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RESEARCH ARTICLE

Financial inclusion role on energy efficiency financing gaps in COVID-19 period: empirical outcomes of emerging nations

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Abstract
The structural imposed crises of the COVID-19 have halted the system of financial intermediation at large. By this, the energy sector needs huge financing for energy efficiency maximization in the COVID-19 crises. Thus, the current research aims to inquire the role of financial inclusion in filling the energy efficiency financing gaps for the period of COVID-19 outbreak. The governments of many countries are facing fiscal deficits and trying to survive under tight substantial fiscal limitations. So providing a cheap and efficient energy in modern times, under COVID-19 crises, is merely impossible for many economies because the main source of income for energy sector is the energy users, and having inefficient energy for consumption is raising energy poverty at large. Therefore, COVID-19 crises raised a wide energy financing gap in modern times that needs a fix. However, this research is suggesting the system to make financial inclusion structure as effective, to fill the energy financing gap, for post-COVID-19 time, and to develop a viable and sustainable financing option for energy sector in long-run perspective. This study also validated the empirical role of financial inclusion on energy poverty and energy efficiency, with historical data, to justify the significance of financial inclusion for energy financing gap fulfillment. More so, this paper is also recommending new policy implications for the stakeholders to utilize. We believe if the recommended policy recommendations are considered for practice, the energy financing gap in post-COVID-19 era would be mitigated, and there is a high probability to supply the efficient energy to the end users.

Keywords Financial inclusion · Energy efficiency financing · Post-COVID-19 period · Energy efficiency · Energy poverty

Introduction

Energy financing lacks adequate financing supports from financial markets and financial intermediaries, due to COVID-19 crises (Li et al. 2021a). Increased access to affordable, clean, stable, and modern energy helps improve the overall socio-economicdevelopment of people and has been linked to SDGs, in particular SDGs on ending poverty and eliminating hunger (Iqbal et al. 2021; Scheyyens and Hughes 2019). However, governments and development organizations have had difficulties supporting the transition of households from traditional to contemporary fuels due to the outlay of contemporary and sparkling energies and restricted buying influence in undeveloped states (Surendra et al. 2014). Economic growth and social progress may be boosted when financial services are made available to low-incomepeople and small companies (Kammen and Kirubi 2008). In particular, women and rural populations may benefit from financial inclusion since it may increase their access to credit, savings, and investment possibilities (Li and

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Umair (2023). Despite the growing awareness of the need for financial inclusion, many people and enterprises in emerging countries still lack access to mainstream financial institutions and services (Liu et al. (2023).

A multi-objective approach to complex problems like energy poverty may assist in both solving social welfare issues and mitigating energy poverty by increasing renewable energy sources (Alemzero et al. 2021). Some things that impact the price of energy, such as costs and weather, are influenced by energy poverty (Chester and Morris 2011). The global community's predicted goal to fulfill by 2030 may not be met due to the SDGs, which supported more people living in energy poverty. Until 2019, a population of 840 million had significant issues with energy poverty. The nations in Asia, Africa, and other worldwide nations are predicted to have their number of people without electricity grow to around 640 million by 2030, according to certain notable databases (Zheng et al. 2022).

Crises do not differentiate between established and emerging economies; similarly, both developed and emerging economies have their own issues. At the 65th session of the UN General Assembly, energy poverty was on the agenda, and as part of the Sustainable Energy for All initiative, a world year event titled "Sustainable Energy for All" highlighted this concept (Thomson et al. 2017). According to this resolution, energy poverty impacts several facets of human wellbeing. It goes on to expand on how, because of the lack of access to clean, affordable, and reliable energy, it is difficult to improve upon human, social, and economic development (Boemi and Papadopoulos 2019), thus affecting the chances of realizing the UN's millennium development goals. The biggest reason restricting the capacity of families to acquire access to electricity is a lack of information of energy poverty. Because of this, resources with a limited amount of energy are less capable of meeting the requirements of industrialized economies' energy users, which are called energy poverty (Bouzarovski et al. 2012).

Apart from low buying power impeding families' road out of energy poverty and its negative impact on the population, Okushima (2017) argue that when modern fuels become more widely accessible, families must be ready to pay on them. Because developing-country incomes are known to be low, policy approaches that may help families migrate to a more energy-efficient lifestyle and alleviate energy poverty in long-term ways must be investigated. Financial inclusion (FI) is one such policy that has been identified as having the potential to reduce poverty and improve household welfare in general (Bonatz et al. 2019), but its impact on energy poverty has yet to be empirically examined at the household level. Adults' access to and successful use of a variety of relevant financial services, including mobile money accounts, are referred to as financial inclusion (Aranda et al. 2017). The need to investigate the FI-energy poverty nexus derives from findings that FI enhances individual and family welfare by facilitating household investments in education, health, and household businesses, as well as efficiency benefits (Bednar and Reames 2020).

Thus, the aim of the study is to provide the two type of answers. One, to test the significance of financial inclusion for energy efficiency and energy poverty on the basis of historical data. For this, the study tests (i) the financial inclusion indicator's nexus with energy efficiency index, (ii) financial inclusion indicator's nexus with energy poverty, and (iii) nexus between the constructs of energy efficiency and energy poverty in selected 17 countries. Two, to provide the real-time innovative and modern solutions to fill the energy financing gap in post-COVID-19 period. However, with the first objective, the study verifies the theoretical verdicts about financial inclusion, energy efficiency, and energy poverty. This is the theoretical contribution of recent research. By responding to the objective two, current investigation contributes practically and replies for associated stakeholders by suggesting novel practical recommendations. This is the key motivation of current investigation. Energy efficiency means using less energy to get the same job done—and in the process, cutting energy bills and reducing pollution. Many products, homes, and buildings use more energy than they actually need, through inefficiencies and energy waste. Energy efficiency is calculated by dividing the energy obtained (useful energy or energy output) by the initial energy (energy input). The terms "energy efficiency" and "indicators" are used in data envelopment analysis (DEA) when it is required to determine the amount of energy poverty that affects the overall social welfare. The solution proposed in this project is intended to help mitigate the risks discussed above and to implement a strategy to decrease the energy poverty indicators' influence on financial inclusion and energy efficiency. In this paper, the authors suggest an operationalized entropy linkage between energy poverty and social welfare evaluation to devise an energy poverty index. To test the results, the index is applied to social welfare losses. As well as the applied DEA and entropy approach, the new energy efficiency and energy poverty brand models are not new.

Our study adds to the overall body of knowledge. This study examines how FI impacts energy poverty at the house level. The previous studies on energy efficiency, income, and energy prices show that energy poverty is largely seen in industrialized countries (see Azpitarte et al. 2015; Boardman 2013; Awaworyi et al. 2020). Boardman (2013) analyzes European countries' statistics to analyze fuel poverty (low wages, high fuel costs, and poor-quality housing). The Azpitarte et al. (2015) study draws on the HILDA survey to analyze Australian households' energy expenditures and experience of fuel poverty. This study deviates from previous studies by focusing on energy poverty in a developing country with high energy poverty levels. Policymakers should pay attention to these findings because they show the relevance of FI in ending energy poverty while helping households mitigate their transition to a more sustainable energy system.

Theoretical background

Financial inclusion (FI) increases family income and reduces inequality and poverty, since it allows families to make future investments, sustain consumption levels over time and absorb economic shocks (Pachauri and Spreng 2011). The FI and income-poverty connection has been widely researched. These studies have shown that gains in FI led to higher incomes for low-income households, utilizing different empirical methods. According to Burgess and Pande (2005), expanding bank branches in rural areas has led to a decline in rural poverty in India. For example, in Ghana, Koomson and Danquah (2021) show that a FI increase is linked with a decrease in a household's probability of poverty and inhibits a household's risk of future poverty. Lakatos and Arsenopoulos (2019) noted that an increase in multi-dimensional FI, including access to bank account, credit, and insurance, is linked with poverty reduction. Other researchers have argued that FI promotes social inclusion by providing low-income and disadvantaged populations with inexpensive financial services (Bouzarovski et al. 2012). In this approach, FI helps impoverished people have access to development opportunities and reduces economic disparity (Omar and Inaba 2020; Park and Mercado Jr 2018). Equal access to financial services encourages the economic integration of socially disadvantaged families and improves society's overall wellbeing (Pereira et al. 2011). The link between energy poverty and poverty or inequality is positive, but the link between energy poverty and family income is negative. This implies that FI's impact on family income, poverty, and inequality might have an impact on energy poverty.

Poverty reduction is a multifaceted notion that encompasses more than simply monetary poverty (Samarakoon 2019). Despite its capacity to promote education, health, and not only income growth, existing research is still interested in the impact of financial inclusion on energy poverty reduction (Thomson et al. 2017). As a result, financial inclusion allows for the reduction of energy poverty, the improvement of family income and education, and the increased use of energy efficiency notwithstanding the negative impact of family income on energy poverty (Awaworyi et al. 2020; Koomson and Danquah 2021). As a result of its influence on family income, poverty, and inequality, financial inclusion will have an influence on energy poverty (Koomson and Danquah 2021).

Energy poverty, also known as fuel poverty or energy vulnerability in the literature, occurs when a household's energy services are insufficient (Thomson et al. 2017). It is mostly caused by low household income, high energy costs, and inefficient structures and appliances, and it may result in social isolation, social disturbance, decreased quality of life, and public health problems (Chibba 2009). There is currently no globally applicable definition of energy poverty for various nations, nor is there a widely acknowledged mechanism for quantifying it. An accurate definition of energy poverty, on the other hand, is critical for policy formation, determining the scope and nature of the issue, selecting a strategy, and tracking progress. In undeveloped nations, access to modern energy is used as a green financing and energy poverty definition, while affordability is utilized to investigate it (Liu et al. 2022; Li et al. 2022; Zhao et al. 2022).

The issue of energy poverty (EP) has long been disputed in poor nations, where it is acutely felt, as well as in industrialized nations, where data is more readily available. EP has also become a worldwide issue, with the United Nations Sustainable Development Goals (Yang et al. 2022; Zhao et al. 2021) accounting for it, igniting political, economic, and scholarly attention. As evidence, the EP is dominating the European agenda as a social concern, but it is also causing a stir in a variety of sectors such as healthcare management and climate change policy (Wang et al. 2021). Reducing EP has several advantages for issues like as poverty, bad health, climate change, and residential energy inefficiency. Considering that poverty alleviation aims should be aimed to people who are energy poor (Teschner et al. 2020), analyzing EP is vital to enhance energy efficiency and combat poverty (Lin and Wang 2020), concentrating on the diverse family groups (Che et al. 2021). Rising energy costs and the relevance of energy have piqued scholarly interest in family fuel poverty (Sánchez et al. 2020). Fuel poverty is described as the inability for families to maintain a comfortable temperature at home while still receiving other basic residential energy services (Sareen et al. 2020). EP and FP definitions are two distinct notions that are often used interchangeably. EP is concerned with developing nations' limited access to energy sources, which raises issues of economics, infrastructure, social fairness, education, and health. When a household's financial resources are inadequate to cover their fundamental energy demands, FP arises. EC (2010) proposes three criteria for evaluating FP: incapacity to keep houses properly warm, energy bill payment delays, and occupancy of faulty premises (Sun et al. 2022; Zhang et al. 2022). As a result, in rich nations, EP affordability is the primary reason, but in poor nations, EP is concerned with cost and accessibility. In general, we may classify families in fuel poverty as those that are unable to pay their fuel bills and are at risk of increased mortality and morbidity throughout the winter and summer months (Papada and Kaliampakos 2020). Zhang et al. (2021) present a thorough examination of existing fuel poverty ideas and metrics (see Table 1). FP, according to Bardazzi et al. (2021), is a condition in which homes are denied of heating and/or cooling, hot water, electricity, and other basic home necessities.

Since the Industrial Revolution, the world's energy need has constantly grown. The fast expansion of the industrial and mining sectors to meet expanding social requirements is primarily responsible for the growth. Low coal and power costs have historically aided the country's energy-intensive growth while also exacerbating the need to enhance energy efficiency (EE). Energy conservation is seen as the most cost-effective strategy for achieving long-term economic growth. Given the present situation of the global economy and the issues that mining faces in general, energy saving methods might prove to be important in ensuring long-term output. Energy efficiency is an important production indicator that has a considerable impact on the long-term viability in energy production. However, the energy efficiency of renewable energy production is strongly linked to energy and material management coordination, as well as the efficiency of critical sub-processes. As a result, improving energy efficiency in terms of the coordination of energy, materials, and manufacturing technology may provide many economic advantages and lower costs for ethylene producers. Researchers have put forth a lot of work to improve the energy efficiency and control of the whole ethylene manufacturing process.

Methodology

Study constructs and empirical data

This research looked at variables to create a percentage index for empirical analysis comprising electricity access, inclusion indicators, rural population (AERP), and electricity access (AEUP), assessed as a total population access (TAE), nuclear alternative and (AN) as (percent of total energy usage), electric electricity (EPC) as kWh per capita, energy imports, net (EIN) as (percent of the energy consumption), energy use (EU) as kg of the per capita oil equivalent, fossil fuel energy usage (FFEC) as (percent of the total), GDP per unit of energy consumption (GDPE) as constant 2017 PPP $ per kilogram equivalent of oil, private-participating R&D (R&DI) energy investment as current US $, the generation of electricity from renewable energy (REO) as a percentage of total power generation, renewable power (REC) as a percentage of total energy consumption, time required to generate electricity (TER). To evaluate reading results and consequence yields, the study data is obtained by the world development indicators and international energy agency database, and some local-national ministries of energy (of every country approximately). The data ranges from 2010 to 2020, correspondingly.

Measuring energy poverty

Its main goal was to assess energy poverty using four distinctive indices. Based on the aforementioned view, it is chosen the designated nations for estimating durable perspectives regarding poor individuals of energy index, which indicate

$$x_{ij}^{'} = \frac{x_{ij} - \min(x_{ij}, \ldots, x_{nj})}{\max(x_{ij}, \ldots, x_{nj}) - \min(x_{ij}, \ldots, x_{nj})} \tag{1}$$

$$x_{ij}^{'} = \frac{\min\left(x_{ij}, \ldots, x_{nj}\right) - x_{ij}}{\max(x_{ij}, \ldots, x_{nj}) - \min(x_{ij}, \ldots, x_{nj})} \tag{2}$$

$$p_{ij} = \frac{x_{ij}^{'}}{\sum_{i=1}^{N} x_{ij}^{'}} \tag{3}$$

$$e_j = -k \sum_{i=1}^{N} p_{ij} \ln\left(p_{ij}\right) \tag{4}$$

$$d_j = 1 - e_j \tag{5}$$

$$w_j = {}^{d_j}\Big/ {\textstyle\sum_{j=1}^{m} d_j} \tag{6}$$

$$EPI_i = \sum_{j=1}^{m} w_j \times p_{ij} \tag{7}$$

Measuring energy efficiency financing

The slack-based effectiveness determination is considered for the invention of opportunity indicated by $\mathrm{DMU}_{\mathrm{j}}$, $(j = 1, \ldots, n)$ unit in a particular division. For this, an output unit serving the DMU for the empirical estimation using k be $x \in R_{mk}^{+}$, $y \in R_{sk}^{+}$ and $z \in R_{dk}^{+}$ is constructed. More so, the invention opportunity indicates two-stage subsets with the following arrangement:

$$\mathrm{PPSstage1} = \left\{ (\mathrm{x}, \mathrm{y}) | \mathrm{x} \geq \sum_{j=1}^{n} \chi_j \, \lambda_j, z \leq \sum_{j=1}^{n} z_j \, \lambda_j, \mathrm{j} = 1, \ldots, \mathrm{n} \right\} \tag{8}$$

The Inventive Chance Indication extends the capacity for DMUk to a two-stage recognition that shows that a consistency declaration has evolved so much that a construction with well-organized exhaust units might survive, and that amorphous ones could survive, since system credentials are generally superior to non-radial models when assessing DMUs with the constitution of the network.

$$\text{PPSstage1} = \left\{ (\text{y}, \text{z}) | \text{z} \geq \sum_{j=1}^{n} z_j \; \mu_j, y \leq \sum_{j=1}^{n} y_j \; \mu_j, \text{j} = 1, \ldots, \text{n} \right. \quad (9)$$

Only a few scientists use the association structure to handle competent DMU positions. As a consequence, the deficiency in the mid-term test may affect the overall impact. When assessing the effectiveness and position of the competent unit, the contribution of midway meals must be taken into consideration. However, the study shows a novel connected and integrated model using the ranking method on the basis of outputs generated by the fundamental occurrence.

$$\begin{aligned} r_k = \min & \left(\frac{1}{m} \sum_{j=1}^{n} \frac{\mathrm{s}_i^-}{\mathrm{x}_{\mathrm{ik}}} + \frac{1}{D} \sum_{d=1}^{D} \frac{T_d^*}{z_{dk}} \right) / \left(1 + \frac{1}{D} \sum_{d=1}^{D} \frac{R_d^*}{Z_{dk}} + \frac{1}{S} \sum_{r=1}^{S} \frac{s_r^+}{y_{rk}} \right) \\ & \text{s.t.} \sum_{j=1}^{n} \lambda_j x_{ij} + \mathrm{s}_i^- = \mathrm{x}_{\mathrm{ik}}, \quad \mathrm{i} = 1, \ldots, \mathrm{m}, \\ & \sum_{\substack{j=1 \\ j \neq k}}^{n} \mu_j \, y_{rj} - s_r^+ = y_{rk}, \quad \mathrm{r} = 1, \ldots, \mathrm{s}, \\ & \sum_{\substack{j=1 \\ j \neq k}}^{n} \lambda_j \, z_{dj} = z_{dk} + R_d^*, \quad \mathrm{d} = 1, \ldots, \mathrm{D}, \\ & \sum_{\substack{j=1 \\ j \neq k}}^{n} \lambda_j \, z_{dj} = z_{dk} - T_d^*, \quad \mathrm{d} = 1, \ldots, \mathrm{D}. \end{aligned} \quad (10)$$

In Eq. (10), an objective model is formed on the basis of supposed DMUs with n, whereas m indicated the variety of inputs ${}^{x}{}_{j}=({}^{x}{}_{1j},\ldots,{}^{x}{}_{mj})$ covering the scope of different non-energy sources and other power sources aligned with the range of yield customs, such as $g_j=(g_{1j},\ldots,g_{sj})$ and $b_j=(b_{1j},\ldots,b_{fj})$, indicated with f an undesired function for an output. Endorsing Eq. (9) in the recent tests, the RAM-DEA model has been used to quantify the power efficiency in unusual discard scenarios for each DMU. Attributes that are un-identical to each other but nonetheless connected are determined by the model's limitations.

$$\begin{aligned} & max_{s,\lambda} \sum_{i=1}^{m} R_i^x \; s_i^x + \sum_{r=1}^{s} R_r^g \; s_r^g + \sum_{f=1}^{h} R_f^b \; s_f^b \\ & \quad s.t. \sum_{j=1}^{n} x_{ij} \; \lambda_j + s_i^x = x_{ij0}, i = 1, \ldots, m \\ & \quad \sum_{j=1}^{n} g_{rj} \; \lambda_j - s_j^g = g_{rj0}, r = 1, \ldots, s \\ & \quad \sum_{j=1}^{n} b_{fj} \; \lambda_j + s_f^b = b_{fj0}, f = 1, \ldots, h \\ & s_r^g \geq 0, r = 1, \ldots, s \; s_f^b \geq 0, f = 1, \ldots, h \end{aligned} \quad (11)$$

Model is created using a two-step model, using the highly competent DMUs (10). The most important central events are discovered during the first phases of the preservative model (ADD), and after this, it is the task of using the best criteria for the central processes applied. Following is a picture of the phenomena illustrated in [Model #10].

$$\begin{aligned} & \xi = max \sum_{d=1}^{D} R_d + \sum_{d=1}^{D} T_d \\ & \text{s.t.} \sum_{j=1}^{n} \lambda_j x_{ij} + s_{i=}^- x_{ik}, \; \mathrm{i} = 1, \ldots, \mathrm{m}, \\ & \sum_{j=1}^{n} \mu_j y_{rj} - s_{r=}^+ y_{rk}, \; \mathrm{r} = 1, \ldots, \mathrm{s}, \\ & \sum_{j=1}^{n} \lambda_j z_{dj} = z_{dk} + R_{d,} \; \mathrm{d} = 1, \ldots, \mathrm{D}, \\ & \sum_{j=1}^{n} \mu_j z_{dj} = z_{dk} - T_{d,} \; \mathrm{d} = 1, \ldots, \mathrm{D}, \end{aligned} \quad (12)$$

Moreover, research model is further designed as below,

$$\begin{aligned} \eta_k = \min & \left(1 - \frac{1}{m} \sum_{i=1}^{m} w_i^d \frac{s_i^-}{x_{ik}} - \frac{1}{D} \sum_{d=1}^{D} \frac{T_d^*}{z_{dk}} \right) \\ & / \left(1 + \frac{1}{D} \sum_{d=1}^{D} \frac{R_d^*}{z_{dk}} + \frac{1}{s} \sum_{r=1}^{s} w_r^d \frac{s_r^+}{y_{rk}} \right) \\ & \text{s.t.} \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{ik,} \; \mathrm{i} = 1, \ldots, \mathrm{m}, \\ & \sum_{j=1}^{n} \lambda_j z_{dj} - s_r^+ = y_{rk,} \; \mathrm{r} = 1, \ldots, \mathrm{s}, \\ & \sum_{j=1}^{n} \lambda_j z_{dj} = z_{dk} + R_d^*, \; \mathrm{d} = 1, \ldots, \mathrm{D}, \\ & \sum_{j=1}^{n} \mu_j z_{dj} = z_{dk} - T_d^*, \; \mathrm{d} = 1, \ldots, \mathrm{D}, \end{aligned} \quad (13)$$

Empirical operationalization framework of study

The multidimensional measure of FI used in this research is in alignment with what has been shown in the literature. In this research, we examine four facets of FI—whether or not one has insurance, whether or not one has access to credit or loans, and whether or not one receives financial remittances from banks or via mobile money. Each dimension is given 0.25 points and added to provide a score for financial hardship in accordance with Eq. (1). To estimate the overall welfare losses from urban water delivery, Li et al. (2021a) utilized the following methodology:

$$W^R = \sum_{t=1}^{T} \sum_{i=1}^{I} \int_0^1 W_i(x) f_{it}(x) dx \quad (14)$$

Numerous researchers inferred the matter of the crude oil supply improving the energy efficiency of different countries. Notably, the role of financial inclusion is less concluded. Therefore, extending to it and considering role of financial inclusion in study sample countries, we indicated these countries with i and time t as Z_{it}, indicating with (0, 1) respectively.

$$W_i(Z_{it}) = \int_{Q_i(Z_{it})}^{Q_i} P_i \, (x) dx \quad (15)$$

Correspondingly, this function is indicated as $f_{it} Z_{it}$ to measure the empirical framework. The willingness to adapt financial inclusion streams are indicated with $W_i Z_{it}$ at t spell in i countries.

$$L_i(Z_{it}) = \int_{Q_i(Z_{it})}^{Q_i} P_i \, (x) dx - C_i(x) dx \quad (16)$$

So as to avoid an all-province communal electricity supply interruption, residents are financially included in the household sector for the period T of the reconstruction process.

$$L_i(Z_{it}) = \int_{Q_i(Z_{it})}^{Q_i} P_i \, (x) dx - P_i\left(Q_i - Q(Z_{it})\right) \quad (17)$$

As a result, renewable energy projects are more likely to include programs that help alleviate energy poverty and increase energy efficiency. On the other hand, however, as the nation has less renewable energy usage, the welfare loss would be greater.

Results and discussion

Role of financial inclusion to fill energy financing gaps

Correlation matrices reveal how financial inclusion, energy efficiency, and energy poverty are related. Our findings show that the IFI index measures the correlation between components as well as determine the level of financial inclusion (the strength of the association is 46% and 89%, respectively).

The correlation matrix findings in Table 2 show that there is no relationship between energy consumption, human resources, per capita GDP (GDP), CO_2 emissions, and financial inclusion (FI). Similarly, Fig. 1 depicts the energy poverty score. As a result of the model's poor pair correlation, no evidence of multicollinearity can be seen.

As Cohen (1988) reports that correlation coefficients in the range of 0.10 to 0.30 are minor, those in the range of 0.30 to 0.60 are medium, and those in the range of 0.60 to 1.00 are big in terms of their impact, the effect sizes should be small, medium, and big. These two coefficients for our FI index and the account indicator have a correlation larger than

Table 1 Energy efficiency financing estimates

	Before COVID-19 period									During COVID-19	
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
USA	1.81	1.57	1.32	1.12	1.11	1.35	1.18	1.21	1.15	1.95	1.35
Italy	1.67	1.88	1.70	1.84	1.78	1.10	1.49	1.87	1.15	1.84	1.46
Canada	1.24	1.47	1.21	1.46	1.23	1.78	1.11	1.23	1.53	1.67	1.84
India	1.13	1.34	1.57	1.04	1.21	1.09	1.54	1.34	1.48	1.81	1.44
UK	1.45	1.29	1.02	1.09	1.28	1.34	1.10	1.41	1.42	1.39	1.19
Russia	1.87	1.40	1.34	1.12	1.09	1.13	1.23	1.09	1.64	1.21	1.34
Norway	1.29	1.21	1.44	1.81	1.00	1.80	1.67	1.67	1.29	1.22	1.17
Kuwait	1.31	1.11	1.88	1.94	1.26	1.32	1.78	1.44	1.01	1.29	1.21
Qatar	1.67	1.54	1.17	1.44	1.84	1.10	1.89	1.01	1.45	1.80	1.11
China	1.24	1.17	1.95	1.56	1.11	1.03	1.21	1.19	1.37	1.13	1.33
Austria	1.39	1.67	1.21	1.37	1.01	1.88	1.67	1.23	1.55	1.88	1.80
Pakistan	1.77	1.89	0.44	1.84	1.22	1.85	1.20	1.67	1.47	1.54	1.44
Germany	1.81	1.48	1.67	1.67	1.36	1.90	1.91	1.21	1.19	1.40	1.46
Spain	1.15	1.95	0.90	1.13	1.67	1.83	1.44	1.28	1.24	1.31	1.34
Thailand	1.44	1.34	1.80	1.79	1.81	1.10	1.01	1.75	1.19	1.88	1.00
Indonesia	1.41	1.20	1.19	1.39	1.48	1.35	1.23	1.66	1.34	1.89	1.71
S. Korea	1.02	1.38	1.11	1.41	1.33	1.06	1.44	1.16	1.50	1.80	1.50

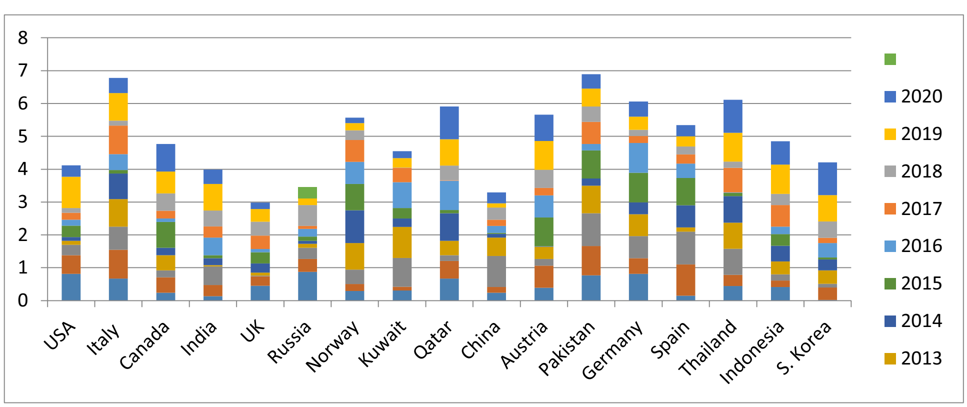


Fig. 1 Energy poverty trends over the sample period

Table 2 Subjective results of study indicators

	VX(1) EC	VX(2) EEF	UY(1) EP	UY(2) FI
USA	1.71	1.91	1.91	1.94
Italy	1.00	1.34	1.75	1.44
Canada	1.45	1.76	1.23	1.41
India	1.59	1.81	1.78	1.88
UK	1.17	1.75	1.24	1.21
Russia	1.11	1.78	1.15	1.31
Norway	1.49	1.39	1.09	1.17
Kuwait	1.35	1.02	1.44	1.09
Qatar	1.46	1.80	1.01	1.24
China	1.77	1.63	1.11	1.16
Austria	1.31	1.55	1.67	1.31
Pakistan	1.67	1.21	1.31	1.27
Germany	1.96	1.21	1.30	1.81
Spain	1.44	1.88	1.14	1.27
Thailand	1.35	1.34	1.77	1.81
Indonesia	1.21	1.81	1.31	1.89
S. Korea	1.11	1.14	1.50	1.69

0.5. There is thus a rather strong, positive, and substantial association between financial inclusion, energy efficiency, and energy poverty.

Role of financial inclusion to mitigate energy poverty

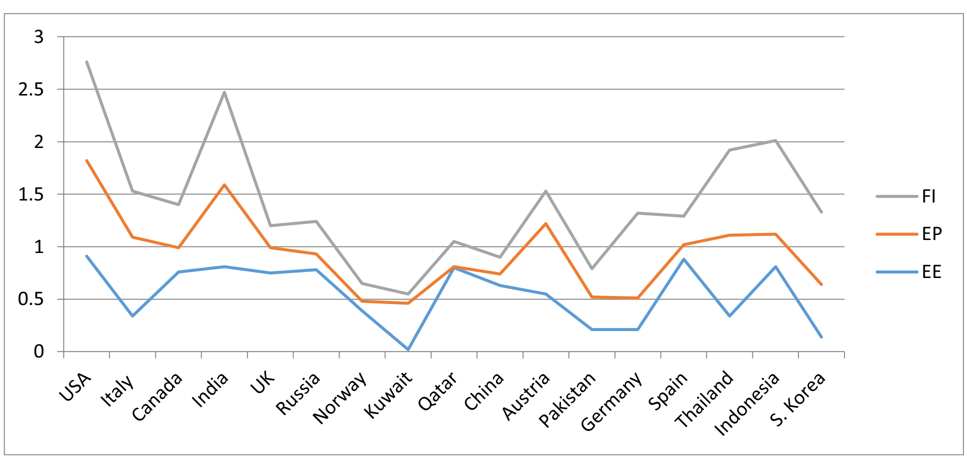
Notably, for greater financial inclusion and to make availability of cash flows as certain the import reliance is desired as 19%, and it is revealed by study results that this has declined with 5% in total in last. Hence, the role of financial inclusion in energy sector is evident and significant.

Despite the concerted measures to eliminate global energy poverty, the dilemma continues with emerging nations bearing the brunt of the burden. Due to the multiple possible energy poverty policies being explored, the FI-energy poverty connection has not been well welcomed. It is unfortunate that just a few extant research have looked at this issue using a multidimensional FI index. For determining the nexus between energy efficiency and financial inclusion, and, financial inclusion and energy poverty if there is indigeneity of FI, it is necessary to calculate the distance to the closest bank. Additionally, we examine the many avenues through which FI (financial inclusion) might lead to energy poverty in the family. We find that FI is detrimental to households living in energy poverty, and this result holds when using different quasi-experimental approaches. Other alternatives are also acceptable for the alternate weighting method for FI and the multifaceted approach to energy poverty. In terms of where it impacts families, FI consistently reduces energy poverty in rural areas more than in urban ones. FI is also consistent in helping to reduce the problem of energy poverty more among homes led by men.

Our data further show that FI affects energy poverty via influencing consumption poverty and family net income. It is possible to combine existing global policies that seek to improve financial inclusion with other policies that seek to raise family net income per capita and decrease consumer poverty. This boosts financial inclusion, while also reducing consumption poverty. A regulatory approach may include measures that lower the average distance between financial institutions. For the financial environment, promoting innovation is vital in lowering greenhouse gas emissions. Natural resource rents have a favorable and considerable influence on the energy efficiency of test nations, especially in nations with a lot of natural resources.

As per Fig. 2, our findings agree with which has shown that foreign investment in natural resources propels technical growth in the host nation. The expansion of global commerce and currency exchange, as well as improvements in energy efficiency, has been aided by natural resources. While technical innovation may help improve energy efficiency, it also has a favorable impact on other technical improvements.

Fig. 2 Empirical interplay between the constructs



Significant and persistent financial inclusion is considerably more required to reduce energy costs to reconcile energy poverty (Table 3).

Expected results in accordance with theory show that innovation has a considerable influence on the energy efficiency coefficient, meaningful at the 1% level. Through innovation, energy consumption expenses are reduced, and energy efficiency is improved. Empirically, it has been shown that innovation has increased China's total factor productivity by a considerable amount. Due to the beneficial influence of innovation on energy efficiency, companies that use it may create more modern equipment, decreasing the amount of energy they use, and resulting in an increase in productivity. We are certain of our findings. The marginal effect of trade on energy efficiency was found to be positive but small in the findings provided in column (1) of Table 4. It is also insignificant for increasing energy efficiency, but for the selected nations, the effect of industrial structure on energy efficiency is too little to be a consideration. So far, most studies have only included carbon dioxide emissions while investigating environmental concerns in the literature. However, for resources such as oil, mining, and forests, carbon dioxide emissions are sometimes unsuitable.

Table 4 Situation breakdown yield of sample countries

Countries	Scenario 1	Scenario 2	Scenario 3	DW
USA	0.031*	0.341*	0.015*	0.201
Italy	0.014*	0.876*	0.677*	0.200
Canada	0.037*	0.401*	0.444*	0.233
India	0.054*	0.539*	0.589*	0.215
UK	0.020*	0.313 *	0.220*	0.237
Russia	0.038*	0.336	0.040*	0.315
Norway	0.044	0.445	0.072*	0.236
Kuwait	0.039	0.555*	0.092*	0.201
Qatar	0.111*	0.011*	0.767	0.015
China	0.153*	0.001*	0.567*	0.034
Austria	0.221*	0.099	0.333	0.021
Pakistan	0.191*	0.027	0.456*	0.015
Germany	0.094*	0.021	0.445*	0.023
Spain	0.077	0.076*	0.080*	0.057
Thailand	0.035	0.023*	0.011*	0.029
Indonesia	0.090*	0.028*	0.121	0.025
S. Korea	0.072*	0.034*	0.081*	0.034

**Significance at P value < 0.05*

Discussion

The urban electricity access rate is nearly 100%, while the rural access rate is 32%. The share of renewable energy in final consumption is 92.2%. According to the study findings, a 1% significance level implies that increasing fiscal imbalance reduces the extent of government environmental control as anticipated by decision makers. A substantial positive correlation between environmental regulation and CO_2 has been found (Li et al. 2021b). This suggests that a 1% increase in environmental regulation results in a 0.206% decrease in energy financing. Correlation coefficient of mediator has more significance in column 4. For every 1% rise in FI, an additional 0.86% rise in energy poverty is emitted (Shah et al. 2019). A supportive role for government and environmental legislation in promoting environmental equity is possible. A rise in energy efficiency also increased energy efficiency via impacting environmental control, leading to an extra 0.14% of energy efficiency is accelerated as a consequence (Alemzero et al. 2021).

Table 3 Estimates of index score of energy poverty

Economy	Energy Poverty Index Score
USA	0.13
Italy	0.65
Canada	0.36
India	0.23
UK	0.39
Russia	0.22
Norway	0.09
Kuwait	0.04
Qatar	0.05
China	0.14
Austria	0.19
Pakistan	0.34
Germany	0.48
Spain	0.23
Thailand	0.48
Indonesia	0.42
S. Korea	0.82

In fact, as stated in the fifth through seventh columns of Table 1, the regression findings of industrial structure mediator are presented. Column 5 posits that FI's effect at manufacturing edifice is large besides having an optimistic stimulus, suggesting for adding to the structure of industry in accordance with these expectations. A 1% increase in the industrial structure in column 6 would generate an 11.14% rise in carbon emissions. This process could be explained as follows: The secondary industry of Pakistan is the dominant source of industrial growth at now. In the progress of industrial modernization, certain older industries remain crucial. Based on the information presented above, it can be concluded that FI may increase industrial structure, which will, in turn, result in better carbon emissions. Indirectly, the vertical fiscal imbalance causes around 0.6% of carbon emissions. Growth of CO_2, in addition to being driven by

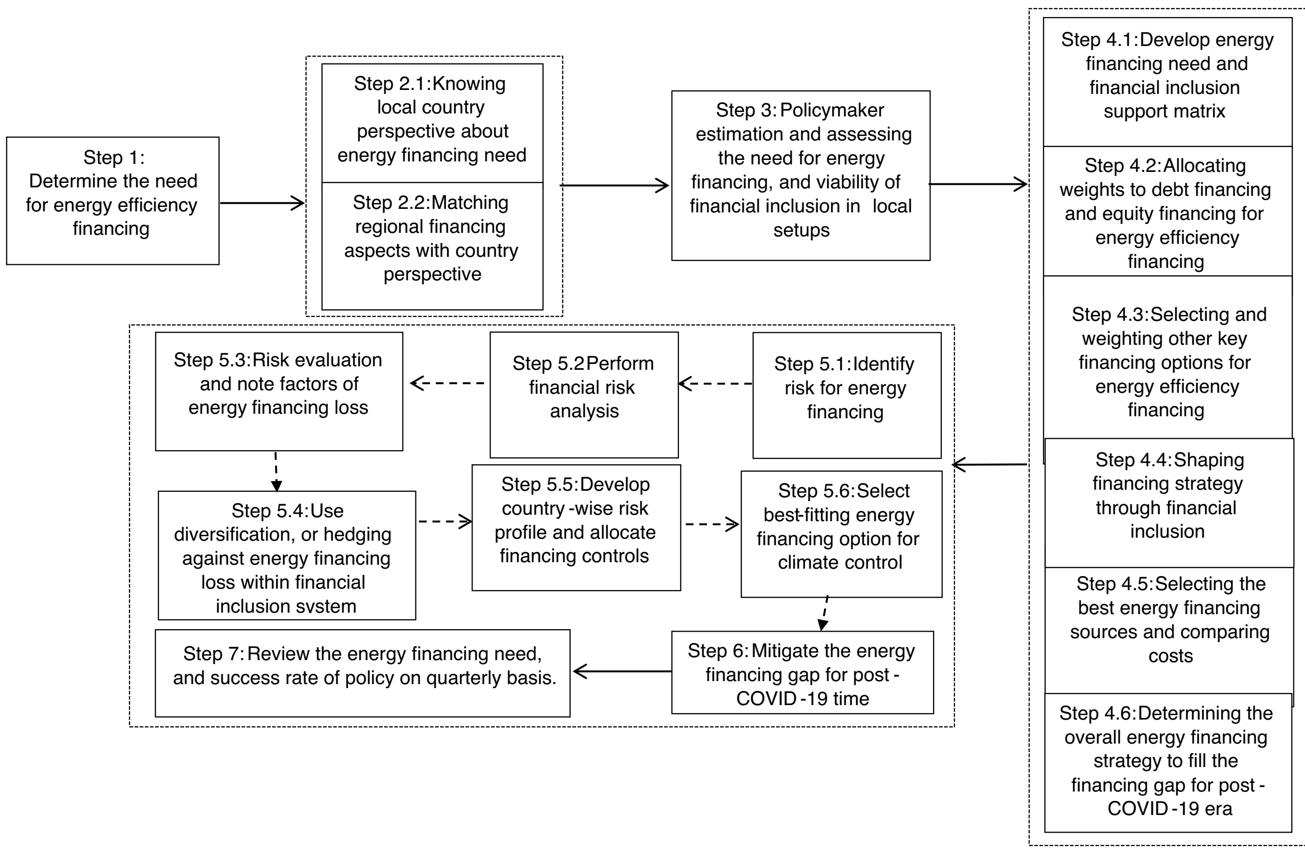


Fig. 3 Framework to fill the energy financing gap for post-COVID-19 period

a rise in vertical fiscal imbalance, similarly subsidized for another 0.7742% of energy efficiency due to its effect on financial inclusion.

Conclusion and policy implication

The study inferred the energy financing in COVID-19 crises and tested the role of financial inclusion to fill the financing gaps. The findings revealed that the fundamental problems of the COVID-19 have interrupted the system of financial intermediation at large. The governments of many nations are experiencing economic imbalances and striving to live under strict severe budgetary restraints. So, delivering a cheap and efficient energy in present times, amid COVID-19 problems, is plain unattainable for many economies because the major way to make money for energy industry is the energy consumers, and having inefficient energy for consumption is creating fuel poverty at broad. Therefore, COVID-19 problems produced a huge energy funding gap in current times that demand a resolution. This study also evaluated the empirical function of financial inclusion on energy poverty and energy efficiency, using historical data, to demonstrate the relevance of financial inclusion for energy funding gap completion. Moreover, this study also offers some new policy implications to use the vibrant system for energy financing (see Fig. 3) to fill the energy financing gaps in post-COVID-19 ages. Figure 3 explains the study recommendation in a comprehensive way and guided the way-forward for stakeholders to utilize. We recommend if the offered policy framework is accepted into practice, the power funding gap in post-COVID-19 period will be decreased, and there is a strong possibility to provide the efficient energy to the end users. We suggest to use following Fig. 3 to fill the energy financing gap through financial inclusion for post-COVID-19 period.

Abbreviations *FI*: Financial inclusion; *EP*: Energy poverty; *EE*: Energy efficiency; *EEF*: Nergy efficiency financing; *FP*: Fiscal policies; *EC*: Energy consumption; *GDP*: Gross domestic product; *UN*: United Nations; *DEA*: Data Envelopment Analysis; *SDGs*: Sustainable Development Goals; *OPEC*: The Organization of the Petroleum Exporting Countries; *NCPC*: National Capital Planning Commission; *HILDA*: The Household, Income, and Labor Dynamics in Australia; *UNEP*: United Nations Environment Program; *UNIDO*: United Nations Industrial Development Organization

Author contribution Conceptualization, methodology, writing—original draft: YC; data curation, visualization: XL; editing, revision, data analysis, supervision: JC.

Data availability The data that support the findings of this study are openly available on request.

Declarations

Ethical approval and consent to participate The authors declared that they have no known competing financial interests or personal relationships, which seem to affect the work reported in this article. We declare that we have no human participants, human data, or human issues.

Consent for publication We do not have any individual person's data in any form.

Competing interests The authors declare no competing interests.

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