.

Table 3: Cointegration results

	M-1	M-2	M-3	M-4
Pedroni cointegration	lnRE lnEN lnGDP lnPOP lnURB ICT FD	lnRE lnEN lnGDP lnPOP lnURB ICT FD FD2	lnRE lnEN lnGDP lnPOP lnURB ICT FD FDICT	lnRE lnEN lnGDP lnPOP lnURB ICT FD FDlnEN
Modified Phillips-Perron t	8.927***	10.489***	10.736***	9.905***
Phillips-Perron t	-7.550***	-7.917***	-10.616***	-4.374***
Augmented Dicky-Fuller t	-7.161***	-7.338***	-9.071***	-3.551***
Westerlund cointegration				
Variance ratio	-3.626***	-2.526***	-4.113***	-2.170***

Note: *** is 1% significance

After confirming the long-run relationship between the dependent and independent variables, we employed IV-GMM which is robust to variable bias and endogeneity. The results are given below.

Results of Emerging Financial market

The estimations for the emerging financial markets are shown in Table 4. M1 to M4, M5 to M8, and M9 to M12 depict the outcomes from Eq. (1), Eq. (2) and Eq. (3) respectively. At the 1% significance level, the anticipated coefficient demonstrates statistical significance regarding financial market development. Thus, renewable energy consumption increases by 4.433%, a 1% upsurge in financial growth. Financial market accessibility and depth significantly positively affect renewable energy consumption at 10% and 1%, correspondingly. According to this empirical conclusion, increasing financial market access and depth by 1% boosts renewable energy use by 0.825% and 2.788%. These outcomes align with the conclusions drawn by the study of (Samour et al., 2022). Notably, the influence of financial markets displays an insignificant effect on the use of renewable energy sources. The substantial influence of financial markets on renewable energy consumption in emerging economies is unsurprising, given the recent growth of their financial systems. Thus, the financial market in developing economies, like the financial market in developed countries, more effectively uses renewable energy by improving the governance of companies (Claessens & Feijen, 2007) while providing corporations with ethical and financial incentives to participate in energy-saving plans.

The coefficients of financial market expansion, depth, and their corresponding squared components in non-linear models present predominantly positive and statistically significant effects on adopting renewable energy. In the case of market depth, the effect is non-significantly negative. These findings suggest that the relationship between financial development and metrics like depth and accessibility follows a pattern similar to an inverted U-shaped curve. When these indicators reach a specific threshold, it decreases renewable energy consumption. Access to the financial markets and its square has positive and insignificant impacts on renewable energy use, but after a particular time, this effect increases. Financial market efficiency demonstrates a statistically insignificant negative influence on renewable energy, while the non-linear effect is statistically positive but also non-significant. This implies that as financial market efficiency increases, it progressively fosters the utilization of renewable energy. The connection between financial market efficiency and renewable energy appears to exhibit a pattern similar to a U-shaped curve.

The combined impacts of financial market growth and ICT and financial market efficiency and ICT show adverse influences on renewable energy utilization. These effects are statistically significant at the 10% and 1% levels in the interaction models. Consequently, the growth of the financial market and efficiency moderate ICT in emerging markets to reduce renewable energy usage. However, the results convey that in the moderating models, the results show that there is no significant impact on the adoption of renewable energy when considering the moderating role of ICT in relation to both market depth and market accessibility. Consequently, when coupled with ICT, financial market depth and accessibility do not contribute to promoting of renewable energy utilization. Furthermore, the findings suggest that ICT exhibits a statistically significant negative effect at the 1% significance level, leading to a reduction in the utilization of renewable energy. Specifically, for each 1% increase in ICT, renewable energy usage experiences a decrease ranging from 1.125% to 2.069%. These results align with the conclusions drawn by (Bano et al., 2022). In contrast, (Lee et al., 2023) reported a positive relationship between renewable energy consumption and ICT. The computed coefficient for economic growth demonstrates a significant adverse connection with the utilization of renewable energy. As economic development increases, businesses and individuals tend to use non-renewable sources in the beginning of economic development and don't care about the environment. These outcomes align with the discoveries of (Ocal & Aslan, 2013) and deviate from the conclusions of (Wang et al., 2022).

In each model, the predicted coefficient has a statistical significance at a 1% level of consumption of energy. The calculated consumption of energy coefficient falls between 0.705% to 0.852%. As a result, energy use in emerging markets is both effective and sustainable, consequently enhancing the utilization of renewable energy. The findings of (Khan et al., 2021) are contradictory to these findings. Urbanization has a substantial impact on renewable energy consumption at the 1% significance level in each model. These results contrast with the empirical findings of the studies conducted by (Wang & Dong, 2021) and (Ali & Khan, 2023), which suggest that urbanization has a negative effect on the utilization of renewable energy, thus increasing carbon emissions. The foreseen coefficient about the population demonstrates a significant and stark negative association at the 1% level. Hence, the ongoing growth of the population in emerging economies is driving their energy consumption toward non-renewable sources like fossil fuels, leading to environmental deterioration. These findings align with the research conducted by (Vo & Vo, 2021). The F-statistics of Cragg-Donald and Kleibergen-Paap suggest that the instruments aren't weak, and the probability value obtained from the Hansen test suggests that the instruments employed for analysis are not over-identified.

Table 4: ICT, financial development, and renewable energy in emerging economies

	M1	M2	M3	M4	M5	M6
lnEN	0.819***	0.782***	0.728***	0.794***	0.833***	0.786***
	(0.069)	(0.073)	(0.071)	(0.074)	(0.068)	(0.075)
lnGDP	-0.233*	-0.256**	-0.288**	-0.247*	-0.206*	-0.255*
	(0.121)	(0.130)	(0.127)	(0.131)	(0.123)	(0.130)
lnPOP	-1.289***	-1.274***	-1.254***	-1.295***	-1.283***	-1.277***
	(0.035)	(0.038)	(0.037)	(0.036)	(0.034)	(0.039)
lnURB	0.490***	0.513***	0.494***	0.517***	0.442***	0.511***
	(0.048)	(0.050)	(0.047)	(0.051)	(0.054)	(0.049)
ICT	-1.807***	-1.740***	-1.780***	-1.626***	-1.716***	-1.739***
	(0.219)	(0.214)	(0.221)	(0.208)	(0.225)	(0.214)
FD	4.433***				21.177***	
	(0.996)				(7.309)	
FAC		0.825*				0.131
		(0.484)				(1.730)
FDE			2.788***			
			(0.507)			
FEF				0.317		
				(0.303)		
FD2					-17.238**	
					(6.952)	
FAC2						0.838
						(1.767)
FDE2						
FEF2						
FDICT						
FACICT						
FDEICT						
FEFICT						
Constant	9.343***	10.656***	10.323***	10.823***	6.265***	10.810***
	(0.872)	(0.918)	(0.825)	(0.867)	(1.610)	(0.969)
Observations	280	280	280	280	280	280
R^2	0.965	0.962	0.965	0.962	0.966	0.962
j	2.422	1.152	1.389	1.871	3.089	1.137
jp	0.120	0.283	0.239	0.171	0.079	0.286
F-statistics	3353.249	857.072	1722.010	1708.148	37.549	79.704

Table 4: Continued

M7	M8	M9	M10	M11	M12
0.705***	0.791***	0.852***	0.791***	0.722***	0.819***
(0.071)	(0.074)	(0.070)	(0.073)	(0.071)	(0.073)
-0.314**	-0.236*	-0.246**	-0.257**	-0.298**	-0.244*
(0.125)	(0.132)	(0.118)	(0.129)	(0.126)	(0.128)
-1.250***	-1.298***	-1.286***	-1.278***	-1.245***	-1.304***
(0.036)	(0.036)	(0.035)	(0.039)	(0.039)	(0.036)
0.501***	0.525***	0.465***	0.528***	0.493***	0.478***
(0.048)	(0.057)	(0.049)	(0.052)	(0.047)	(0.050)
-1.701***	-1.581***	-1.276***	-2.069***	-1.654***	-1.125***
(0.236)	(0.242)	(0.301)	(0.273)	(0.216)	(0.212)
		5.866***			
		(1.174)			
			0.635		
			(0.516)		
7.151*				2.957***	
(3.987)				(0.518)	
	-1.378				0.251
	(3.299)				(0.292)
-5.168					
(4.621)					
	1.465				
	(2.756)				
		-1.492*			
		(0.786)			
			0.826		
			(0.517)		
				-0.450	
				(0.454)	
					-0.992***
					(0.277)
9.599***	11.037***	9.050***	10.472***	10.275***	11.484***
(1.014)	(0.854)	(0.882)	(0.910)	(0.826)	(0.855)
280	280	280	280	280	280
0.964	0.962	0.966	0.962	0.965	0.963
1.583	1.819	2.003	1.053	1.287	1.528
0.208	0.177	0.157	0.305	0.257	0.216
46.795	19.436	1519.444	718.336	1523.618	1609.470

Note: Standard errors robust to heteroscedasticity are in brackets. Hansen J-statistics (j) assesses the strength of instrument identity, as indicated by the p-value of Hansen J-statistics (jp). The F-statistics, particularly the Cragg-Donald and Kleibergen-Paap tests, corroborate these findings. Collectively, the results from the Hansen J-statistics, F-statistics, and p-value affirm that the instrumental variables employed in this analysis are not weak or over-identified, *** $p < 0.01$

Results of Standalone financial economies

The outcomes for the standalone financial markets are outlined in Table 5. M1 to M4, M5 to M8, and M9 to M12 correspond to the conclusions derived from Equation (1), Equation (2), and Equation (3). The calculated coefficient for financial market growth and indicators, accessibility to markets (insignificant positive), and market depth significantly contribute to the adoption of renewable energy. Additionally, the findings emphasize the substantial differences in financial sector development between developing and developed nations, as corroborated by the study conducted by (Svirydzenka, 2016). For example, although stock markets in developed nations are usually well-functioning, they are still in their early phases in emerging economies of development, with tiny sizes and defective functions. This phenomenon introduces the possibility of disparities in how financial development influences the utilization of renewable energy, with potential variations emerging between developing and developed nations. These outcomes are consistent with the research conducted by (Shahbaz et al., 2021), while in contrast, (Assi et al., 2021) did not observe a significant effect of financial market advancement on renewable energy utilization. Additionally, it's worth noting that financial market efficiency exhibits a noteworthy significant inverse relationship with renewable energy usage is observed at the 1% significance level. Therefore, it may be argued that the growth of the financial market growth in its entirety facilitates the adoption of renewable energy. The outcomes indicate that the financial development stage in standalone financial markets is notably advanced, thus fostering the utilization of renewable energy sources.

However, the expansion of financial markets and the indicators linked to them exhibit a nonlinear influence on the adoption of renewable energy. Within these intricate nonlinear models, it becomes apparent that within standalone financial markets, a combination of significant positive and negative impacts on renewable energy consumption arises from growth of financial market, market depth, and respective squared components. Though financial market accessibility and efficiency, as well as squared terms, the usage of renewable energy exhibits both negative and positive impacts. This discovery substantiates the presence of a curvilinear link, resembling an inverted U-shape, between the utilization of renewable energy and the growth of financial markets and depth in standalone markets. As a result, total financial market growth and depth boost renewable energy utilisation, however, usage falls after these financial market indicators reach a specific benchmark. In contrast, a distinct U-shaped relationship emerges when we delve into the connections among financial market accessibility, efficiency, and the adoption of renewable energy. These financial market policies initially reduce renewable energy use, but at a specific limit, they enhance the usage of renewable energy.

Moreover, the moderating influence of ICT in conjunction with financial market indicators exerts a notably on the adoption of renewable energy, there is a consequential significant and negative impact. As the impact of the interaction between ICT and financial development, along with its subsidiary indicators, intensifies, it results in a noticeable decrease in renewable energy consumption. This suggests that the progress of financial markets complements ICT in influencing the renewable energy utilization within standalone economies. ICT has significant negative effects in models M1, M3, M5, M7, and M9 whereas significant positive effects in models M9 and M11. Whereas non-significant negative and positive effects in models M2, M4, M8 and M6, M10, M12 respectively. The negative results align closely with the discoveries of (Bano et al., 2022) whereas the positive results are similar with (Yu et al., 2023) respectively. (Haldar & Sethi, 2022) reported that the combined effects of ICT and financial development on carbon emissions are insignificant. In models M1-M4, M7, M8, and M12, the energy consumption coefficient demonstrates non-significant negative sign whereas negatively significant in model M11 at 1%. Furthermore, it is positive and non-significant in M5, M9, and M10 whereas significant positive in model 6 at 10%. (Khan et al., 2021) reported an inverse correlation between renewable energy and fossil energy. The coefficients related to economic growth exhibit non-significant results, both negative and positive, across all models except for model M5. Population estimated coefficient is negative and significant at

1% As a consequence, it results in a reduction in the utilization of renewable energy. Urbanization exerts a twofold effect, characterized by positive and negative consequences on incorporating renewable energy. These results align with the research outcomes of (Li & Shao, 2021), illustrating a similarity in their findings.

Table 5: Nexus ICT, financial market development, and renewable energy in standalone economies

	M1	M2	M3	M4	M5	M6
lnEN	-0.001	-0.094	-0.256	-0.247	0.201	0.910*
	(0.138)	(0.606)	(0.179)	(0.194)	(0.145)	(0.473)
lnGDP	-0.199	-0.091	-0.022	0.030	-0.403*	-0.196
	(0.178)	(0.284)	(0.268)	(0.292)	(0.212)	(0.141)
lnPOP	-0.829***	-0.921***	-0.749***	-0.893***	-0.836***	-1.383***
	(0.040)	(0.245)	(0.082)	(0.066)	(0.045)	(0.192)
lnURB	0.603***	0.728***	0.379	0.805***	0.416**	0.872***
	(0.160)	(0.251)	(0.313)	(0.210)	(0.169)	(0.165)
ICT	-1.610***	-0.249	-1.055**	-0.087	-2.888***	0.307
	(0.318)	(0.260)	(0.525)	(0.218)	(0.599)	(0.225)
FD	10.038***				99.895***	
	(1.525)				(27.571)	
FAC		1.331				-18.338***
		(4.141)				(4.925)
FDE			4.762**			
			(2.299)			
FEF				-5.901***		
				(2.270)		
FD2					-181.447***	
					(55.763)	
FAC2						44.408***
						(5.098)
FDE2						
FEF2						
FDICT						
FACICT						
FDEICT						
FEFICT						
Constant	5.008**	6.150	10.924**	5.714*	-1.728	4.141
	(2.267)	(4.821)	(4.554)	(3.374)	(2.832)	(3.624)
Observations	79	79	79	79	79	79
R^2	0.984	0.978	0.979	0.979	0.982	0.991
j	0.774	2.115	1.994	0.404	1.146	0.574
jp	0.379	0.146	0.158	0.525	0.284	0.449
F-statistics	992.124	27.957	140.545	37.274	11.450	7.864

Table 5: Continued

M7	M8	M9	M10	M11	M12
-0.166	-0.163	0.057	0.543	-0.431***	-0.252
(0.190)	(0.174)	(0.056)	(0.733)	(0.085)	(0.203)
-0.234	0.066	-0.018	-0.087	0.008	0.029
(0.280)	(0.226)	(0.112)	(0.248)	(0.165)	(0.292)
-0.766***	-0.934***	-0.984***	-1.191***	-0.716***	-0.893***
(0.082)	(0.071)	(0.039)	(0.303)	(0.056)	(0.067)
0.432	0.723***	0.339***	0.788***	-0.275	0.813***
(0.306)	(0.201)	(0.089)	(0.246)	(0.192)	(0.228)
-1.659**	-0.004	5.125***	0.654	3.803***	0.074
(0.787)	(0.226)	(0.952)	(0.416)	(0.883)	(1.679)
		0.012			
		(1.667)			
			0.630		
			(3.967)		
16.605*				-0.737	
(9.238)				(1.985)	
	-33.036**				-7.662
	(13.948)				(18.311)
-25.086					
(17.107)					
	39.467**				
	(18.852)				
		-18.269***			
		(2.086)			
			-7.306***		
			(2.389)		
				-20.227***	
				(2.598)	
					-2.803
					(28.992)
9.113**	8.446**	13.101***	4.432	23.839***	5.677*
(4.295)	(3.404)	(1.640)	(4.972)	(2.933)	(3.426)
79	79	79	79	79	79
0.979	0.979	0.993	0.980	0.989	0.979
1.488	0.750	0.000	0.678	1.012	0.392
0.223	0.387	0.994	0.410	0.314	0.531
11.004	8.135	262.942	28.774	91.547	3.228

Note: Standard errors robust to heteroscedasticity are in brackets. Hansen J-statistics (j) assesses the strength of instrument identity, as indicated by the p-value of Hansen J-statistics (jp). The F-statistics, particularly the Cragg-Donald and Kleibergen-Paap tests, corroborate these findings. Collectively, the results from the Hansen J-statistics, F-statistics, and p-value affirm that the instrumental variables employed in this analysis are not weak or over-identified, *** p < 0.01

Results of Developed Financial Economies

The estimations for the developed market economies are shown in Table 6. Eq. (1) is used for estimating M1-M4, Eq. (2) is used for estimating M5-M8, and Eq. (3) is used for estimating M9-M12. The findings indicate that the coefficient related to the growth of financial markets, as well as the depth and accessibility of these markets, holds statistical significance and demonstrates a positive impact at a notable 1% significance level.

Therefore, an escalation in financial market development and its associated indicators leads to an increase in renewable energy utilization by 3.863%, 1.538%, and 2.668%, respectively. These outcomes are consistent with the discoveries made by (Shahbaz et al., 2021). It is also noteworthy that the effectiveness of financial markets does not exert a significant effect on the acceptance of renewable energy. Conversely, the distinctly positive impact of financial market growth, depth, and accessibility underscores the propensity within developed markets for fostering the advancement of sustainable renewable energy technologies. These outcomes lend support to the supposition that well-established financial markets play a role in stimulating technological innovations in this domain that reduce the use of fossil fuels, thereby reducing environmental degradation (Zagorchev et al., 2011), as well as creating credibility for companies or business sectors to make investments in green-technological initiatives.

In the context of non-linear models, it's notable that financial market growth and depth demonstrate non-significant positive impact. On the other hand, there is a significant and positive impact on the adoption of renewable energy attributed to financial accessibility and efficiency. Additionally, it's worth highlighting that the squared term of financial accessibility reveals a noteworthy negative significance, in contrast, The coefficients for financial market growth, depth, and efficiency all yield non-significant negative results. The non-monotonic impacts demonstrate that financial market growth does not necessarily have a linear influence on renewable energy usage. This research is in accordance with the viewpoints put forth by(Shahbaz et al., 2018), emphasizing the curvilinear impact of financial development. As a result, within developed economies, a complex interconnection emerges, marked by a U-shaped relationship between the usage of renewable energy sources and the expansion of financial markets, their accessibility, depth, and efficiency. The ultimate results highlight that enhanced financial market accessibility and efficiency play a pivotal role in substantially increasing the utilization of renewable energy sources, whereas, in developed nations, the adoption of renewable energy exhibits a decline once particular financial market sub-indicators reach certain thresholds.

The moderating influence of advancement of financial market, accessibility of the market, and efficiency of the market demonstrates an adverse impact on ICT concerning its role in shaping the consumption of renewable energy. Additionally, the interaction variables involving financial market growth (lnFD×lnICT), access (lnFAC×lnICT), efficiency (lnFD×lnFEF) and ICT apply significantly negative influence on the usage of renewable energy at a 5%, 1%, and 1% level correspondingly. Hence, within developed financial economies, the progress of financial markets, their accessibility, and efficiency collaborates with ICT to restrict the utilization of renewable energy. This indicates that the allocation of financial resources to the ICT sector in these countries primarily hinges on significant amounts of fossil fuels, leading to detrimental environmental repercussions. Economic growth coefficient in all models is negative and non-significant. These non-significant findings are consistent with the observations made in earlier research conducted by (Bhuiyan et al., 2022; Chen et al., 2020). Furthermore, the outcomes reveal that the estimated energy consumption coefficient holds statistical significance in the models M1, M2, M4-M9, and M12 at 5% and 10% in all the models whereas non-significant positive in models M3, M10, and M11. These findings contradict those of (Khan et al., 2021). The estimated coefficient of ICT is negatively significant at 5% and 10% in models M1, M2, M3, M5, M6, and M7 whereas non-significant negative in models M4, M8, M10, and M11. The adverse impact of ICT on environmental harm corresponds with the findings of (Chang et al., 2022) whereas (Chowdhury et al., 2022) identified relationship between renewable energy and ICT. Furthermore, it is non-significant positive in models M9 and M12. Population estimated coefficient is significant negative at 1% in all the models. As a result, population growth combined with excessive usage of non-renewable energy sources may harm the environment in developed financial markets. In all models, the anticipated coefficient related to urbanization displays at the 1% level significance, except model M8, which is non-significantly positive. This study suggests that as urbanisation grows in developed nations, so will renewable energy usage. Both individuals and enterprises exhibit a predilection for adopting renewable energy resources as a means to protect and preserve their environmental surroundings.

Table 6: ICT, financial development, and renewable energy in developed economies

	M1	M2	M3	M4	M5	M6
lnEN	0.171**	0.145*	0.122	0.178**	0.220**	0.166*
	(0.085)	(0.086)	(0.084)	(0.088)	(0.089)	(0.087)
lnGDP	-0.129	-0.113	-0.186	-0.058	-0.239	-0.071
	(0.142)	(0.138)	(0.142)	(0.128)	(0.169)	(0.136)
lnPOP	-1.063***	-1.039***	-1.046***	-1.076***	-1.080***	-1.033***
	(0.047)	(0.046)	(0.046)	(0.050)	(0.048)	(0.047)
lnURB	0.246***	0.151**	0.240***	0.163**	0.253***	0.205***
	(0.073)	(0.070)	(0.071)	(0.070)	(0.072)	(0.073)
ICT	-0.415*	-0.544**	-0.384*	-0.339	-0.499**	-0.447*
	(0.235)	(0.273)	(0.231)	(0.252)	(0.209)	(0.271)
FD	3.863***				26.449	
	(0.857)				(17.567)	
FAC		1.538***				9.813*
		(0.396)				(5.083)
FDE			2.668***			
			(0.428)			
FEF				0.661		
				(0.413)		
FD2					-15.362	
					(11.765)	
FAC2						-6.866*
						(4.077)
FDE2						
FEF2						
FDICT						
FACICT						
FDEICT						
FEFICT						
Constant	12.232***	15.722***	13.462***	15.982***	4.106	12.573***
	(1.455)	(1.209)	(1.217)	(1.141)	(6.709)	(2.204)
Observations	285	285	285	285	285	285
R^2	0.942	0.940	0.944	0.938	0.944	0.939
j	0.067	0.416	0.079	0.001	0.169	0.447
jp	0.796	0.519	0.779	0.973	0.681	0.504
F-statistics	1793.013	1525.523	3053.757	455.957	27.010	24.339

Table 6: Continued

M7	M8	M9	M10	M11	M12
0.166*	0.168*	0.173**	0.131	0.121	0.209**
(0.097)	(0.086)	(0.085)	(0.086)	(0.084)	(0.091)
-0.282	-0.027	-0.170	-0.177	-0.202	-0.107
(0.185)	(0.128)	(0.142)	(0.141)	(0.143)	(0.127)
-1.063***	-1.065***	-1.067***	-1.030***	-1.047***	-1.082***
(0.050)	(0.048)	(0.048)	(0.046)	(0.047)	(0.051)
0.244***	0.109	0.252***	0.151**	0.242***	0.159**
(0.070)	(0.078)	(0.073)	(0.071)	(0.070)	(0.069)
-0.473*	-0.379	0.697	-0.056	-0.090	0.436
(0.251)	(0.254)	(0.592)	(0.317)	(0.353)	(0.311)
		3.671***			
		(0.818)			
			1.616***		
			(0.391)		
7.252				2.578***	
(5.690)				(0.401)	
	6.240*				0.245
	(3.656)				(0.378)
-3.505					
(4.262)					
	-4.598				
	(2.853)				
		-1.516**			
		(0.721)			
			-0.939***		
			(0.334)		
				-0.428	
				(0.417)	
					-1.288***
					(0.371)
12.148***	15.582***	12.326***	15.736***	13.527***	16.321***
(2.122)	(1.142)	(1.443)	(1.209)	(1.221)	(1.143)
285	285	285	285	285	285
0.944	0.940	0.942	0.940	0.944	0.940
0.091	0.028	0.022	0.566	0.076	0.158
0.763	0.867	0.883	0.452	0.783	0.691
28.355	10.764	1586.669	1440.689	2621.051	427.536

Note: Standard errors robust to heteroscedasticity are in brackets. Hansen J-statistics (j) assesses the strength of instrument identity, as indicated by the p-value of Hansen J-statistics (jp). The F-statistics, particularly the Cragg-Donald and Kleibergen-Paap tests, corroborate these findings. Collectively, the results from the Hansen J-statistics, F-statistics, and p-value affirm that the instrumental variables employed in this analysis are not weak or over-identified, *** $p < 0.01$.

Results of Frontier financial economies

The findings pertaining to financial markets in frontier economies are showcased in Table 7. M1 to M4, M5 to M8, and M9 to M12 represent the outcomes derived from Eq. (1), Eq. (2), and Eq. (3), correspondingly. The estimated coefficient for the growth, accessibility, depth, and efficiency of the financial market is 1%, which is negative and statistically significant. As the financial market growth and sub-measures increase by 1%, renewable energy usage reduces by 6.540%, 1.824%, 3.335%, and 5.632%, respectively. Our results are negative, which is in line with those of (Amin et al., 2022). On the other hand, research conducted by (Sadorsky, 2010) found that metrics tied to value traded and stock market capitalization, often referred to as market depth indicators, had no observable influence on energy consumption. This conspicuous negative impact of financial market expansion, depth, and efficiency pertaining to the reduction in the adoption of renewable energy resources within frontier markets alludes to the notion that the financial markets of these frontier countries exhibit fragility and inefficiency. In contrast to the established market, the immature financial market fails to foster good corporate governance, create inventiveness, or encourage businesses to adopt sustainable technological developments, and it lacks adequate legislation that ban enterprises from investing in non-renewable energy projects. As a result, the findings show that financial sectors might successfully assist the renewable energy industry, facilitating sustainable growth. As the results shows, the contribution of financial organizations in fostering the adoption of renewable energy can be depicted as a pivotal provider of enduring and significant financial backing. This monetary assistance empowers renewable energy firms to extend their activities and advance their technological proficiencies (Sun et al., 2023).

In compliance with the nonlinear models, it becomes apparent that the development of the financial markets, efficiency of financial markets, accessibility, depth along with their corresponding squared terms, noticeably have both positive and negative impacts on the usage of renewable energy within frontier markets. Hence, the advancement in the financial market and its associated measures leads to a decrease in the utilization of renewable energy, yet at a specific threshold of financial market expansion and measures, renewable energy consumption experiences an upsurge. The findings unveil a nuanced perspective on the impact of financial market advancement, indicating a non-monotonic trend. Furthermore, the results elucidate a connection that exhibits a U-shaped pattern when exploring the linkage between financial market advancement and its distinct components concerning renewable energy utilization. Initially, both the progress of the financial market and its component factors display a decrease in renewable energy consumption. However, once a certain threshold is surpassed, renewable energy starts upsurge remarkably.

Among the variables scrutinized, it's worth noting that only the moderating influences of market efficiency and ICT reveal a considerable adverse influence on renewable energy consumption, signifying statistical significance at the 10% level within the moderating models. Hence, the efficacy of financial markets, when acting as a moderating element in conjunction with ICT, collaboratively contributes to the reduction in the utilization of renewable energy. The interaction between the financial market, its accessibility, and depth serves as a catalyst, fostering the utilization of ICT to drive and improving the consumption of renewable energy. With each 1% increment in financial development, there is a positive relationship between renewable energy and ICT which is projected to increase, ranging approximately from 2.536% to 6.313%. Consequently, these findings robustly suggest that financial development acts as a moderator for ICT, enhancing the utilization of renewable energy. Improvements in financial development will encourage ICT's favourable influence on renewable energy usage. The outcome proposes an approach for boosting renewable energy usage using ICT and suggests that a collaborative effort between ICT and financial growth vital in the usage of renewable energy. The results also reveal the presence of both significant and non- significant negative relationship between renewable energy and economic growth. Findings suggests that, in frontier financial economies economic activities are mostly carried out by using fossil fuels. Hence, it is advisable to conduct economic activities reliant on energy sources from the renewable energy sources rather than depleting non-renewable energies.

In each model, the anticipated energy consumption coefficient is notably positive at a 1% significance level. Consequently, the consumption of renewable energy is positively influenced by the use of consumption of energy within frontier markets. The estimated coefficient for ICT, conversely, exerts significant adverse impacts on the usage of renewable energy. Therefore, it can be concluded that information and communication technology has a discouraging effect on the utilization of renewable energy. These results are the opposite with (Pasalic, 2023) and in line with (Amin et al., 2022). Simultaneously, the coefficient linked to energy consumption is significantly positive across each model, at the significance of 1%. Hence, energy consumption in frontier financial markets promotes the adoption of renewable energy, while the estimated coefficient indicates a substantial negative impact of ICT on the usage of renewable energy. Therefore, the information and communication technology hinder the deployment of renewable energy.

Table 7: ICT, financial development, and renewable energy in frontier economies

	M1	M2	M3	M4	M5	M6
lnEN	0.467***	0.504***	0.483***	0.501***	0.424***	0.487***
	(0.088)	(0.094)	(0.103)	(0.092)	(0.087)	(0.094)
lnGDP	-0.235	-0.290**	-0.220	-0.105	-0.288**	-0.288**
	(0.144)	(0.145)	(0.151)	(0.144)	(0.146)	(0.144)
lnPOP	-1.098***	-1.081***	-1.079***	-1.071***	-1.116***	-1.079***
	(0.051)	(0.054)	(0.052)	(0.049)	(0.054)	(0.054)
lnURB	0.581***	0.304***	0.445***	0.491***	0.542***	0.308***
	(0.108)	(0.093)	(0.108)	(0.102)	(0.106)	(0.093)
ICT	-1.474***	-1.906***	-1.782***	-1.862***	-1.214**	-1.882***
	(0.460)	(0.481)	(0.470)	(0.445)	(0.478)	(0.482)
FD	-6.540***				-16.443***	
	(1.128)				(5.077)	
FACC		-1.824***				-2.885*
		(0.456)				(1.620)
FDEP			-3.335***			
			(0.780)			
FEF				-5.632***		
				(0.956)		
FD2					18.464**	
					(8.629)	
FAC2						1.526
						(2.183)
FDE2						
FEF2						
FDICT						
FACICT						
FDEICT						
FEFICT						
Constant	10.697***	13.907***	11.602***	10.804***	12.656***	13.930***
	(1.674)	(1.573)	(1.805)	(1.722)	(1.878)	(1.584)
Observations	331	331	331	331	331	331
R^2	0.931	0.928	0.927	0.930	0.932	0.928
j	5.362	0.328	0.165	5.183	4.869	0.236
jp	0.021	0.567	0.685	0.023	0.027	0.627
F-statistics	2398.657	1315.444	983.166	126.539	77.306	102.950

Table 7: Continued

M7	M8	M9	M10	M11	M12
0.398***	0.411***	0.457***	0.428***	0.457***	0.490***
(0.107)	(0.089)	(0.083)	(0.089)	(0.102)	(0.092)
-0.211	-0.118	-0.160	-0.264*	-0.181	-0.094
(0.152)	(0.139)	(0.144)	(0.140)	(0.151)	(0.145)
-1.061***	-1.062***	-1.100***	-1.099***	-1.067***	-1.080***
(0.053)	(0.050)	(0.050)	(0.055)	(0.051)	(0.050)
0.464***	0.516***	0.675***	0.246***	0.426***	0.490***
(0.110)	(0.098)	(0.104)	(0.092)	(0.108)	(0.101)
-1.644***	-1.664***	-2.690***	-1.814***	-2.107***	-1.591***
(0.471)	(0.434)	(0.478)	(0.453)	(0.471)	(0.481)
		-5.917***			
		(0.978)			
			-1.253***		
			(0.383)		
-8.763***				0.474	
(3.248)				(1.189)	
	-17.288***				-6.795***
	(3.461)				(1.235)
9.279*					
(4.853)					
	18.846***				
	(5.208)				
		5.952***			
		(0.873)			
			2.536***		
			(0.432)		
				6.313***	
				(1.490)	
					-2.259*
					(1.200)
11.746***	11.157***	9.063***	15.249***	11.733***	10.936***
(1.780)	(1.663)	(1.602)	(1.607)	(1.800)	(1.716)
331	331	331	331	331	331
0.927	0.934	0.937	0.931	0.928	0.930
0.018	0.810	6.075	0.588	0.179	5.350
0.892	0.368	0.014	0.443	0.673	0.021
61.532	20.714	2239.285	1025.261	110.340	33.207

Note: Standard errors robust to heteroscedasticity are in brackets. Hansen J-statistics (j) assesses the strength of instrument identity, as indicated by the p-value of Hansen J-statistics (jp). The F-statistics, particularly the Cragg-Donald and Kleibergen-Paap tests, corroborate these findings. Collectively, the results from the Hansen J-statistics, F-statistics, and p-value affirm that the instrumental variables employed in this analysis are not weak or over-identified, *** $p < 0.01$

These findings contradict (Pasalic, 2023) but are consistent with (Amin et al., 2022). In all models, precisely at the 1% significance level, the population variable's coefficient reveals a statistically significant inverse relationship. Similarly, the calculated urbanization coefficient holds statistical significance at the 1% level in all models. The Kleibergen-Paap and Cragg-Donald F-statistics, along with the Hansen test probability value, indicate that the instruments employed are not excessively identified and display no signs of weakness.

Results on the interaction role of financial market and energy consumption on renewable energy consumption

Table 8 displays the results concerning how the interaction between energy consumption and financial market growth impacts the adoption of renewable energy for frontier, developed, standalone, and emerging financial markets using Eq. (4). In Table 8, specifically within models M1-M4, we can observe that the influence of financial market growth and its associated metrics (such as financial market efficiency and depth), in in moderating model with energy consumption, significantly affects the adoption of renewable energy in developed economies, significant both positive and negative outcomes. The inference drawn from this analysis is that within developed financial markets, the expansion of financial markets doesn't promote energy consumption, thereby failing to significantly impact the usage of renewable energy.

Table 8: Interaction terms models

Variables	M1	M2	M3	M4	M5	M6	M7	M8
	Developed Financial economics				Emerging Financial economics			
lnEN	0.115	0.276***	0.075	0.319**	0.987***	0.715***	0.774***	0.919***
	-0.192	-0.093	-0.116	-0.15	-0.159	-0.085	-0.08	-0.103
lnGDP	-0.12	-0.194	-0.175	-0.08	-0.233*	-0.264**	-0.294**	-0.250*
	-0.148	-0.139	-0.144	-0.132	-0.12	-0.129	-0.126	-0.128
lnPOP	-1.062***	-1.040***	-1.045***	-1.081***	-1.294***	-1.270***	-1.248***	-1.304***
	-0.048	-0.046	-0.046	-0.051	-0.034	-0.039	-0.038	-0.037
lnURB	0.244***	0.152**	0.239***	0.169**	0.471***	0.536***	0.493***	0.501***
	-0.074	-0.071	-0.07	-0.069	-0.051	-0.053	-0.047	-0.05
ICT	-0.409*	-0.399	-0.363	-0.437	-1.820***	-1.793***	-1.772***	-1.633***
	-0.236	-0.261	-0.238	-0.286	-0.216	-0.214	-0.213	-0.206
FD	3.617***				6.410***			
	-1.189				-1.928			
FDlnEN	0.074				-0.342			
	-0.209				-0.295			
FAC		2.708***				0.17		
		-0.616				-0.621		
FAClnEN		-0.315***				0.194*		
		-0.111				-0.117		
FDE			2.483***				3.407***	
			-0.586				-0.751	
FDElnEN			0.063				-0.163	
			-0.1				-0.144	
FEF				0.986*				0.910*
				-0.538				-0.47
FEFlnEN				-0.154				-0.190**
				-0.1				-0.088
Constant	12.442***	15.280***	13.613***	15.607***	8.770***	10.500***	10.151***	10.748***
	-1.642	-1.257	-1.26	-1.163	-0.986	-0.908	-0.85	-0.866
Observations	285	285	285	285	280	280	280	280
R^2	0.942	0.94	0.944	0.939	0.965	0.962	0.965	0.962
j	0.089	0.629	0.08	0.037	2.194	1.145	1.34	1.792
jp	0.765	0.428	0.777	0.848	0.139	0.285	0.247	0.181
F-statistics	676.224	515.014	1333.304	155.066	348.102	278.154	524.499	363.659

Table 8: Continued

M9	M10	M11	M12	M13	M14	M15	M16
Frontier Financial Economies				Standalone Financial Economies			
0.241***	0.412***	0.441***	0.517***	1.347***	1.874**	0.211***	-0.408**
-0.092	-0.091	-0.117	-0.092	-0.092	-0.746	-0.069	-0.179
-0.128	-0.271*	-0.209	-0.108	0.114	-0.061	0.165	0.012
-0.146	-0.141	-0.152	-0.142	-0.097	-0.19	-0.14	-0.296
-1.099***	-1.089***	-1.066***	-1.076***	-1.201***	-1.701***	-0.773***	-0.885***
-0.049	-0.054	-0.051	-0.049	-0.028	-0.305	-0.031	-0.063
0.659***	0.261***	0.432***	0.494***	0.347***	1.057***	-0.402***	0.775***
-0.107	-0.092	-0.11	-0.101	-0.091	-0.227	-0.14	-0.206
-1.649***	-1.765***	-1.810***	-1.799***	1.967***	0.798**	2.634***	-0.388
-0.441	-0.463	-0.46	-0.439	-0.236	-0.338	-0.413	-0.261
-10.174***				15.762***			
-1.358				-0.693			
1.301***				-4.564***			
-0.193				-0.267			
	-2.964***				10.948**		
	-0.566				-5.052		
	0.464***				-2.981***		
	-0.097				-0.454		
		-3.537***				19.557***	
		-0.785				-1.713	
		0.374				-6.397***	
		-0.335				-0.508	
			-5.210***				-9.058***
			-0.933				-3.503
			-0.352				4.102**
			-0.283				-1.748
10.049***	15.008***	11.842***	10.752***	9.547***	-2.071	24.154***	6.158*
-1.621	-1.607	-1.854	-1.717	-1.543	-4.996	-2.198	-3.324
331	331	331	331	79	79	79	79
0.936	0.93	0.927	0.931	0.994	0.985	0.993	0.98
5.754	0.479	0.149	5.358	0.298	0.102	0.746	0.77
0.016	0.489	0.7	0.021	0.585	0.75	0.388	0.38
1519.13	964.243	934.962	92.282	722.81	27.431	49.886	19.571

Note: Standard errors robust to heteroscedasticity are in brackets. Hansen J-statistics (j) assesses the strength of instrument identity, as indicated by the p-value of Hansen J-statistics (jp). The F-statistics, particularly the Cragg-Donald and Kleibergen-Paap tests, corroborate these findings. Collectively, the results from the Hansen J-statistics, F-statistics, and p-value affirm that the instrumental variables employed in this analysis are not weak or over-identified, *** $p < 0.0$

Within model M9-M12, the interaction of energy consumption and the progress of financial markets, and financial market accessibility results in a significant influence on renewable energy utilization in frontier financial economies. Conversely, the influence of financial market depth and efficiency, on the contrary, lacks statistical significance in the moderating models. As noted in the case of frontier markets, the advancement of financial markets in these regions is capable of increasing energy consumption, hence increasing energy from renewable energy. In models M13 to M16, in standalone economies, the moderating effect of energy consumption, financial market growth, accessibility, and depth is associated with a decrease in renewable energy utilization. However, it's important to note that financial market efficiency shows a statistically significant positive impact in this context. Conversely, the utilization of renewable energy experiences a decline due to the moderating influence of financial market accessibility and energy consumption. In emerging financial market in models M5-M8, the moderating influence of energy consumption, along with financial market access and efficiency yields a mixed impact on renewable energy utilization, with both positive and negative effects observed at the 10% and 5% significance levels. On the contrary, the interaction variables involving advancement of financial market and depth do exhibit a negative influence, but it is not statistically significant in their influence on usage of renewable energy. This finding implies that financial market accessibility and efficiency help enhance and minimize renewable energy use. Thus, financial market accessibility assures consumption of energy efficiency, which enhances renewable energy usage.

Conclusions and policy implications

In recent times, policymakers have been engaging in discussions concerning the impact of financial development on environmental sustainability, raising questions and deliberations on this matter. While the rising theoretical literature is incoherent, empirical proof is conflicting thus fails to account for disparities in financial growth stages. As a result, there are contradictions in the literature. Within the scope of this investigation, our objective is to assess the effects of the growth and development of financial markets on the adoption and utilization of renewable energy sources, utilizing an extensive panel dataset spanning from 1990 to 2020 for 83 countries by employing IV-GMM. We utilize a comparative approach to investigate how financial market expansion affects renewable energy adoption across emerging, developed, standalone, and frontier financial economies, while also considering factors such as ICT, population, economic growth, urbanization, and energy consumption. Below are the outcomes of this study:

To begin, the results disclose that the impact of financial markets on renewable energy varies based on the type of financial economy. According to the empirical findings, financial market expansion, accessibility, and depth in emerging financial economies improve environmental quality through encouraging the usage of renewable energy. Furthermore, despite the depth and expansion of the financial market in standalone markets, the usage of renewable energy is encouraged but diminished by market efficiency. The advancement of the financial market, coupled with increased accessibility and depth, contributes to the increased utilization of renewable energy within developed financial markets, however, in the context of frontier financial economies, the expansion of financial markets and the metrics associated with it have a pronounced and statistically significant negative impact on the adoption of renewable energy. These findings indicate that in emerging, standalone, and developed financial markets, eco-technological advances are facilitated, effective corporate governance is promoted, and credibility and economic benefits are created for businesses to make investments in eco-enhancing initiatives, thus boosting the use of renewable energy (Sun et al., 2023). Contrasting to these financial markets, the frontier economies' undeveloped and inadequate financial markets fail to promote effective corporate governance, improve innovation, encourage business sectors to adopt environmentally friendly technologies, and do not have adequate laws to encourage industries to make investments in green projects that promote sustainability. In addition, the insignificant influence of financial market efficiency in the emerging and developed markets, as well as financial market access in the standalone market, on renewable energy consumption may be related to their financial industry's immaturity. Moreover, empirical data underscores a relationship that is non-linear rather than linear one, regarding the adoption of renewable energy and the progress of financial markets. Financial market development policies have a somewhat non-linear influence on renewable energy adoption in certain economies, despite the fact that they have no linear impact. Consequently, within emerging markets, the growth and depth of financial markets exhibit intricate, inverted U-shaped associations with the usage of renewable energy.

Additionally, within these emerging markets, market efficiency exhibits a connection characterized by an inverted U-shaped pattern in terms of renewable energy utilization. Meanwhile, in isolated markets, the growth and depth of financial markets present a nuanced, inverted U-shaped relationship with the adoption of renewable energy. Moreover, the financial market and its components in developed financial markets exhibit a similar inverted U-shaped relationship with renewable energy consumption. The findings provide support for the existence of an inverted U-shaped relationship between the utilization of renewable energy and financial market components, indicating that these measures encourage the utilization of renewable energy up to a specific threshold, after which there is a decline in the consumption of renewable energy. In contrast, financial market growth and sub-measures in frontier markets show a U-shaped link with the usage of renewable energy. This illustrates that financial growth and sub-measures reduce renewable energy usage, but after a particular threshold, it increases.

Third, the research outcomes elucidated that the financial market exerts an influence on both energy consumption and ICT, which in turn influences renewable energy use. Financial market accessibility plays a moderating role in shaping consumption of energy patterns within advanced financial economies, effectively curbing the reliance on renewable energy sources. Furthermore, ICT is influenced by financial growth, accessibility, and efficiency in developed nations, in contrast, reduces the adoption of renewable energy. In emerging economies, access to financial markets and efficiency govern energy consumption to increase and decrease reliance on renewable energy. The results indicate that the financial market acts as a moderator for ICT and energy consumption, thereby impacting the utilization of renewable energy. Specifically, financial market accessibility moderates' energy usage within developed financial markets, limiting the usage of renewable energy. Moreover, within developed nations, financial expansion, the accessibility of financial markets, and their efficiency collectively act as moderators for ICT, subsequently in a decrease in the renewable energy utilization. Financial market access and efficiency in emerging financial markets moderate energy consumption to increase and decrease the use of renewable energy.

Though this article proves that an advanced financial market increases the usage of renewable energy directly, it indirectly increases ICT and energy usage, which degrades environmental quality. In conclusion, this research has shown that when evaluating the effect of financial markets on renewable energy use, the stages of financial development. The current research posits that the connection between the adoption of renewable energy and advancement of financial market isn't strictly to a linear shape but may, in fact, display a curvilinear character. Furthermore, the paper emphasizes the indirect relationship between utilization of renewable energy and financial market, but financial market also moderates use of energy and ICT to affect renewable energy consumption. Our work not only advances our understanding of the financial market's influence on renewable energy use, but it also has substantial policy implications, particularly for policymakers in standalone financial markets. While taking advantage of the financial market, policymakers from standalone financial markets should embrace and invest in sustainable and green technology. Furthermore, this research demonstrates that the financial market directly contributes to the improved usage of renewable energy in emerging and developed financial markets since business sectors or companies in these markets have benefit of making investments in sources of renewable energy as a due to stringent regulations and laws. As an outcome, financial markets should be used as a regulatory tool which is available to regulators in pursuit of environmental sustainability and long-term well-being and, to a large extent, combat the impact of climate change. Whereas the financial sector indirectly reduces renewable energy use in standalone markets by driving ICT and consumption of energy, in developed countries, the financial industry indirectly curtails the utilization of renewable energy by encouraging the information and communication technology (ICT) sector. These economies' policymakers should encourage investments in renewable energy resources and ICT industries that support renewable energy.

Appendix 1

Table 1A. Descriptive statistics

Developed financial economies	mean	SD	min	max
lnRE	14.869	7.154	-.061	23.629
lnEN	2.294	3.370	-3.050	9.042
lnGDPC	1.223	.848	-3.196	4.488
lnPOP	4.665	7.190	-3.749	17.453
lnUPOP	16.503	1.673	13.156	21.067
lnICT	-.136	.827	-.741	2.465
lnFD	.697	.146	.33	1.000
lnFAC	.527	.236	.01	1.000
lnFDE	.604	.270	.07	1.000
lnFEF	.669	.285	.06	1.000
Emerging financial economies				
lnRE	13.737	8.870	-2.995	23.660
lnEN	2.727	3.535	-3.028	8.872
lnGDPC	1.167	.901	-2.496	3.900
lnPOP	6.094	7.817	-5.490	18.668
lnUPOP	16.497	1.601	13.788	21.057
lnICT	.191	1.209	-.7413946	5.057
lnFD	.418	.142	0.11	.85
lnFAC	.354	.192	0.000	1.000
lnFDE	.331	.210	0.02	0.95
lnFEF	.516	.321	0.000	1.000
Frontier Financial economies				
lnRE	13.869	8.058	-1.660	24.381
lnEN	2.729	3.386	-2.969	8.905
lnGDPC	1.162	.846	-3.556	3.264
lnPOP	5.159	7.363	-6.078	17.673
lnUPOP	16.495	1.455	12.998	19.241
lnICT	-.000	.967	-.741	2.322
lnFD	.227	.130	0.0001	0.58
lnFAC	.198	.247	0.0001	0.99
lnFDE	.124	.161	0.0001	0.77
lnFEF	.113	.186	0.0001	1.000
Standalone financial economies				
lnRE	12.064	7.968	-.494	21.263
lnEN	2.595	3.199	-1.862	8.994
lnGDPC	1.250	.906	-3.091	2.908
lnPOP	4.910	7.983	-2.896	19.619
lnUPOP	16.904	1.592	14.051	19.428
lnICT	-.1481	.815	-.741	1.703
lnFD	.290	.103	0.0001	.52
lnFAC	.222	.205	0.0001	.83
lnFDE	.160	.136	0.0001	.74
lnFEF	.210	.300	0.0001	1.000

Table 1B. Symbols, definitions, and sources

Symbols	Variable	Unit	Literature source	Source
RE	Renewable energy	Renewable energy consumption % of total final energy consumption	(Shahbaz et al., 2021)	WDI
EN	Energy use	Energy use (kg of oil equivalent per capita)	(Khan et al., 2021)	WDI
GDPC	Gross domestic product	GDP per capita growth	(Wang et al., 2022)	WDI
POP	Total population	-	(Acheampong et al., 2020)	WDI
UPOP	Urban population	-		WDI
ICT	Information and communication technology	-	(Shehzad et al., 2022)	WDI
FD	Financial development	Ranges from 0 to 1	(Shahbaz et al., 2021)	IMF
FAC	Financial market access	Ranges from 0 to 1	-	-
FDE	Financial market depth	Ranges from 0 to 1	-	-
FEF	Financial market efficiency	Ranges from 0 to 1	-	-

Table 1C. Correlation matrix

	lnRE	lnEN	lnGDP	lnPOPT	lnUPOP	lnICT	lnFD	lnFMA	lnFMD	lnFME
lnRE	1									
lnEN	-0.863^{***}	1								
lnGDPC	0.418^{***}	-0.448^{***}	1							
lnPOPT	-0.962^{***}	0.917^{***}	-0.445^{***}	1						
lnUPOP	0.167^{***}	-0.194^{***}	0.132^{***}	-0.115^{***}	1					
lnICT	-0.880^{***}	0.875^{***}	-0.452^{***}	0.890^{***}	-0.172^{***}	1				
lnFD	0.0754^{*}	-0.104^{***}	0.0723^{*}	-0.0807^{*}	0.127^{***}	-0.0598	1			
lnFMA	0.188^{***}	-0.203^{***}	0.137^{***}	-0.204^{***}	0.0881^{**}	-0.145^{***}	0.687^{***}	1		
lnFMD	0.115^{***}	-0.106^{***}	0.110^{***}	-0.103^{**}	0.128^{***}	-0.0789^{*}	0.912^{***}	0.583^{***}	1	
lnFME	0.0611	-0.0912^{**}	0.108^{***}	-0.0599	0.150^{***}	-0.0714^{*}	0.767^{***}	0.366^{***}	0.694^{***}	1

Note: $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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