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Research methods on the role of financial inclusion, energy efficiency and energy R&D: Evidence from G7 economies

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ABSTRACT

Countries around the globe are rapidly targeting energy efficiency goal achievement due to the unproductive and inefficient use of traditional energy sources. Several factors are discovered that are critical for energy efficiency in the region. Still, there are many economic, financial, energy, and research and development factors that could influence energy efficiency and remained ignored in the scholarly research, which is important from economic growth as well as environmental sustainability perspective. This research contributes to the existing literature by providing novel factors affecting energy efficiency in the developed nations. Specifically, the current study investigates the influence of financial inclusion, energy R&D, political-economic-financial risk index, and the energy-related inflation on the energy efficiency of G7 economies covering the period from 2004 to 2020. This study employed the slope heterogeneity and cross-section dependence test, which led to using the second-generation unit root test. For empirical estimations, the current study utilizes the panel Quantile regression, and the outcomes reveal that all the considered variables positively influence the energy efficiency in the region. However, the influence of these variables increases except for the energy-related inflation when moving from lower quantile $Q_{0.25}$ to medium $Q_{0.50}$ to higher quantile $Q_{0.75}$, respectively. The estimated results are found robust, confirmed by the FMOLS estimator. Based on the empirical findings, it is recommended that financial inclusion and energy-related research and development be enhanced to achieve the region's energy efficiency.

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1. Introduction

Countries around the globe remarkably increases their energy efficiency strategies for various energy, economic, and environment-related motives, such as decarbonizing the energy system of Europe (Baldini & Jacobsen, 2016). However, economies are still

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aiming higher economic growth via targeting industrial growth and expansion. As a result, the global energy demand is rapidly increasing with the sole objective of sustaining the countries' development, and ignoring the environmental concerns. Generally, the G7 total final energy consumption includes 40% to 60% petroleum products other than electricity, which makes it the main source of energy consumed whereas the petroleum products in the G7 economies between 1991 and 2015 have been reported to fall and remained only 10-30% of the total energy. However, with the pressure on the world-leading industrialized economies to expand and improve energy efficiency, societies and organizations are supposed to find new approaches for reducing the demand for energy consumption with the objective to decrease pollution and energy waste and consequently promote economic development and sustainability (Narayan et al., 2007). Since 1975, the G7 economies have generated 458 commitments regarding energy.[1] Therefore, these economies are more concerned about achieving the energy efficiency target, which can be achieved via constructing innovative policies and improvement in the existing policies.

It is important to note that energy consumption and economic growth are interrelated (Belke et al., 2011). Therefore, it is essential to consider the direct and indirect influences of energy consumption on economic growth and the counter effects of economic growth on energy consumption while planning energy efficiency policies conservation. Hence, it could be assumed that a higher economic activities' level requires higher energy use, which consequently affects the environment and causes global warming and climate change issues by enhancing the carbon dioxide emission level (Farooq et al., 2019; Fernando & Hor, 2017). On the other hand, energy efficiency could be beneficial by providing security and benefits in the shape of carbon and other greenhouse gases emission reduction and decreasing the supply of imported energy (Selvakkumaran & Limmeechokchai, 2013). Following the discussion, this study tends to empirically examine this nexus of whether economic growth, which is a source of enhanced energy utilization, have any influence on the energy efficiency, which is important yet unexplored area in the scholarly research.

Concerning economic growth, financial inclusion provides access to multiple financial products and services, including payment, saving, insurance, transaction, credit, and remittances flow (World Bank, 2018). However, access to these financial products and services accelerates economic growth and shrinks income inequality by providing diverse opportunities. Thus, a high financial inclusivity level could be considered an indicator of the country's economic stability (Sahay et al., 2015). Therefore, higher economic growth could be related to higher financial inclusion. For now, it is well known that financial inclusion plays a vital role in expanding an economy. However, this economic expansion could contribute to gross fixed capital formation, which could be expected to increase the energy demand (Qin et al., 2021). Thus, a higher level of financial inclusion could inherently lead to maximizing energy consumption. Empirical studies already explored the financial inclusion and environmental quality nexus (Le et al., 2020; Zaidi et al., 2021), and asserted the substantial role of financial inclusion in environmental quality. Similarly, the higher level of financial inclusion could also influence the energy efficiency by various means, such as the green finance could inherently contribute to enhancing energy efficiency activities and renewable energy transition. The literature concerning financial inclusion and energy efficiency nexus is very limited, and no such study is available that empirically investigates the relationship between financial inclusion and energy efficiency. Therefore, it is crucial to explore the said nexus, which this study considers to provide empirical evidence regarding the said association and provide innovative and appropriate policies.

In the recent literature, most of the policies have been made to combat the carbon emission level, while policies concerning energy efficiency remain ignored. As in the case of Germany, Ringle (2017) argued that the German Sustainable Energy Action Plans (SEAPs) gave more importance to the reduction of emissions and neglected the monitoring and verification regarding energy efficiency, which ultimately influences the environmental-related policies. Hence, economies with objectives to achieve higher economic growth, sustainable development, and the environment must efficiently utilize the resources. Thus, it is important to empirically investigate the countries' potential concerning energy saving, emissions mitigation, and sustainable development.

1.1. Overview of the G7 economies

Despite numerous artificial and natural disasters, the major industrialized economies still largely regulate the global economy. Besides the prominent position in technology, capital, markets, and productivity, the group of seven (G7), including the United States, United Kingdom, Germany, France, Japan, Italy, and Canada, still plays a leading role in the world (Li, 2017). Similarly, the G7 economies are also among the leading energy importer globally. These countries aimed to maintain their economic development, which forces them to use more energy for domestic as well as industrial purposes. In 2014, the G7 was combinedly responsible for 30,624,000 kg of oil equivalent per capita energy use. Though the energy use contributes to the economic growth of the G7 economies, it also disturbed environmental sustainability, where the US alone is the world's second-largest emitter.

Concerning financial inclusion in the G7 economies, Ozili (2021) reveals that financial inclusion in the United States is significantly improving, which decreases the poverty level by increasing income and increasing the prosperity of the US citizens. Similarly, in the UK, the government has taken steps for the long-term implication of financial well-being via financial inclusion by providing useful and affordable financial products and services to the consumers, as reported by the UK's financial inclusion report 2019-2020. Concerning Germany, the banks-based financial system offers a higher level of financial inclusivity, measured via banks' outreach financial services usage. However, as per Asian Development Bank report 2015 (2016), Germany's financial system also constrained vulnerable individuals and small enterprises across the country.[2] 99% of Canadian citizens have access to a formal financial institution in Canada. Still, the Canadian government has made efforts to boost the financial capabilities of Canadians via Canada's Financial Literacy Strategy[3]. Similarly, France, Italy, and Japan also extended their policies for improving the financial inclusion level.

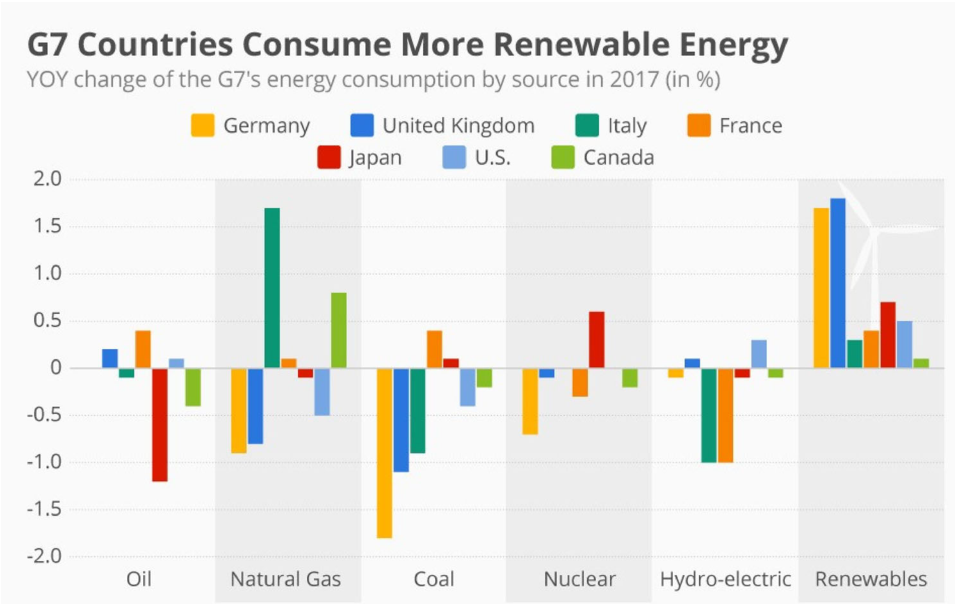

Figure 1. Energy consumption in G7 countries.
Source: Statista[4] (2018)

Thus, the G7 economies finally took a step in the Energy Ministers Meeting in Rome in May 2014 and the Brussels Summit of June 2014. The highly considered agenda of the meetings were efficient with less use of energy. Therefore, these countries have attained environmental sustainability and energy efficiency without disturbing economic progress.

Apart from the prior discussion, several patterns may be identified when comparing the energy use of the G7 economies, as can be seen in Figure 1. In 2017, all nations raised their renewable energy contribution, although Germany and the United Kingdom remain at the forefront of this trend. Interestingly, Japan appears to be limiting its oil usage to increase nuclear power output, despite public support for this energy source plummeting after the Fukushima accident in 2011.

1.2. Objectives and contribution

Currently, the studies have paid attention towards emissions mitigation. However, important factors that affects energy efficiency, such as financial inclusion remained ignored. This study aimed to investigate the influence of financial inclusion on energy efficiency to fill this gap. Though its impact on economic growth has been well studied, while remained ignored in the energy efficiency sector. Besides, the current study also investigated the effect of economic growth on energy efficiency, where energy consumption significantly promotes economic growth. However, its influence on energy efficiency is yet unexplored. Thus, this study tends to attract the scholarly attention towards this hardly discussed and undoubtedly explored issue.

Additionally, this study considers energy-related R&D, Energy-related inflation, and the Political Risk Index to investigate their influence on energy efficiency.

Although these variables are comprehensively analyzed in relation to economic growth and environmental quality. Still, the literature is scant in terms of its relationship with energy efficiency. Hence, there is an immediate need for empirical study that could explore this ignored nexus. Following the objectives, this study is regarded as pioneering in terms of contribution to the existing literature as it provides evidence regarding the economic, financial, and energy related variables that could influence energy efficiency and could provide a pathway to the future researcher to explore relevant factors affecting energy efficiency in other developed and developing regions. This study used various econometric approaches to achieve these objectives, such as slope heterogeneity, cross-section dependence, stationarity test, long-run estimation test via quantile regression, and a fully modified ordinary least square (FMOLS) estimator. Such analysis can deliver convenient evidence concerning energy policies, which also contribute to the nations' sustainable development that consequently affects or contributes to global economic structure.

This study is novel and contributes to the existing literature in many ways. Firstly, it is a novel study that empirically analyzes the influence of financial inclusion on energy efficiency. Nonetheless, the existing studies provide evince regarding the economic and non-economic impact of financial inclusion. Yet, this study contributes to the literature by providing empirical results regarding the association between financial inclusion and energy efficiency, which remained ignored in the existing literature. Secondly, the influence of energy efficiency on economic growth has been well identified (see, Cantore et al., 2016; Pao & Tsai, 2010). However, this study offers empirical evidence regarding the impact of economic growth on energy efficiency, which relatively remained ignored, while there is a dire need of exploring this nexus to save energy and environment. Additionally, this study also delivers empirical results concerning the specific influence of political risk, energy related inflation, and energy related research and development on energy efficiency, which the existing research lacks. Hence, this study could be an essential research and policy tool concerning energy efficiency policies.

The rest of the study is organized as Section-2 presents Literature Review; Section-3 provides Methodology, Data and Model Specifications; Section-4 presents Results and Discussion of the obtained results; Section-5 presents Conclusion and Policy Implications.

2. Review of literature

The literature concerning the influence of energy efficiency on the environmental elements and other macroeconomic indicators is extensively available. However, the literature concerning the influence of financial inclusion, economic growth, energy-related R&D and inflation, and the political risk index is scant. Yet, the available literature is concerning energy efficiency is discussed with this.

The recent study of Liu et al. (2022) analyzed emerging seven economies over the period 2016-2020. It asserted that various innovative financing techniques, including financial inclusion, green financing, and FinTech, encourage energy efficiency in the region. However, green finance's influence has been observed greater in magnitude.

Wang et al. (2020) examined the influence of energy efficiency, oil price, and research and development (R&D) on renewable energy for G20 economies over the period from 1990 to 2017. The study employed fully modified ordinary least square (FMOLS) and Dynamic OLS and cointegration and stationarity techniques. The estimated results asserted that research and development is the leading factor for promoting renewable energy in the middle-income economies in G20. In contrast, the decreasing effect of research and development is found in developed economies in G20. Concerning energy efficiency in China, Cheng et al. (2020) investigated 30 provinces during the 1997-2016 period and revealed that the total factor energy efficiency has substantial heterogeneity based on regions. The Eastern region has the largest total energy efficiency, followed by the Central and Western regions. The study argued that China's poor management is the root cause of energy inefficiency, while technological factors enhance energy efficiency. On the other hand, Liao and He (2018) found consistent results for the same country, as mentioned by the later study. They argued that the industrial structure, energy consumption structure, technological progress, and enterprise scale are the significant factors that influence energy efficiency between the 2005-2011 period. Similarly, Qi et al. (2020) used a super-efficiency model for 14 major coal-intensive industries in China over the 2006-2015 period. The major findings reveal that the total energy efficiency indicates growth; however, this growth mainly occurs due to technological factors.

Rashidi et al. (2015) investigated the OECD countries' eco-efficiency by considering the energy inputs, undesirable outputs, and non-discretionary factors. The study found that countries may not eco-efficiently perform by manufacturing highly undesirable products. Due to this, these countries have a severe optimum energy-saving potential. For BRIC economies, Pao and Tsai (2010) argued that these countries must expand their energy supply investment and measure energy efficiency without compromising their economic growth. Concerning developed and developing economies, Niu et al. (2011) reveal that energy efficiency, energy consumption, and carbon emissions are much more in the developed OECD economies than the developing economies. However, the developed economies' participation in global energy consumption is reported to decline over time, while the participation of developing economies in the global energy consumption has relatively surged more than 100% in the past three decades. The study of Nehler et al. (2018) investigated the drivers, barriers, and non-energy benefits in the energy efficiency implementation and claimed that investment is mainly associated with barriers, while the positive decision from organizations promotes energy efficiency. For the Western US and Canada, Hopper et al. (2009) discuss policies targeting energy efficiency provision and revealed that California's investor-owned utilities mandated goals for energy saving and the renewable portfolio standard for energy efficiency in Nevada directly influence the energy-saving level. However, the emissions control policies also affect the energy efficiency commitments of the utilities.

The study of Rasmussen (2017) provides a systematic review of the existing literature by providing the benefits of energy efficiency investments. The study argued that the energy efficiency investments could be more attractive if the non-energy benefits in the investments have been included in the investment process. Also, the non-energy benefits strengthen the drivers and counter the barriers to investments in energy efficiency. In the case of Germany, Ringel (2018) studied policy governance in energy efficiency while targeting a multilevel structure of administration. The study found that most of the German Sustainable Energy Action Plans (SEAPs) emphasize emissions reduction and ignore monitoring and verification concerning energy efficiency. However, it is argued that harmonized monitoring and verification contribute to energy saving, facilitating policy feedback.

Literature concerning energy efficiency and the current study variables is hardly available. However, other studies concerning energy efficiency include: the study of Schützenhofer (2021) provides a measurement for overcoming the energy efficiency gap in the large Australian firms, Wiese et al. (2020) examined the auctioning revenues' strategic use in fostering energy efficiency, Kermeli et al. (2015) investigated the improvement in energy efficiency and pollution reduction in the global production of primary aluminum, Cui and Li (2015) studied the improving capacity of energy efficiency for 15 countries. Additionally, Patt et al. (2019) provide policy-oriented findings to promote energy efficiency while achieving low carbon emission targets. Finally, Fikru (2021) study investigated rooftop photovoltaics with energy efficiency in residential buildings. All these studies concluded diverse outcomes concerning the focused sector impact on energy efficiency. However, to the best of our knowledge and in the available literature, no such study is available that empirically investigates such important economic, financial, and political indicators such as financial inclusion, economic growth, energy-related R&D, energy-related inflation, and political risk index. To bridge the gap, this study empirically analyzes the impact of the said variables on energy efficiency.

2.1. Literature summary and research gap

Nonetheless, the existing literature is richer concerning the factors affecting energy efficiency. Where the empirical results of these studies concludes that financial innovation, FinTech, green financing, research and development, industrial sector, energy consumption structure, technical innovation, and enterprise scale are the leading factors influences energy efficiency. Where the increased level of energy efficiency also contributes to the economic growth and reduce environmental quality degradation. In the existing literature, this study observed that the academic literature paid their utmost attention towards the development of energy efficiency in various countries. Nonetheless, the existing literature covers some crucial elements of energy efficiency which are positively associated to the enhancement of energy efficiency. Still. There are number of factors that may have a substantial role in the energy efficiency sector and are not explored yet. Therefore, the research gap prevails as no study attempted to explore political, financial, and economic factors affecting energy efficiency. As a result, various economic, financial, political and energy related variables are taken into consideration that includes financial inclusion, economic growth, energy public research and development, energy related inflation, and political risk index to fill the literature gap and validate the contribution of this study in the existing literature. This study tends to explore the critical factors that are influencing the energy efficiency in developed region. The gap discussed will be filled via appropriate empirical estimators to provide relevant policy measures as well as a pathway to future researchers.

3. Methodology, data, and model specification

3.1. Theoretical framework

The available literature concerning financial inclusion broadly reveals that the term significantly contributes to economic growth (Sahay et al., 2015). Thus, the higher economic growth via financial inclusion increases the income level, consequently increasing energy demand for consumption. From a theoretical perspective, there are two types of outcomes concerning financial inclusion. Firstly, it is assumed that a higher level of financial inclusivity enhances the accessibility to multiple financial products and services, including payment, saving, insurance, transaction, credit, remittances flow, among others (World Bank, 2018). However, access to these financial products and services enhances consumer demand for energy. Likewise, financial inclusion provides access to industrialized financing capital, which further enhances the fossil fuel energy demand, harming the environment (Gill et al., 2019). Thus, the inefficient use of energy positively influences economic growth on the one hand. However, on the other hand, it causes environmental degradation and resource depletion. Secondly, the accessibility to the prior financial products and services via financial inclusion can also contribute to lower environmental hazards and promote energy saving. Improvement in access to financial services motivates the restructuring of environmentally hazardous production processes (Qin et al., 2021). It adopts innovative and environmentally friendly technologies that encourage efficient use of resources, specifically in developed economies such as G7. Specifically, financial inclusion can be considered a financing source for energy-efficient technology adaptation, inherently reducing environmental degradation (Gill et al., 2019) and encouraging energy saving.

Economic growth could also be considered an energy efficiency factor since it is well known that higher energy consumption leads to better economic growth (Rahman & Velayutham, 2020). However, the higher income in response to the energy could influence the energy consumption in two directions. On the one hand, the higher income level increases demand for higher energy emissions (Gill et al., 2019), which could only benefit economic growth and causes resource depletion. On the other hand, the higher income level promotes the efficient use of energy by adopting environmentally friendly technologies. This condition could resemble the environmental Kuznets curve (EKC) hypothesis, where economic growth causes environmental degradation in the initial stage. After achieving a threshold income level, the economy adopts efficient and renewable energy technologies that promote environmental sustainability and increase energy saving or energy efficiency. However, the main role in overcoming the negative influence of energy and enabling energy efficiency is energy-related research and development (R & R&D). Specifically, the developed economies are investing more in the energy-related R&D relative to the developing nations, which lead them to decline the participation in the global energy consumption and emissions. In contrast, the energy efficiency of these economies is reported to improve over time (Niu et al., 2011).

3.2. Data and model specification

Based on the previously mentioned theoretical framework and previous literature review (see Section-2), the current study used five exogenous variables, including the main independent variable financial inclusion (FIN), composed of other variables as presented in Table 1. Other control variables such as gross domestic product (GDP), energy public research, development and demonstration (EPRD), energy-related consumer price index (CPIE) or inflation, and political risk index (PRI) consist of all the three indices of political, economic and financial risks. However, the endogenous variable this study adopted is "energy efficiency," The energy productivity is used as a proxy and measured as the GDP per unit of total primary energy supply. The data for all these variables are obtained from different sources, such as Organization for Economic Cooperation and Development (OECD, 2021), International Monetary Fund (IMF, 2021), World Bank (2021), and the Political Risk Services (PRS, 2021). Panel data for all of these discussed variables are selected for the most advanced economies listed as "group of seven" (G7) countries: Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States covering the period from 2004 to 2020. Table 1 presents the variables under consideration, their specifications, and data sources as follows:

Regarding estimations, the model is generally specified from the priorly mentioned variables and given in Model-1 and Model-2 below:

Model-1

$$EP_{it} = f(FIN_{it}, EPRD_{it}, CPIE_{it}, PRI_{it})$$

Model-2

$$EP_{it} = f(GDP_{it}, EPRD_{it}, CPIE_{it}, PRI_{it})$$

Table 1. Data description and sources.

Variable	Description	Sources
Energy productivity (EP)	GDP per unit of Total primary energy supply.	https://stats.oecd.org/#
Financial Inclusion (FIN)	Index computed by using variables such as Institutions of commercial banks, Branches of commercial banks, Outstanding deposits with commercial banks (% of GDP), Numbers of ATMs per 100,000 adults, and outstanding loans from commercial banks (% GDP).	https://data.imf.org/
GDP	Measured at constant US 2010 prices.	https://databank.worldbank.org/source/world-development-
	indicators#advancedDownloadOptions	**Energy public RD&D budget (EPRD)**
Percentage of GDP	https://stats.oecd.org/#	
CPI: Energy	Percentage change on the same period of the previous year	https://stats.oecd.org/#
Political Risk Index (PRI)	The index covers all three political, economic, and financial risk indices.	https://www.prsgroup.com/explore-our-products/international-country-risk-guide/

This study constructed two models where Model-1 consists of financial inclusion and the other exogenous variables, and Model-2 consists of GDP and the same explanatory variables as Model-1. The reason for selecting these two models is "what-if analysis," which reveals the variables' behavior under consideration. The above Model-1 and Model-2 could be transformed into the regression form as Eq. (1) and Eq. (2) given below:

$$EP_{it} = \beta_1 + \beta_2 FIN_{it} + \beta_3 EPRD_{it} + \beta_4 CPIE_{it} + \beta_5 PRI_{it} + \varepsilon_{it} \tag{1}$$

$$\mathrm{EP}_{it} = \beta_1 + \beta_2 GDP_{it} + \beta_3 EPRD_{it} + \beta_4 CPIE_{it} + \beta_5 PRI_{it} + \varepsilon_{it} \tag{2}$$

Where β_1 is intercept and $\beta_{2,3,4,5}$ are the coefficients that represent the magnitude of each exogenous variable in the model. The "i" and "t" in the subscript represent the cross-sections and time series, respectively.

3.3. Estimation strategy

This study initiates the empirical investigation section by diagnostic tests including slope heterogeneity and cross-section dependence or independence of the selected G7 economies. After the emergence of globalization and international trade, the world is considered a globalized village, where one country is solely or partially dependent on the other countries. Therefore, countries across the panel could vary or resemble in some directions. However, the homogeneous characteristics of the countries across the panel lead to biased estimates, particularly in econometric panel analysis Wei et al. (2022). In this regard, it is essential to test the homogeneous characteristics of the selected group of countries. Therefore, the current study employed Hashem Pesaran and Yamagata (2008) slope coefficient homogeneity test (SCH), assuming the null hypothesis as homogeneous. Generally, the equation form of Hashem Pesaran and Yamagata (2008) SCH test is presented as Eq. (3) and Eq. (4)

$$\hat{\Delta}_{SCH} = (N)^{1/2} \frac{1}{(2k)^{1/2}} \left(\frac{1}{N} \acute{\mathrm{S}} - \mathrm{K} \right) \tag{3}$$

$$\hat{\Delta}_{ASCH} = (N)^{1/2} \frac{1}{\left(\frac{2K(T-K-1)}{T+1} \right)^{1/2}} \left(\frac{1}{N} \acute{\mathrm{S}} - 2\mathrm{K} \right) \tag{4}$$

Where the $\hat{\Delta}_{SCH}$ and $\hat{\Delta}_{ASCH}$ denotes the SCH and adjusted SCH, respectively. As earlier mentioned, globalization enhances the dependence of one country on other countries by many factors, which raises the issue of cross-section dependence in the econometric analysis. However, ignoring the cross-section dependence issue leads to inconsistent results (Campello et al., 2019). In this regard, we utilized the Breusch-Pagan LM test, the Pesaran scaled LM test, and the Pesaran CD to investigate whether the cross-section dependency is valid for the panel. The Breusch-Pagan LM test, proposed by Breusch and Pagan (1980), is generally presented as Eq. (5) below:

$$CD_{LM} = \frac{1}{[N(N-1)]^{1/2}} \sum_{i=1}^{N-1} \sum_{K=i+1}^{N} T\hat{P}_{ij}^{2} - 1 \tag{5}$$

The above Eq. (5) reveal that under the null hypothesis, where T $\rightarrow \infty$ and N $\rightarrow \infty$, we could obtain:

$$CD_{LM} \sim N(0,\ 1)$$

Additionally, to identify the cross-section dependency, we utilized both the Pesaran Scaled Lagrange Multiplier (LM) test and the cross-section-dependence (CD) test, both of which are proposed by Pesaran (2004). The null hypothesis for these prescribed tests is no cross-section dependency in the panel. Generally, the CD test in the equation form is presented as Eq. (6) below:

$$\mathrm{CD}_{Test} = (2T)^{1/2} \frac{1}{[N(N-1)]^{1/2}} \sum_{i=1}^{N-1} \sum_{k=1+i}^{N} T_{ik} \tag{6}$$

After estimating the panel's cross-section dependence and slope heterogeneity, we move to examine for the stationarity or presence of unit root in the data. Empirical estimations need to have stationary data while dealing with cross-sections and time series. Otherwise, the results estimated could be misleading or biased. Thus, we utilized the cross-sectionally augmented IPS (CIPS) unit root test developed by Pesaran (2007). The current unit root test effectively tackles homogeneity and cross-section dependency issues, termed as the second-generation unit root test. The null hypothesis (H_0) for the Pesaran (2007) unit root test is that the unit root is present in the data. Therefore, in the empirical estimations, both the leveled [I(0)] and the first differenced [I(1)] data are taken into consideration.

After the unit root or stationarity testing, we examine the long-run association between the heterogeneous variables in the next step. In this regard, we use the Westerlund (2007) cointegration or error correction model (ECM), which resolves cross-section dependency issues and considers the slope parameters' heterogeneity. The Westerlund (2007) cointegration test offers both the group mean statistics, generally presented as $G_t = \frac{1}{N}\sum_{i=1}^{N} \frac{\hat{\alpha}_i}{SE\hat{\alpha}_i}$ and $G_t = \frac{1}{N}\sum_{i=1}^{N} \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)}$ and the panel statistics, generally presented as $P_t = \frac{\hat{\alpha}}{SE(\widehat{\alpha})}$ and $P_t = T\hat{\alpha}$.

An efficient estimator must regress the variables after the stationarity and cointegration association between the variables under consideration. Therefore, this study uses a panel quantile regression estimator proposed by Koenker and Bassett (1978). The over and under-estimate biases of coefficients estimated by conventional regression estimation techniques, which only offer the average impact, led to the adoption of quantile regression in this study (Qin et al., 2021). However, the quantile regression method follows the specifications of normality and provides estimated results at each quantile. Moreover, this technique also considers cross-section dependency issues and slope coefficient heterogeneity (Amin et al., 2020). The general equations for panel quantile regression for both Model-1 and Model-2 are given as Eq. (7) and Eq. (8) below:

$$Q_{EP_{it}}(\theta|\ \alpha_i, \beta_t, X_{it}) = \alpha_i + \beta_t + \beta_{1,\theta}FIN_{it} + \beta_{2,\theta}EPRD_{it} + \beta_{3,\theta}CPIE_{it} + \beta_{4,\theta}PRI_{it} + \varepsilon_{it} \tag{7}$$

$$Q_{EP_{it}}(\theta|\ \alpha_i, \beta_t, X_{it}) = \alpha_i + \beta_t + \beta_{1,\theta}GDP_{it} + \beta_{2,\theta}EPRD_{it} + \beta_{3,\theta}CPIE_{it} + \beta_{4,\theta}PRI_{it} + \varepsilon_{it} \tag{8}$$

Where in Eq. (7) and Eq. (8) θ represent quantile, which is 25th, 50^{th,} and 75th. The "i" and "t" represent cross-section and the time period, respectively.

To examine the average impact of these endogenous variables on the energy efficiency and robustness check, this study utilizes the fully modified ordinary least square (FMOLS) approach. In the panel data, issues are probable such as heterogeneity and non-stationarity. However, the non-parametric estimator (FMOLS) provides robust estimates by controlling for serial correlation and endogeneity. The final form of the FMOLS is provided as Eq. (9) below:

$$\hat{\emptyset} = \begin{bmatrix} \alpha \\ \hat{\beta} \end{bmatrix} = \left(\sum_{t=2}^{T} Z_t \acute{Z}_t\right)^{-1} \left(\sum_{t=2}^{T} Z_t y_t^{+} - T\begin{bmatrix} \hat{\theta}_{12}^{+} \\ 0 \end{bmatrix}\right) \tag{9}$$

Here, $Z_t = \left(\acute{X}_t, \acute{D}_t\right)^{\prime}$. The long-run covariance matrix estimator is the key for FMOLS analysis. The results obtained via the discussed methodology are explained in Section-4 (Results and Discussion).

4. Results and discussion

Before moving to the empirical impact via the regression approach, the descriptive statistics of the selected group of countries are provided in Table 2. The descriptive statistics consist of average, median, standard deviation, range, and normality tests. The mean, median, and maximum values for EP are approximately the same: 4.003252, 4.035518, and 4.220876, respectively. At the same time, the minimum value is reported as 3.685710. The lower difference between the range values reveals the lower standard deviation values, i.e., 0.142724. The Jarque-Bera normality test assumed the normal distribution of the sample data by considering the skewness and excess kurtosis being zero. The probability value is highly significant as $P < 0.05$. Thus, it is concluded that the EP is not normally distributed. On the side, the

Table 2. Normality check.

	EP	FININC	CPIE	EPRD	PRI	GDP
Mean	4.003252	−0.233194	1.296430	−1.463459	1.907008	12.56122
Median	4.035518	−0.162742	1.356699	−1.468195	1.912709	12.44898
Maximum	4.220876	0.529091	1.557879	−1.084952	1.943453	13.26246
Minimum	3.685710	−1.133558	−0.219834	−2.434230	1.834368	12.13535
Std. Dev.	0.142724	0.480650	0.228899	0.241101	0.024704	0.308359
Skewness	−0.683151	−0.154832	−3.311376	−1.013033	−0.780609	1.061781
Kurtosis	2.503765	2.091055	19.70295	5.160986	2.922418	3.050241
Jarque-Bera	10.47***	4.57	1600.7***	43.50***	12.11***	22.37***
Probability	0.005	0.101	0.000	0.000	0.002	0.000

*Note: Significance level is denoted by ***, ** and * for 1%, 5% and 10%.*
Source: Authors.

financial inclusion is reported normally distributed as the probability of occurrence is more than 10% level. Thus, the Jarque-Bera normality test revealed that the sample data of the said variable is normally distributed. Besides, the mean, median, and minimum values are reported negative, that is, −0.233194, −0.162742, and −1.133558, respectively.

In contrast, the index values for financial inclusion reached the maximum value of 0.529091. Therefore, the standard deviation value is 0.480650. Concerning energy-related inflation (CPIE), the mean, median, and maximum values are reported positive, including 1.296430, 1.356699, and 1.557879, respectively. While the minimum value goes down to −0.219834, indicating the deviation from the mean value as 0.228899. The energy public research and development budget is declining as the mean, median, maximum, and minimum values suggest −1.463459, −1.468195, −1.084952, and −2.434230, respectively, where less standard deviation from the mean value is found, which is 0.241101. The PRI and the GDP reported positive figures. Specifically, the descriptive stat for PRI presents the mean, median, and range values as 1.907008, 1.912709, 1.943453, and 1.834368, respectively. The lower difference between these values reports a lower standard deviation from the mean value, reported as 0.024704.

Similarly, the mean, median, maximum, and minimum values for the GDP are 12.56122, 12.44898, 13.26246, and 12.13535, respectively. While the standard deviation values are found greater than the PRI, reported as 0.308359. Thus, the Jarque-Bera normality test for CPIE, EPRD, PRI, and GDP rejects the null hypothesis of combined skewness and excess kurtosis being zero. Furthermore, as the P-values for the said variables are significant at 1% and 5% levels, it could be assumed that the sample data for these variables are not normally distributed. This further supports the decision to use panel quantile regression techniques to estimate the coefficients across various quantiles of energy productivity level.

Table 3 provides the empirical estimates for Hashem Pesaran and Yamagata (2008) slope coefficient heterogeneity (SCH), and the Breusch and Pagan (1980) LM test, Pesaran (2004) Scaled LM test, and the Pesaran (2004) CD test for the cross-sectional dependency. The Hashem Pesaran and Yamagata (2008) SCH test reports both the SCH and adjusted SCH values for the two models. The empirical statistics for SCH and adjusted SCH for both Model-1 and Model-2 are statistically significant at the 1% level. This reveals that the null hypothesis of homogeneous slopes has been rejected and that the slope coefficients are heterogeneous.

Table 3. Slope heterogeneity and cross-section dependence.

Slope Heterogeneity Test	Model-1	Model-2
$\tilde{\Delta}$	3.753***	4.769***
$\tilde{\Delta}_{Adjusted}$	4.665***	5.928***
Cross-Section Dependence	**Model-1**	**Model-2**
Breusch-Pagan LM	114.82***	101.795***
Pesaran scaled LM	14.477***	12.466***
Pesaran CD	8.251***	7.411***

*Note: Significance level is denoted by ***, ** and * for 1%, 5% and 10%.*
Source: Authors.

Table 4. Unit root testing (Pesaran, 2007).

	Intercept and Trend	
Variables	I(0)	I(1)
EP	−2.202	−4.121***
FINC	−2.597	−3.208***
GDP	−1.525	−3.236***
CPIE	−3.327***	–
EPRD	−3.765***	–
PRI	−2.528***	–

*Note: Significance level is denoted by ***, ** and * for 1%, 5% and 10%. I(0) is for level, and I(1) is for the first difference.*

Table 5. Cointegration results (Westerlund, 2007).

Statistics	Model-1	Model-2
G_t	−4.290***	−3.539***
G_a	−8.531***	−9.421***
P_t	−11.696***	−10.575***
P_a	−13.242***	−13.211***

*Note: Significance level is denoted by ***, ** and * for 1%, 5% and 10%.*

Besides, the cross-section dependence issue is important in the panel data estimation. The cross-section dependence helps deal with the biased unit root and cointegration estimates (Salim et al., 2017; Westerlund, 2007). The estimated results for Breusch and Pagan (1980) LM test, Pesaran (2004) Scaled LM test, and the Pesaran (2004) CD test is reported highly significant at a 1% level. This leads to rejecting the null hypothesis of having no cross-section dependence for all these mentioned tests. Hence, it is confirmed that the cross-section dependency exists across the panel countries of G7. Furthermore, it is revealed that the energy efficiency could not be achieved solely, but the other countries' cooperation and objectives also matter in the energy efficiency achievement.

Table 4 presents the empirical estimates of unit root calculated via the Pesaran (2007) CIPS at leveled [I(0)] and the first differenced data [I(1)]. The Pesaran (2007) CIPS revealed that three out of six variables, CPIE, EPRD, and PRI, are significant at I(0) by a 1% significance level. This rejects the null hypothesis for the said variables of the unit root and indicates that the sample data for CPIE, EPRD, and PRI is stationary. In contrast, the three variables EP, FINC, and GDP are found insignificant at I(0), while significant at I(1) by a 1% significance level. Thus, these variables also rejected the null hypothesis at I(1) and assumed that the sample data for EP, FINC, and GDP is stationary.

Table 5 presents the estimated cointegration results achieved via employing the Westerlund (2007) cointegration test. This test assumed whether the error correction term (ECT) in a conditional panel error correction model (ECM) is zero (that is, ECT $= 0$). The estimated result from the table reports highly significant values for both Model-1 and Model-2 at 1% and 5% levels. Furthermore, the error correction for both the group means statistics and panel statistics are observed negative and highly statistically significant. This reveals the convergence of the group and panel towards equilibrium and rejects the null hypothesis of the ECT being zero. Instead, these variables are found approaching the equilibrium state. Thus, it is concluded

Table 6. Panel quantile regression results.

$q_{0.25}$ Variables	Model – 1 Coefficients[Std.Error]	Model – 2 Coefficients[Std.Error]
FINC	0.054* [0.030]	–
GDP	–	0.582*** [0.0782]
CPIE	0.224*** [0.0454]	0.0594*** [0.0067]
EPRD	0.224*** [0.0454]	0.255*** [0.0347]
PRI	0.572*** [0.1042]	0.492*** [0.0518]
Constant	1.443*** [0.1152]	1.247*** [0.372]
$q_{0.50}$		
FINC	0.138*** [0.0241]	–
GDP	–	0.587*** [0.0691]
CPIE	0.0436*** [0.0102]	0.013*** [0.0021]
EPRD	0.248*** [0.0687]	0.137*** [0.0235]
PRI	0.592*** [0.1043]	0.492*** [0.0891]
Constant	1.811*** [0.2910]	1.729*** [0.2041]
$q_{0.75}$		
FINC	0.298*** [0.0521]	–
GDP	–	0.691*** [0.0124]
CPIE	0.107*** [0.0241]	0.086*** [0.0211]
EPRD	0.180*** [0.0412]	0.245*** [0.0421]
PRI	0.393*** [0.0671]	0.501*** [0.1003]
Constant	1.632*** [0.2635]	1.486*** [0.223]

*Note: Significance level is denoted by ***, ** and * for 1%, 5% and 10%.*
Source: Authors.

that all the variables under consideration, i.e., energy productivity, financial inclusion, GDP, energy-related CPI, Energy public RD&D budget, and the political risk index, are associated in the long run.

The estimated long-run coefficients predicted via Koenker and Bassett (1978) are presented in Table 6. These long-run coefficients are estimated across three quantiles (i.e., 25th, 50th, and 75th) for energy productivity as a proxy for energy efficiency. In Model-1, the marginal effect of financial inclusion is found positive and statistically significant across the quantiles. From lower $Q_{0.25}$ to higher $Q_{0.50}$ quantile, the magnitude of financial inclusion is reported increasing and become highly significant at 1% level. The influence of financial inclusion reports that a one percent increase in financial inclusion increases energy productivity by 0.054 in $Q_{0.25}$, 0.138 in $Q_{0.50}$, and 0.98 percent in $Q_{0.75}$, respectively. These coefficients are statistically significant at 10% and 1% levels, respectively. Such findings are statistically significant to the existing study of Liu et al. (2022), demonstrating that an increase in financial inclusion and financial activities enhances energy efficiency in the emerging seven economies. This reveals an increase in the commercial banks, branches of commercial banks, outstanding deposits with commercial banks, numbers of ATMs per 100,000 adults, and the outstanding loan from commercial banks provides the opportunity to invest in the production energyefficient activities. In Model-2, the GDP is also positively and significantly affecting the energy efficiency in the G7 economies. A one percent increase in the GDP of G7 economies enhances the GDP per unit of total primary energy supply by 0.582 in $Q_{0.25}$, 0.587 in $Q_{0.50}$, and 0.691 percent in $Q_{0.75}$, respectively. The results are found highly significant at a 1% level concerning GDP and energy productivity. However, the magnitude of the coefficients is reported increasing while moving from lower quantile $Q_{0.25}$ to medium $Q_{0.50}$ and higher quantile $Q_{0.75}$, respectively. Such findings are consistent with Pao and Tsai's existing findings (2010). Also, Cantore et al. (2016) reveals that enhancement in the energy efficiency could trigger total factor productivity in the industrial sector. This indicates that GDP growth could be a significant factor for increasing energy productivity and efficiency. Specifically, enhancement in the income level leads to the enhancement of technological progress and innovation, which encourages the use of energy efficient products and services in the industrial sector, reducing energy demand and reducing environmental degradation. Thus, due to the high-income level, the investments in energy productivity and efficiency increase.

Further, the energy-related inflation is reported as positively influencing the energy productivity at all the three quantiles in both Model-1 and Model-2. Specifically, a percent increase in the energy-related inflation increases the energy productivity by 0.224 in $Q_{0.25}$, 0.0436 in $Q_{0.50}$, and 0.107 in $Q_{0.75}$, respectively in the Model-1, and 0.0594 in $Q_{0.25}$, 0.013 in $Q_{0.50}$, and 0.086 in $Q_{0.75}$, respectively. The magnitude of the energy-related inflation varies across the quantiles. However, the significance at the 1% level reveals that energy-related inflation enhances energy productivity. These statistics are consistent with Juselius (2020) existing study, which reveals that enhancement in the general and/or energy related products prices leads to the adoption and encouragement of energy-efficient machinery and vehicles. Thus, energy-related inflation could be an essential measure to improve energy efficiency in the G7 economies. Additionally, the EPRD and political risk also contribute significantly to the energy productivity in both models. Specifically, a one percent increase in the EPRD increases the energy productivity by 0.224 in $Q_{0.25}$, 0.248 in $Q_{0.50}$, and 0.180% in $Q_{0.75}$, in Model-1, and 0.255 in $Q_{0.25}$, 0.245 in $Q_{0.50}$, and 0.98% in $Q_{0.75}$, respectively. The results are found statistically significant at 1%, 5%, and 10% levels. This reveals that an increase in the energy public research development and demonstration budget promotes energy productivity. It is well known that research and development encourage innovation and technological advancement, which consequently increase energy efficiency (Cheng et al., 2020). Thus, the energy public research development and demonstration budget contribute to achieving energy efficiency in the G7 economies. Moreover, the political, economic, and financial risk also helps encourage energy productivity. Concerning, a percent increase in the PRI significantly increases the energy productivity by 0.572 in $Q_{0.25}$, 0.592 in $Q_{0.50}$, and 0.393% in $Q_{0.75}$, in

Table 7. Robustness tests (FMOLS).

Variables	**Model – 1** **Coefficients**	**Model – 2** **Coefficients**
FINC	0.180***	–
GDP	–	1.033***
CPIE	0.133***	0.083***
EPRD	0.038***	0.024***
PRI	0.422***	0.304***
Constant	1.025***	1.092***

*Note: Significance level is denoted by ***, ** and * for 1%, 5% and 10%..*
Source: Authors.

Model-1, and 0.492 in $Q_{0.25}$, 0.492 in $Q_{0.50}$, and 0.501% in $Q_{0.75}$, respectively. The outcomes are highly statistically significant at a 1% level in all the quantiles. The political risk index reveals that the risk factor increases, the stability and quality of the financial, economic, and bureaucratic institutions increase. This further strengthens the implementation of policies concerning conventional fossil fuels, which degrade the environment and encourage energy efficiency to promote a sustainable environment.

The earlier discussed quantile regression provides the relationship between the variables and estimates coefficient values for each variable outside the mean of the data. However, the FMOLS considers the mean values for estimating the coefficient values concerning the relationship between variables. The estimated results obtained via FMOLS are provided in Table 7. The results support the findings of the quantile regression and reveal that financial inclusion, GDP, energy-related inflation, EPRD, and PRI positively and significantly promote energy productivity. Specifically, Model-1 report that a one percent increase in the financial inclusion, energy-related inflation, EPRD, and political risk index causes energy productivity to increase by 0.180, 0.133, 0.038, and 0.422%, respectively.

Similarly, in Model-2, a one percent increase in GDP, energy-related inflation, EPRD, and political risk index causes an increase in the energy productivity by 1.033, 0.083, 0.024, and 0.304%, respectively. The results for both Model-1 and Mode-2 are found highly statistically significant at a 1% level. The FMOLS estimates confirm the previous findings of quantile regression estimates and reveal that all these variables contribute to the energy efficiency of G7 economies.

5. Conclusion and policy implications

5.1. Conclusion

Since the group of seven (G7) are the leading industrialist and developed economies globally, these economies are still targeting rapid economic growth, financial stability, and energy efficiency achievement. Besides development, six out of the listed seven economies, i.e., the United States, Italy, Germany, Canada, France, and Britain, are among the top energy importers in the world. Accompanying such higher economic growth and energy imports, these economies are most likely to be affected by energy import costs and environmental degradation. As a consequence, these economies are now mostly concerned about achieving their energy efficiency target to reduce energy consumption and promote environmental quality. The primary objective of this study is to explore whether economic, financial, and energy related indicators affect energy efficiency in the developed economies. Most of the existing literature asserted that technological innovation is the leading factor that enhance energy efficiency. However, there are other important factors that could influence energy efficiency and are not explored yet. To answer the question of whether economic, financial, and energy related indicators affect energy efficiency, this study investigates the influence of financial inclusion, GDP, energy R&D, political-economic-financial risk index, and the energy-related inflation on the energy efficiency of G7 economies covering the period from 2004 to 2020. Since all the variables report irregular distribution: therefore, appropriate estimator, i.e., panel quantile regression is used. The empirical results of the study discovered that financial inclusion, economic growth, energy R&D, political-economic-financial risk index, and the energy-related inflation positively and significantly enhances energy efficiency, which is increasing from lower to higher quantile. Since the panel quantile regression provides estimated outcomes at specific quantile, yet these results are found robust as validate by FMOLS approach, which provides the average impact of explanatory variables on energy efficiency. Apart from the robust estimates, this study answers the questions that the economic, financial, energy, and R&D related indicators substantially affect energy efficiency, which creates a new strand of debate among authors that other indicators could also influence energy efficiency rather than the technological and financial indicators.

5.2. Policy implications

Based on the empirical findings, the current study recommends that it is pertinent for the G7 economies to improve their financial inclusivity degree to achieve energy efficiency. This will support the industries and production sector by providing green financial support in loans, which enhances the probability of adapting energy-efficient techniques for production and manufacturing by enhancing economic growth. More importantly, the G7 governments must implement such financial inclusion policies to enhance energy efficiency in the region. Further, since most G7 economies are energy importers and highly dependent upon traditional fossil fuel energy consumption, it is time to either adopt transition towards renewable energy sources or increase energy efficiency by focusing on energy-related research and development with an innovative solution. Moreover, the political, economic, and financial risks must be reduced as the national and international investors are greatly influenced by the political and economic circumstances in the country, which reduced the political risk index, and the investors refused to invest in the emerging sectors such as energy efficiency or energy transition. Implementing such policies will encourage the energy productivity or energy efficiency of the economy and lead to the sustenance of higher economic growth in the G7 economies.

5.3. Limitations and future research directions

This study investigates the leading factors that inherently influence energy efficiency by targeting many economic, financial, R&D variables. However, this study focused only on the G7 economies due to some limitations concerning data availability.

Therefore, future researchers are recommended to enhance this research by investigating middle-income or low-income economies. Also, this study could be enhanced by including other economic and energy-related variables such as FDI, remittances, trade, globalization, renewable energy consumption, technological advancement, etc. Apart from the above-mentioned limitations, this study is also limited in terms of excluding the Covid-19 pandemic due to data unavailability. Therefore, the future researchers could empirically investigate this nexus as it is a global concern that disturbs various economic activities across the developed as well as developing economies.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes

1. See https://www.globalgovernanceproject.org/g7-performance-on-energy/
2. See https://www.adb.org/publications/financial-inclusion-regulation-and-education-germany
3. See for instance: https://www.afi-global.org/newsroom/blogs/promoting-financial-inclusion-at-scale-a-canadian-perspective/
4. For more details, visit: https://www.statista.com/chart/14305/change-of-energy-consumption-by-source-in-g7-countries/.

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