



Assessing the impact of green fiscal policies and energy poverty on energy efficiency

Fengsheng Chien^{1,2} · Ching-Chi Hsu¹ · YunQian Zhang^{1,3} · Tai Duc Tran⁴ · Li Li^{1,3}

Received: 4 July 2021 / Accepted: 3 August 2021 / Published online: 18 August 2021

© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2021

Abstract

This article estimates the ties between green fiscal policies and energy efficiency in COVID-19 era. For this purpose, data envelopment analysis (DEA) approach is considered and applied. The study findings show that green fiscal policies, such as public supports and tax rebates, have significant role in reducing energy poverty of different international countries by advancing energy efficiency. Therefore, a panel data ranging from 2010 to 2020 is used. Our findings indicate that the aggregate degree of green fiscal policies help to decline energy poverty. Renewable energy companies had larger series of net fiscal competence and size efficiency, and their levels of energy efficiency were greater than 0.457%, with the 16% effect of current public supports and 11% effect of taxation rebates supported to diminish energy poverty with 29.7% in different international economies. This is a positive effect by green fiscal policies. The study also presented policy implications suggesting effectively implementing green fiscal policies for more efficient carbon reduction and making climate change supportive for peoples in post COVID-19 period.

Keywords Green fiscal policies · Energy efficiency · COVID-19 era · Financing efficiency · Fiscal restructuring

Introduction

In past few decades, intersection of environmental deterioration, energy, and economic development has gained scholarly

Responsible editor: Nicholas Apergis

✉ Tai Duc Tran
tai.td@vlu.edu.vn

Fengsheng Chien
jianfengsheng@fzfu.edu.cn

Ching-Chi Hsu
chingchi@fzfu.edu.cn

YunQian Zhang
340336066@qq.com

Li Li
26061545@qq.com

¹ School of Finance and Accounting, Fuzhou University of International Studies and Trade, Fuzhou 350202, China

² Faculty of Business, City University of Macau, Macau, China

³ Faculty of International Tourism and Management, City University of Macau, Macau, China

⁴ Faculty of Business Administration, Van Lang University, 45 Nguyen Khac Nhu, Dist.1, Ho Chi Minh City, Vietnam

interest (Chien et al. 2021d). Major issue involves economic development and ecology. World economic development has increased since the turn of the eighteenth century to the detriment of electricity reliability, a natural consequence of conventional sources of energy used in production. Income activity, energy, and economic quality are thus a triad complex system—a triad. Energy efficiency is substantially dependent (Iqbal et al. 2021a, b) on resource extraction and usage since the first steam engine was created. But population expansion, economic development, and modern technology advances in the twenty-first century improved energy efficiency (Li et al. 2021a, b, c). In the past, this is very rare, creating a global climate emergency via continued use of carbon energy and associated alternative fuels (Anh Tu et al. 2021).

The necessity to diversify energy is covered by two literary perspectives: first, the need to conserve and, second, the need to ensure energy supplies (Li et al. 2021a, b, c). Research on renewable energy started in 1973 following the first oil shock. After the oil crisis of 1973, energy efficiency and literature on economic development came (Iqbal et al. 2021a, b). This research examined the connection between US empirical energy and economic growth. Several studies have since modified this paradigm taking macroeconomic factors into account which may affect the connection between energy and growth (Anh Tu et al, 2021), including renewable energies, financial

growth, and employment. Studies using impact categories have begun to increase as a result of climate change. The ecological impact criteria led to an increase in models, incorporating environment pollution caused by energy efficiency (Boemi and Papadopoulos 2019).

Because their impact on energy conservation and efficiency is indirect and difficult to measure, government policy design and institutional structures are often ignored (Aranda et al. 2017). Lately, Chinese technology has made significant strides in energy and pollution reduction. However, China remains the world's largest energy efficiency and emitter. Scholars across the world are worried that China will not meet its stated carbon reduction targeted (Okushima 2017). China's energy savings and efficiency are severe, with progress falling behind goals, which may be related to failures in energy efficiency programs and programs that do not contribute to stated savings targets (Li et al, 2021a; Alemzero et al, 2021; Iqbal et al, 2021a, Li et al, 2021c; Ahmad et al, 2021; Anh Tu et al, 2021). The reason is China's energy-saving and pollution reduction policies (Bonatz et al. 2019).

They have gradually become the world's most successful energy-saving and emission-reducing methods, chosen by major countries (Dobbins et al. 2019). China has yet to implement a carbon tax, and the nation's emission trading system was just created in 2017, limiting its effect on energy conservation and efficiency. Whether China can support future energy savings and energy efficiency relies on whether state expenditure can save energy and decrease emissions efficiently (Xueying et al. 2021). As a result, energy conservation and emission reduction obligations must be created at all levels of government. A study of national and local government expenditure on decreasing energy efficiency in China is needed (Bednar and Reames 2020).

Additionally, the increased variable variability in the Kuznets curve analysis will be minimized (Betto et al. 2020). Additional transmission channels emphasize the variety of macroeconomic variables as causal drivers for energy efficiency. Studies that emphasize the economic impact of energy efficiency rise or reduction are uncommon. Few studies have demonstrated a genuine link between government spending and environmental stewardship, with four major transmission systems: size, composition, engineering, and income. The result is increasing environmental stress as a result of economic growth. Human capital activities must be prioritized above physical assets in order to improve composition. The technological effect will increase labor efficiency by improving work routines. Higher economic levels result in increased priority and environmental demand. Backwards, Li et al. (2021a, b, c) showed experimentally that although economic freedom generates higher energy efficiency, government size is small. The only situation in which an increase in government spending may benefit the environment is if growth is in the public interest.

The main aim of this study is to investigate the dynamic relationship between fiscal policy and energy efficiency from various fossil fuels by including structural breaks between 1972 and 2014 into the EKC framework. Very little infrequent study exists on the topic; however, the effect of fiscal policy is limited by incorporating public spending and tax revenue on energy efficiency—but GHG's climate change problem can only be handled via proper fiscal response. Studies like Iqbal et al. (2021a, b) incorporated tax spending and income in the model of energy-environmental deterioration. A possible research deficiency is to ignore the structural disturbances in the fiscal policy-polluting nexus that may skew long-run parameter values. The research investigates the long-term connection between energy, income, and energy efficiency while monitoring structural disturbances and evaluating the EKC hypothesis. While this study focuses on the Turkish economy, our analysis targets Thailand. Although Halkos and Paizanos (2016) used a VAR to assess the heterogeneous effect of expanding fiscal policy on energy efficiency consumption and production, this study isolates for the first time the impact of fiscal policy on energy efficiency from various fuels, taking into account the specific characteristics of Thai energy sector. This impacts total energy efficiency given the continuing shift to natural gas as the main energy source.

Ecological effects of fiscal policy may be empirically shown in Thailand's newly industrialized net energy importing industry. A novel empirical approach is used to examine the effect of tax stimulus on renewable energy from credible facts (coal variations) and decreased poverty. This is critical if we are to evaluate fiscal policy effects on fossil fuels in Thailand and explain the connection between fiscal policy and energy efficiency. Lastly, the Zivot and Andrews single-break unit root test and the Lagrange multiplier (LM) endogenous double-breaking unit root test are employed to assess the stationary properties of the investigated series. Fourth, Maki co-integration is avoided to distort structural fractures within the co-integration link. Dols is also used to predict long-range fiscal policy parameters, such as energy poverty, and efficiency, amid a structural collapse.

Moreover, this research adds value to existing studies on the greenhouse gas emissions' impact of fiscal decentralization. These analyses see rising demand for fossil fuels as the fundamental reason of growing energy efficiency. When central government provides greater authority over fiscal expenditure to local governments, local governments are more likely to reduce energy use via subsidies and other resources. Naturally, rising municipal tax spending will not always yield to energy and carbon reductions because government spending policy lags behind when businesses or individuals comprehend greater energy savings and reduced emission requirements.

Literature review

Fossil fuel use has resulted in many environmental and contaminant discharges. Global warming is caused by inefficient energy usage and SO₂ precursors. Severe weather has kept the globe informed (Sadiq et al. 2021; Sokołowski et al. 2020). Pollution is gaining public attention. Several countries have adopted different energy saving and emission reduction measures to reduce pollution emissions. A major developing nation, China, confronts significant energy conservation and reduction issues. According to BP statistics, China's energy efficiency was 9232.6 million tonnes in 2017. Two hundred thirty-nine out of 338 cities in China breached the Air Quality Directive in 2017, according to CEEB statistics (70.7% of all cities). In recent years, the Chinese government has launched a variety of energy-saving and energy efficiency programs (Doukas and Marinakis 2020).

The Chinese government proposed the Comprehensive Demonstration of the National Energy Saving and Energy Efficiency (ESER) Policy in 2011. With the use of specific demonstration cities, this plan seeks to improve national energy conservation and efficiency (Lin and Wang 2020). The Chinese government's environmental deterioration in the city is evident in this legislation. The ESER plan's success is not required for future energy savings and efficiency initiatives. As a result, the ESER policy's impact has to be much of the world's GDP spent on government expenditure and investment. Many governments have also implemented expansionary macroeconomic policies to help and speed up their countries; economic recovery in response to the global economic crisis of 2008. More and more research shows that fiscal spending has a significant effect on environmental deterioration. While fiscal policies are not intended to enhance environmental quality, their potential impact on environmental effectiveness and pollution levels must be assessed (Karpinska and Śmiech 2020; Othman et al. 2020). The goal of this study is to examine the relationship between environmental quality and macroeconomic variables by examining how tax policies affect energy efficiency (Li et al. 2021b; Primc and Slabe-Erker 2020). To do so, we utilize quarterly US economic statistics from 1973 to 2013. The environmental variable we use is energy efficiency, with quarterly data accessible throughout the whole study period. We differentiate between production and consumption sources of this pollutant and estimate a model that includes macroeconomic and other important factors (Lowitzsch and Hanke 2019). Other than fiscal policy, a broad variety of research has been done on air pollution (Bouzarovski 2014).

In order to meet aggressive carbon reduction goals, the Chinese government has created tax refund and subsidy programs (Anh Tu et al. 2021). China has provided direct funding for R&D, interest, programs, grid subsidies, and renewable energy grid subsidies (Chien et al., 2021c). As a consequence,

China has implemented value-added taxes, corporate taxes, and revenue taxes. Renewability is promoted through government incentives (Phimister et al., 2015). Federal and state support, on the other hand, aids renewable energy businesses in securing financing while increasing income streams and financial capital gaps for project viability (Li et al., 2021b). The market for financial institutions including industrial investment, lower lending rates, and operational and overall efficiency of renewables businesses is also signaled (Phimister et al. 2015).

It currently offers R&D tax credits, VAT refunds, commercial incentives, and savings in energy production costs (Kyprianou et al. 2019). Companies' cash flow choices may improve as they reduce costs and increase indirect investment (Huang et al. 2020). Free financing enables renewable energy businesses to control their resource flows. In this way, renewable energy technology is efficient and money is free (Hsu et al. 2021). Increased tax incentives will lower corporate financing costs, encourage renewable energy purchases, and improve renewable energy efficiency (Wu et al., 2021). Traditional public goods lose investments, and public funds are repaid for corporate errors that are corrected with R&D revenue (Maxim et al., 2016). The funding will enhance technical R&D's competitive edge, extend renewable energy firms' technological monopolies, motivate them to invest on R&D and technology, and raise performance (Maxim et al. 2016).

Depending on the technique used, the quality of innovation should be similar in all safety and emission categories (Bollino and Botti 2017; Del Rosal et al. 2019). Based on their emissions footprint, new technology may harm or benefit the environment. Companies that pollute produce higher "compliance expenses" and less "consumer value" (Damigos et al. 2021). High-polluting businesses have an extra cost burden due to budget constraints. The expense of eliminating pollution must match the amount of output in new systems. Polluting businesses struggle to reduce pollution (Chien et al. 2021c; Wang et al. 2021). Enviro-innovation may therefore decrease net efficiency. Lessening pollution is expected to be less expensive than other green efficiency measures. Finally, the Porter hypothesis favors the clean industry (Day et al. 2016; Ehsanullah et al. 2021). So, healthy industries gain more from innovation than pollution producers (Barnes et al. 2011; Chien et al. 2021d).

These results came by combining creative and green productivity courses. Innovators' discoveries are likely to come from a variety of angles (Romero et al. 2018). Input is effort and output is performance. In the past, research has demonstrated that innovations contribute to overall productivity and commercial impact (Casillas and Kammen 2010; Chien et al. 2021a; Chien et al. 2021b). However, due to concerns about innovation's vulnerability, they will resist. Furthermore, workers are unable to start businesses owing to insurance risks

(Athiyaman and Magapa 2019; Thomson et al. 2017). We may therefore evaluate the effect of development on green production (overestimating the benefits and underestimating the risks). Patenting a company's innovations, however, would not represent the entire value. It may be attempted to steal its intellectual property and reduce its competitive edge. A stronger and more transparent green growth strategy is possible with greater climate transparency (Barnes et al. 2011; Kimanzi 2019), in this sense, green bonds. Despite this, their impact on the real economy and capital markets remains unclear. Furthermore, their distribution and remuneration were ignored (Muposhi 2019). Integration assessment systems (IAMs) cannot represent a complex system with many sector-to-sector feedback mechanisms, short-term deficits, macroeconomic circumstances, and business strategy (Li et al. 2021a, b, c; Phan and Quang Thanh 2019).

Population expansion, economic development, consumer price, and energy efficiency are all variables that affect fossil fuel efficiency (Lakatos and Arsenopoulos 2019). Reducing fiscal costs may differ depending on pollution source, i.e., whether contamination is created or consumed (Streimikiene et al. 2020). Pachauri et al. (2004) suggest four different industrial pollution routes that public spending may affect. Demand for improved environmental quality is fueled by increasing income levels and government expenditure (income effect). A greater tax burden also benefits small companies (Chester and Morris 2011).

Data and methodology

Economic hardship, high energy costs, and inefficient systems all contribute to energy poverty. These problems should be addressed in conjunction with income growth, fuel price controls, and building energy efficiency improvements. Thus, increasing energy costs affect disadvantaged socioeconomic groups' decreasing family income in a variety of ways depending on present conditions and financial, regulatory, and fiscal policies. Extra energy price restrictions, such as energy taxes, often impact low-income households, leading to energy poverty and a decline in living standards. However, balancing taxes with energy subsidies and direct financial aid tools like house heating allowances only provides temporary relief and does not address the root causes of energy poverty.

Study data

To estimate study findings and result outputs, the data is collected from the different databanks including World Bank record, energy council, world development indicators, and worldwide energy support catalogue. Oppositely, some

contextual databases of all these different sample countries were also considered to validate the background dynamics and related empirical association between the constructs using real time statistical data. These include Indian Energy Ministry, Ministry of Finance Pakistan, development and reforms databases, and Bureau of Statistics Pakistan. The study includes the data ranging from 2010 to 2020.

Energy poverty measurement

The main aim of this study was to evaluate energy poverty using four different indexes: accessibility (percent of people with electricity intake), power feeding (per capita GDP) (time required getting electricity in days). Sufficient means the capacity and readiness of a person to use current electricity while in a city. The two metrics in issue are home energy use and home electricity generation. Residents' technology diffusion is the first determinant of their usage, expressed in two measures (carbon free use and highly energetic utilization). The housing affordability issue now offers energy saving possibilities with two criterion (power and capital groups) and four factors. The term "accessibility" relates both to housing and economic operations and the cost aspect. The following elements are important not just for present energy poverty but also for future policies to eradicate it. In summary, there are four energy scarcity components in the overview index. The Li et al. (2021a, b, c) entropy techniques are employed, however, to measure and deduce the index of energy poverty.

(Grounded on the aforementioned outlook, the chosen countries are selected to estimate the long-term prediction for the energy poverty indices, presenting the value of the j -th range or location of the i -th territory and x_{ij} $i = 1, 2, \dots; j = 1, 2, \dots$). We utilized a mutual technique to evaluate the general energy poverty directory in an optimistic manner, which is quantitatively expounded as follows:

$$x_{ij} = \frac{x_{ij} - \min(x_{ij}, \dots, x_{nj})}{\max(x_{ij}, \dots, x_{nj}) - \min(x_{ij}, \dots, x_{nj})} \quad (1)$$

$$x_{ij} = \frac{\min(x_{ij}, \dots, x_{nj}) - x_{ij}}{\max(x_{ij}, \dots, x_{nj}) - \min(x_{ij}, \dots, x_{nj})} \quad (2)$$

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^N x_{ij}} \quad (3)$$

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

Here $k = 1/\ln(n) > 0; e_j \geq 0$. Grounded on Equation (4), entropy dismissal is estimated by using the following equations; more so the weight of measurement is shown in Equation (6), and all-inclusive catalog dimension of energy poverty is equated in Equation (7):

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

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

$$\text{Energy Poverty Index}_i = \sum_{j=1}^m w_j \times p_{ij} \tag{7}$$

Constructing energy efficiency index

For such creation of the possibility specified in a specified area by the DMU component (e.g., DMU_j, (j=1,...,n)), the wiggle room functional selection of Pitch is examined. For this, an evidence backing is created that serves the DMU for empirical testing with *k* be $x \in R_{mk}^+$, $y \in R_{sk}^+$, and $z \in R_{dk}^+$ is made. Furthermore, the inventive possibility indicates the following structure for subcategories.

$$\text{PPS}_{\text{stage1}} = \left\{ (x, z) \mid x \geq \sum_{j=1}^n \chi_j \lambda_j, z \leq \sum_{j=1}^n z_j \lambda_j, j = 1, \dots, n \right\} \tag{8}$$

$$\text{PPS}_{\text{stage1}} = \left\{ (y, z) \mid z \geq \sum_{j=1}^n z_j \mu_j, y \leq \sum_{j=1}^n y_j \mu_j, j = 1, \dots, n \right\} \tag{9}$$

The total impact could be affected by the insufficiency of the intermediate research. It is important to note the effect of intermediate nutrition on the effectiveness and location of the unit responsible. However, the research shows that the system is developed and linked depending on the classification techniques generated by the basic event.

$$r_k = \min \left(\frac{1}{m} \sum_{j=1}^n \frac{s_i^-}{x_{ik}} + \frac{1}{D} \sum_{d=1}^D \frac{T_d^*}{z_{dk}} \right) / \left(1 + \frac{1}{D} \sum_{d=1}^D \frac{R_d^*}{z_{dk}} + \frac{1}{S} \sum_{r=1}^S \frac{s_r^+}{y_{rk}} \right) \tag{10}$$

$$\begin{aligned} \text{s.t. } & \sum_{j=1}^n \lambda_j x_{ij} + s_i^- = x_{ik}, \quad i = 1, \dots, m, \\ & \sum_{j=1}^n \mu_j y_{rj} - s_r^+ = y_{rk}, \quad r = 1, \dots, s, \\ & \sum_{j=1}^n \lambda_j z_{dj} = z_{dk} + R_d^*, \quad d = 1, \dots, D, \\ & \sum_{j=1}^n \lambda_j z_{dj} = z_{dk} - T_d^*, \quad d = 1, \dots, D, \end{aligned}$$

$$\begin{aligned} s_r^+ &\geq y_{rk}, \quad r = 1, \dots, s, \\ s_i^- &\geq 0, \quad i = 1, \dots, m, \\ s_r^+ &\geq 0, \quad r = 1, \dots, s, \\ \lambda_j &\geq 0, \mu_j \geq 0, \quad j = 1, \dots, n. \end{aligned}$$

$$\max_{s, \lambda} \sum_{i=1}^m R_i^x s_i^x + \sum_{r=1}^s R_r^g s_r^g + \sum_{f=1}^h R_f^b s_f^b \tag{11}$$

$$\text{s.t. } \sum_{j=1}^n x_{ij} \lambda_j + s_i^x = x_{ij0}, i = 1, \dots, m$$

$$\sum_{j=1}^n g_{rj} \lambda_j - s_j^g = g_{rj0}, r = 1, \dots, s$$

$$\sum_{j=1}^n b_{fj} \lambda_j + s_f^b = b_{fj0}, f = 1, \dots, h$$

$$\begin{aligned} & \sum_{j=1}^n \lambda_j = 1 \\ & \lambda_j \geq 0, j = 1, \dots, n \quad s_i^x \geq 0, i = 1, \dots, m \\ & s_r^g \geq 0, r = 1, \dots, s \quad s_f^b \geq 0, f = 1, \dots, h \\ & \xi = \max \sum_{d=1}^D R_d + \sum_{d=1}^D T_d \tag{12} \\ \text{s.t. } & \sum_{j=1}^n \lambda_j x_{ij} + s_i^- = x_{ik}, \quad i = 1, \dots, m, \\ & \sum_{j=1}^n \mu_j y_{rj} - s_r^+ = y_{rk}, \quad r = 1, \dots, s, \\ & \sum_{j=1}^n \lambda_j z_{dj} = z_{dk} + R_d, \quad d = 1, \dots, D, \\ & \sum_{j=1}^n \mu_j z_{dj} = z_{dk} - T_d, \quad d = 1, \dots, D, \\ & s_i^- \geq 0, \quad i = 1, \dots, m, \\ & s_r^+ \geq 0, \quad r = 1, \dots, s, \\ & R_d \geq 0, T_d \geq 0, \quad d = 1, \dots, D, \\ & \lambda_j \geq 0, \mu_j \geq 0, \quad j = 1, \dots, n. \end{aligned}$$

Empirical research structure

Throughout this study, the multivariate estimate of FI conforms to what was shown in the research. We look at four aspects of green fiscal policies in this study—whether or not one has a bank’s or a mobile cash account, has insurance, has access to loans or has access to credit, and gets green fiscal economic transfers through banks or phone funds. Each component is 0.25 points and combined to produce a financial difficulty score according to Equation (1). We utilize a cut-off of 0.5 to measure financial difficulty and give a household a rating of 1 if their financial deprivation is below 0.5 and 0 otherwise (Robinson et al. 2019).

$$W^R = \sum_{t=1}^T \sum_{i=1}^I \int_0^1 W_i(x) f_{it}(x) dx \tag{13}$$

Many scholars have deduced the issue of crude oil supplies that improve energy improvements in different countries. The role of green fiscal policies is, in particular, less resolved (Bouzarovski 2018). Therefore, we referred to these nations with *I* and *t* times as *Z* it, with corresponding indications of 0 and 1, as expanding the function of green fiscal policies in study sample countries (Buzar 2007).

$$W_i(Z_{it}) = \int_{Q_i(Z_{it})}^{Q_i^0} P_i(x) dx \tag{14}$$

Assuming the function of probability density and interruption of the availability of oil reserves, this feature is shown as a functional of measuring the analytical review in line with the role of green fiscal policies in energy poverty and energy efficiency.

$$L_i(Z_{it}) = \int_{Q_i(Z_{it})}^{Q_i^0} P_i(x) dx - C_i(x) dx \tag{15}$$

The readiness of the nations to adjust the streams of green fiscal policies is represented by $-W_i Z$ total it during the time period in i . In order to prevent a disruption in community supply of power from the whole county, people are involved economically in the domestic economy for the time T of the rebuilding process (Li et al. 2021a, b, c).

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

This means that energy projects are much more able to fit policies that contribute to reducing energy poverty and increasing energy efficiency by the effect of green fiscal policies. On the other side, though, the net benefit might be higher since the country makes reduced consumption of green energy sources.

Results and discussion

Quantitative findings

Because of the significant domestic transmission losses, fuel poverty is closely linked to energy inefficiency. People with low earners have to far experienced major benefits from renewable energy upgrading, and improvements in health and medical treatment represent up to 75% of the payoff. It is clear that there are positive impacts, such as reduced energy use. Parametric test shows the connections between green fiscal policies, energy efficiency, and renewable poverty. The IFI

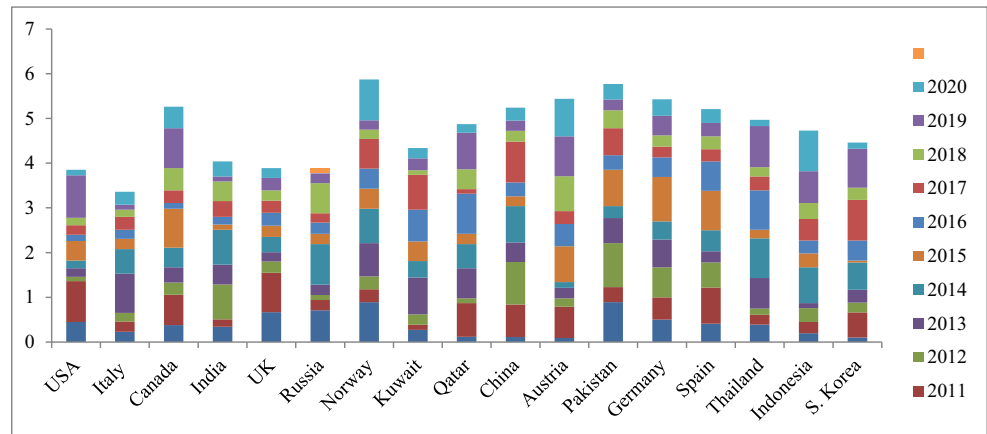
score analyzes the relationship between elements and determines the degree of financial participation our results indicate (the strength of the association is 46% and 89%, respectively). As Cohen (1988) states that correlation coefficients between 0.10 and 0.30 are minor, between 0.30 and 0.60, between 0.60 and 1.00, and between 0.60 and 1.00 are medium in magnitude; they ought to be minor and middle size in impact. These two local find a trend greater than 0.5 for our FI index and the account indication. Thus, the association between green fiscal policies, energy efficiency, and energy inequality is quite powerful, optimistic, and significant.

The statistics of the correlation coefficients in Table 1 indicate that energy consumption, human resources, GDP per capita (GDP), resource profitability, and market participation are unrelated (FI). Figure 1 also shows the energy deprivation score. Due to the low pair correlations of the model, there is no indication of autocorrelation. It is predicted that it would be extremely difficult to maximize at least 10% or up to nearly 25% of cost profits in close to zero homes with no actual policies eliminating renewable energy obstacles in reduced dwellings. Despite living in energy-efficient buildings, this group still tries to pay for energy. Around 27.2% of families struggle to pay their energy costs, and in some cases, their debt has increased over the last year (0.5%). 27.7% are investigating shutting off any energy-consuming equipment to save money. Worryingly, 46.7% of this group cannot afford any kind of energy saving to ensure basic thermal comfort with limited resources. Fortunately, this group has no health problems (84.7%), but this cannot be sustained if the heating is inadequate.

Table 1. Energy efficiency score

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
USA	0.45	0.91	0.10	0.19	0.17	0.44	0.14	0.21	0.17	0.95	0.12
Italy	0.23	0.23	0.19	0.88	0.55	0.23	0.20	0.29	0.16	0.11	0.29
Canada	0.38	0.68	0.27	0.34	0.44	0.87	0.13	0.28	0.50	0.89	0.48
India	0.34	0.17	0.78	0.44	0.78	0.12	0.17	0.35	0.44	0.11	0.34
UK	0.67	0.88	0.25	0.21	0.34	0.25	0.29	0.27	0.23	0.28	0.22
Russia	0.71	0.23	0.11	0.23	0.91	0.23	0.25	0.21	0.67	0.22	0.11
Norway	0.89	0.29	0.29	0.74	0.77	0.45	0.45	0.66	0.21	0.21	0.91
Kuwait	0.27	0.12	0.23	0.82	0.37	0.44	0.71	0.78	0.10	0.27	0.23
Qatar	0.12	0.75	0.11	0.67	0.54	0.23	0.90	0.10	0.44	0.82	0.19
China	0.11	0.73	0.95	0.44	0.81	0.22	0.31	0.91	0.24	0.23	0.29
Austria	0.09	0.70	0.19	0.23	0.13	0.80	0.50	0.29	0.78	0.89	0.84
Pakistan	0.89	0.34	0.98	0.56	0.27	0.81	0.33	0.60	0.40	0.24	0.35
Germany	0.50	0.50	0.67	0.62	0.41	0.99	0.44	0.24	0.25	0.44	0.37
Spain	0.41	0.81	0.56	0.25	0.47	0.88	0.66	0.27	0.29	0.30	0.31
Thailand	0.39	0.22	0.14	0.68	0.89	0.19	0.88	0.31	0.21	0.92	0.14
Indonesia	0.20	0.25	0.31	0.11	0.80	0.31	0.29	0.48	0.36	0.71	0.91
S. Korea	0.10	0.56	0.22	0.29	0.61	0.04	0.45	0.91	0.27	0.87	0.14

Figure. 1 Energy poverty output



This article offers a new technique for mapping household and municipal fuel poverty that may be used in all European countries and modified in other countries that require data sources. This novel method combines data from the general population and housing censuses with data from the household budgeting survey. EPCs were created in the European Union in 2002 to collect and share information on the energy usage of buildings. Table 2 shows weighted outputs.

In 2012, 4.9% of households spent more than 10% of their income on electricity and 7.4% on electricity + natural gas. With energy costs almost doubling between 1994 and 2013, families dedicated 2.8% of their overall energy expenditure, resulting in 7.9% of households in Atlantic Canada experiencing energy poverty.

Table 2 Weighted outputs

	VX(1) EC	VX(2) EE	UY(1) EP	UY(2) GFP
USA	0.45	0.60	0.45	0.12
Italy	0.12	0.21	0.23	0.90
Canada	0.78	0.34	0.19	0.34
India	0.19	0.77	0.80	0.23
UK	0.17	0.30	0.34	0.55
Russia	0.23	0.21	0.29	0.57
Norway	0.41	0.44	0.91	0.27
Kuwait	0.34	0.22	0.34	0.21
Qatar	0.45	0.90	0.10	0.34
China	0.88	0.57	0.21	0.10
Austria	0.24	0.56	0.19	0.01
Pakistan	0.90	0.82	0.23	0.73
Germany	0.19	0.34	0.56	0.77
Spain	0.21	0.67	0.19	0.57
Thailand	0.44	0.27	0.90	0.45
Indonesia	0.32	0.19	0.12	0.06
S. Korea	0.23	0.33	0.81	0.01

Figure.1 shows energy poverty score. Overall cost for busy times is expected to decrease to 10–8 units, while need for an off period would increase from 5 to 8 units, provided that energy poverty and social welfare are affected. The overall surplus is thus projected to decrease from 29.17 to 26.67. The findings remain constructively and country-wise positively significant. As per the models, with the lower proportion and 77% assuming the greatest percentage of remaining mistakes properly distributed, it is possible to depend on the findings. Oil robbery is a danger in maritime waters to 43% of the world’s territory, almost half of the world’s people and 46% of global assets. In rising ocean regions, 68% of theft may occur by tide and storms, while in light of the study, regional increase in sea levels can cause 47% of theft. Taking into account the main oil consumers and producers, the analyses verify the flow of funding for renewable energy in these areas. The research corresponds to Li et al. (2021a, b, c).

Diverse micro-variables impact the effectiveness of renewable energy investments. A rise in energy prices reduces investment responsiveness by making companies more cautious. Capacity adjustment and market power rents are the main causes of economic value differences in renewable energy firms. Socially responsible investments’ capital structure, business size, financing methods, investor demand, knowledge base, and asset price enable their investment inputs. Factors both macroeconomic and firm-specific affect investment efficiency. The results show the potential economic value of renewable energy businesses.

Determining investment gaps is difficult due to a lack of information about how government subsidies and tax incentives influence investment efficiency. Various government incentives and tax breaks could help renewable energy businesses improve their investment efficiency. A renewable energy company must evaluate whether government subsidies and tax advantages really promote excessive development. To enhance factor investment efficiency, policymakers and business executives want to identify the relationship between green fiscal policy and corporate intention.

Subsidies and tax incentives complementing or replacing private sector investment are significant problems in emerging and developing countries.

To estimate the long-run effects of green fiscal policies on energy poverty and energy efficiency, study used economic growth (Y) and applied the equation for VECM as shown in Equation (20). Our study considered three major areas assessing the dynamic interplay between the variables including “green fiscal policies,” “energy efficiency,” and “energy poverty” as measured previously in the “Data and methodology” section. In Equation (20), first difference is indicated with Δ , variables are indicated with β (e.g., β_1 , β_2 , and β_3), dimensions of all variables are indicated with λ (e.g., λa_1 to λa_8 , λb_1 to λb_8 , and λc_1 to λc_9 , respectively), time frame is shown with t , and countries are designated with i with the error term μit .

Growth regression is calculated by applying an index of energy poverty indicators to the main oil producing and consuming nations. Importantly, renewable energy sources have swung the balance to a more favorable direction in this connection. A notable application of green funding may be seen with the use of renewable energy sources. Through this procedure, renewable energy sources get more assistance in order to provide a higher level of green fiscal policies. Growth hypothesis is verified by the provided data, suggesting that poverty and social wellbeing are unidirectional linked. The indirect impact of these improvements on green fiscal policies is important; however, the primary impact is the growth in energy efficiency and decrease in energy poverty.

The inter-temporal link between green fiscal policies and energy poverty has become a major topic for discussion and study. The green fiscal policies of Pakistan have grown to the greatest level over the past three decades, but the shortfall at the end of 2018 rose to 7.2% of GDP compared to 3.17% yearly (see Table 3). Despite concerted efforts to eradicate global energy poverty, the issue remains with the weight of developing countries. The link between FI and energy poverty was not well received because of the many potential energy poverty measures being investigated. It is unfortunate that just a few researchers who have been investigating this problem have used a multivariate green fiscal policies score. To determine the link between energy efficiency and green fiscal policies and access to financial services and food insecurity, if the GFI is endogenous, the distance from the nearest bank must be calculated. In addition, we look at the various ways in which GFI (green fiscal policies) may contribute to fuel poverty in the household. We found FI to be harmful to energy poverty families, which results in various quasi-experimental methods.

Other options to the alternative FI weighting technique and the multi-faceted approach to energy poverty are also suitable. As far as family effects are concerned, FI steadily decreases energy poverty in rural rather than urban regions. GFI also

Table 3 Energy poverty index score

Economies	EPI
USA	0.29
Italy	0.77
Canada	0.31
India	0.17
UK	0.29
Russia	0.18
Norway	0.15
Kuwait	0.30
Qatar	0.78
China	0.29
Austria	0.21
Pakistan	0.44
Germany	0.40
Spain	0.10
Thailand	0.55
Indonesia	0.59
S. Korea	0.39

contributes to reducing energy poverty issue more in men’s households. Table 4 illustrates the inverse correlation between both the components of the research: green fiscal policies, energy efficiency, and energy poverty. Five units for 4 dollars off-peak hours allow electricity to be generated off-peak hours. Likewise, at peak times, power consumption would amount to 10 units at a price of \$8 per unit and would be reduced to \$3 per unit by a fine economic development.

Table 4 Scenario analysis output to estimate long-run perspective

States	Situation 1	Situation 2
USA	0.031*	0.341*
Italy	0.014*	0.876*
Canada	0.037*	0.401*
India	0.054*	0.539*
UK	0.020*	0.313*
Russia	0.038*	0.336
Norway	0.044	0.445
Kuwait	0.039	0.555*
Qatar	0.111*	0.011*
China	0.153*	0.001*
Austria	0.221*	0.099
Pakistan	0.191*	0.027
Germany	0.094*	0.021
Spain	0.077	0.076*
Thailand	0.035	0.023*
Indonesia	0.090*	0.028*
S. Korea	0.072*	0.034*

*Significance at P -value < 0.05

Nevertheless, substantial and persistent green fiscal policies are significantly more essential for reducing electricity prices, reconciling energy poverty, and improving energy savings.

In particular, to increase economic development and to increase cash flow accessible, certain import dependence is wanted at 19%, and studies show that this has fallen by 5% in total in the past decade (e.g., 1990–2010). On a continuous sufficient scale, Germany has the most economy per unit of electricity use (of \$16.48), while Canada is ranked 2 (of \$14.05). As hydroelectric resources are plentiful in Korea, renewable energy ranks first with a figure of 99.67%. Pakistan, by comparison, earned the lowest, 2.51%. While the energy level of the nation remained steady in 2012, it dropped slightly. In India and Germany, energy intensity dropped from 5.37 in 2001 to 4.19 in 2015. In Qatar, the energy demand is assessed at 4.55%. Notably, research results showed that green fiscal policies contributed to a 28% reduction in energy poverty from 2010 to 2020 and 14% improvement in energy efficiency. One way or the other, with financial integration, 1% energy efficiency increase causes 2% energy global poverty in chosen nations. The role of green fiscal policies is thus obvious and important in the energy industry.

Our data also indicate that green fiscal policies are affecting food insecurity via consumerism and household net income. It is feasible to integrate current global policies aimed at improving financial integration with additional policies aimed at raising per capita family net income and reducing consumer poverty. This increases green fiscal policies and reduces poverty in consumption. A regulatory strategy may include steps that reduce the average gap between financial institutions. In the financial context, it is essential to promote innovation to reduce greenhouse gas emissions. Natural resource rents have a positive and significant impact on the energy efficiency of test countries, particularly in countries with many natural resources. Our results accord with that international resource development promotes technological development for the host country. The growth of global trade and currency exchange and fuel efficiency advances has been supported by environmental assets. While technological progress may contribute to energy efficiency, it also has a positive effect on other technical advances.

Anticipated theoretical findings indicate that innovation has a substantial effect on the coefficient of energy efficiency, significant at the 1% level. Innovation reduces energy consumption and improves energy efficiency. Scientifically, creativity has demonstrated a significant rise in China's economic growth factor. Because of the positive effect of innovation on energy efficiency, businesses that utilize it may develop more contemporary equipment, reduce their energy consumption, and improve production. We are sure of our results. The regression coefficients of trade on energy efficiency in the results given by row (1) of Table 3 were positive but were modest. The impact of the industrial structure on energy

efficiency is similarly negligible for increased energy efficiency but too small for the chosen countries to consider. Too far, most studies have solely considered emissions of carbon dioxide when studying environmental issues in the literature. However, carbon dioxide emissions are sometimes inappropriate for commodities such as oil, coal, and forestry.

Discussion of findings

Energy poverty may be reduced by adopting the following two strategies: discrete energy poverty targeting policy groups and a complete policy implementation approach for low-income households through green fiscal policies. If not, governments and policymakers should set up policies to reduce the energy and greenhouse gas emissions of residential sectors and implement them completely to reduce the effect of energy poverty in low-income households. There are three measures: per capita consumption of electricity, per capita monthly energy costs, and per capita consumption of LPG, respectively, 27.3% of which are 18% and 13.9% of HEPI values that are positive, which are the major energy variables. The study also shows the importance of energy services, particularly the role played in energy poverty by electrical equipment, dominating the energy industry, among other components. Washing machinery, laptop, or personal computers are the major contribution of 29% of equipment/appliances, followed by 21% of refreshing equipment (i.e., AC). Refrigerators, by comparison, had the lowest contribution of 6%. Forest covered area, height level, radio stations, TVs, fans, telephone devices, and conventional fuels have an adverse effect (Princ et al. 2019). The following results directly affected energy policy in the major countries of energy production and consumption.

Furthermore, the welfare losses in an inelastic situation would be substantial compared to those in an elastic one. If energy instability continues in such countries, the earlier losses will be more than two times the later losses. The data also provide the income decile spending amounts in IBT and DBT systems. Under the IBT, the highest consumption would be from non-poor households at 3.9% of their income, while the poorest families would spend at least 3.1%. It is worth noting that the richest would want to spend 4.6% on comparison with other non-poor families as well (Kulinska 2017). This is because the average monthly income of the wealthiest family is very large, with a relatively low age proportion of household spending. The opposite happens under the DBT paradigm, with the poorest outperforming the energy poverty level (spending 23% of their electrical revenue) and the richest household paying at least 1.9%.

In fact, the regression results of the industrial structure mediator are given as shown in Table 1 in the fifth to seventh columns. Column 5 states that VFI has a broad impact on the industrial structure and a positive influence, indicating that it adds in line with the expectations of H2B to the structure of

the industry. In column 6, an expansion of 1% of the industrial structure would result in an increase in carbon emissions of 11.14%. The following may be explained: Pakistan's secondary sector is currently the main source of industrial development. Certain older industries remain important in the development of industrial modernization. It can be inferred based on the facts above that VFI can enhance the industrial structure, which in turn will lead to improved emissions of carbon. Indirectly, approximately 0.6% of carbon emissions are caused by vertical fiscal imbalance. In addition to increasing vertical fiscal imbalance, energy efficiency growth also contributed to an additional 0.6205% of carbon emissions owing to its industrial structural impact. Furthermore, the indirect impact is greater than the direct effect, making pollution considerably worse.

According to statistics, an increase in the vertical fiscal imbalance of 1% would decrease the amount of government environmental control expected by decision-makers. A significant positive connection has been observed between environmental regulation and energy efficiency. This indicates that an increase of 1% in environmental regulation leads to a reduction of 0.206% in energy efficiency. The mediator's correlation coefficient is particularly important in column 4. An extra 0.86% increase in energy efficiency is released for every 1% increase in VFI. As a result, VFI may directly emit energy efficiency. It is feasible to assist government and environmental law in fostering environmental equality. An increase in VFI also increases carbon emissions via environmental controls, which results in an additional 0.14% of energy efficiency.

Conclusion and policy implication

Wasteful measures may lead to a rise in energy poverty. Low-income households are more effective in reducing the causes of energy poverty if energy poverty efforts target these households directly. Policies that are proper will help to reduce the burden of energy poverty while also aiding the attainment of medium- to long-term climate and energy goals. Reducing energy poverty and curbing the demand for it helps to lessen the economic and psychological costs of energy poverty. There is a pressing need for governments to speed up action in order to establish favorable investment conditions for energy poverty. To escape the vicious circle of inadequate cost recovery, underinvestment, and lack of public support, nations risk being locked in the vicious circle of higher cost recovery, less investment, and less public support. This will lead to a virtuous cycle in which energy poverty inspires investment in it, resulting in lower levels of energy poverty and other co-benefits while improving the overall economy and increasing public support.

In order to compensate for the loss of social welfare, fiscal expenditure should be cut to counterbalance the burden on the

budget of paying for the Social Security changes. Using compensation to help one kind of industry, while inhibiting another, would boost energy-intensive sectors while impeding the development of skill-intensive sectors, which are key to economic diversification. Additionally, the plans' subsidies benefit the middle- and upper-class earners. Likewise, renewable energy sources might improve energy output while also increasing overall energy efficiency. Through this study, it has been shown that energy shortage has a significant detrimental impact on social wellbeing among energy consumers. In order to reduce this inescapable invisible deficit, the findings outlined in this report advise that government officials must identify homes who consume insufficient amounts of energy to satisfy fundamental necessities. For starters, making sure that citizens have power and a means of paying for it should be the number one priority in the creation of these programs.

Besides, regulation should focus on on-grid and off-grid energy poverty in a distinct way. The best way to assist these vulnerable families having enough energy is to implement an effective energy strategy for them. To enhance household incomes and resources, we also have to link them to utilities, piped water services, and other infrastructure. In order to utilize more sustainable energy to light and heat the home, access to power is the first step. To guarantee that customers are connected to the electric grid as easily as possible, policymakers will need to use suitable measures. While power infrastructure and distribution building will continue to be constrained by technological trends, other initiatives, such as rooftop solar photovoltaics, solar farms, and tiny stand-alone generators, will help to provide convenience for distant areas. Regional policies must be devised to support distributed energy systems in this area.

The results indicate that the Indian government cannot achieve its unrealistic development goals and that strong promotion of renewable energy technologies is required to reduce energy poverty in India. Aside from the above study, few studies have looked at the link between natural gas and energy poverty. This study extends the cost approach to measure fuel poverty. We employ a metric that combines the low-income high-cost (LIHC) methodology with the Italian government's national energy plan indicator to calculate fuel poverty (PNIEC, 2019). Like the LIHC fuel poverty indicator⁵, we use average heating expenses from EPCs to calculate required expenditures. As a result, the hidden fuel poverty issue does not affect households forced to choose between heating and food. A renewable energy company must evaluate whether government subsidies and tax advantages really promote excessive development. To enhance factor investment efficiency, policymakers and business executives want to identify the relationship between green fiscal policy and corporate intention. Subsidies and tax incentives complementing or replacing private sector investment are significant problems in emerging and developing countries.

Author contribution Write up, data curation, and supervision: Fengsheng Chien. Visualization, editing, and writing of draft: Cheng-Chi Hsu. Writing and software: YunQian Zhang. Writing, methodology, and visualization: Tai Duc Tran. Conceptualization and review: Li Li.

Data availability Data is publicly available at mentioned sources in data section.

Declarations

Ethics approval and consent to participate 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, and we give consent for publication in true letter and spirit.

Competing interests The authors declare no competing interests.

References

- Ahmad B, Iqbal S, Hai M, Latif S (2021) The interplay of personal values, relational mobile usage and organizational citizenship behavior. *Interactive Technology and Smart Education*
- Alemzero DA, Iqbal N, Iqbal S, Mohsin M, Chukwuma NJ, Shah BA (2021) Assessing the perceived impact of exploration and production of hydrocarbons on households perspective of environmental regulation in Ghana. *Environmental Science and Pollution Research* 28(5):5359–5371
- Anh Tu C, Chien F, Hussein MA, Ramli MMY, Psi MM MSS, Iqbal S, Bilal AR (2021) Estimating role of green financing on energy security, economic and environmental integration of BRI member countries. *Singap Econ Rev*
- Aranda J, Zabalza I, Conserva A, Millán G (2017) Analysis of energy efficiency measures and retrofitting solutions for social housing buildings in Spain as a way to mitigate energy poverty. *Sustainability* 9(10):1869
- Athiyaman A, Magapa T (2019) Market intelligence from the internet: an illustration using the biomass heating industry. *Int J Econ Financ Stud* 11(1):1–16
- Barnes DF, Khandker SR, Samad HA (2011) Energy poverty in rural Bangladesh. *Energy Policy* 39(2):894–904
- Bednar DJ, Reames TG (2020) Recognition of and response to energy poverty in the United States. *Nat Energy* 5(6):432–439
- Betto F, Garengo P, Lorenzoni A (2020) A new measure of Italian hidden energy poverty. *Energy Policy* 138:111237
- Boemi SN, Papadopoulos AM (2019) Energy poverty and energy efficiency improvements: a longitudinal approach of the Hellenic households. *Energy Build* 197:242–250
- Bollino CA, Botti F (2017) Energy poverty in Europe: a multidimensional approach. *PSL Quart Rev* 70(283)
- Bonatz N, Guo R, Wu W, Liu L (2019) A comparative study of the interlinkages between energy poverty and low carbon development in China and Germany by developing an energy poverty index. *Energy Build* 183:817–831
- Bouzarovski S (2014) Energy poverty in the European Union: landscapes of vulnerability. *Wiley Interdiscipl Rev Energy Environ* 3(3):276–289
- Bouzarovski S (2018) Energy poverty policies at the EU level. In: *Energy poverty*. Palgrave Macmillan, Cham, pp 41–73
- Buzar S (2007) When homes become prisons: the relational spaces of postsocialist energy poverty. *Environ Plan A* 39(8):1908–1925
- Casillas CE, Kammen DM (2010) The energy-poverty-climate nexus. *Science* 330(6008):1181–1182
- Chester L, Morris A (2011) A new form of energy poverty is the hallmark of liberalised electricity sectors. *Aust J Soc Issues* 46(4):435–459
- Chien F, Ajaz T, Andlib Z, Chau KY, Ahmad P, Sharif A (2021a) The role of technology innovation, renewable energy and globalization in reducing environmental degradation in Pakistan: a step towards sustainable environment. *Renew Energy* 177:308–317. <https://doi.org/10.1016/j.renene.2021.05.101>
- Chien F, Ngo QT, Hsu CC, Chau KY, Iram R (2021b) Assessing the mechanism of barriers towards green finance and public spending in small and medium enterprises from developed countries. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-021-14907-1>
- Chien F, Sadiq M, Kamran HW, Nawaz MA, Hussain MS, Raza M (2021c) Co-movement of energy prices and stock market return: environmental wavelet nexus of COVID-19 pandemic from the USA, Europe, and China. *Environ Sci Pollut Res* 28:32359–32373. <https://doi.org/10.1007/s11356-021-12938-2>
- Chien F, Chau KY, Ady SU, Zhang Y, Tran QH, Aldeehani TM (2021d) Does the combining effects of energy and consideration of financial development lead to environmental burden: social perspective of energy finance? *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-021-13423-6>
- Cohen J (1988) *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Lawrence Erlbaum Associates: Hillsdale
- Damigos D, Kaliampakou C, Balaskas A, Papada L (2021) Does energy poverty affect energy efficiency investment decisions? First evidence from a stated choice experiment. *Energies* 14(6):1698
- Day R, Walker G, Simcock N (2016) Conceptualising energy use and energy poverty using a capabilities framework. *Energy Policy* 93: 255–264
- Del Rosal JCC, del Rosal DEC, Ocerin JMC, Tabales JN (2019) Spanish real estate market: a tool for supply analysis. *Cuad Econ* 42(120): 207–218. <https://doi.org/10.32826/cude.v42i120.82>
- Dobbins A, Nerini FF, Deane P, Pye S (2019) Strengthening the EU response to energy poverty. *Nat Energy* 4(1):2–5
- Doukas, H., & Marinakis, V. (2020). Energy poverty alleviation: effective policies, best practices and innovative schemes.
- Ehsanullah S, Tran QH, Sadiq M, Bashir S, Mohsin M, Iram R (2021) How energy insecurity leads to energy poverty? Do environmental consideration and climate change concerns matters. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-021-14415-2>
- Halkos G, Paizanos E (2016) The effects of fiscal policy on CO2 emissions: Evidence from the USA. *Energy Policy* 88:317–328. <https://doi.org/10.1016/j.enpol.2015.10.035>
- Hsu CC, Quang-Thanh N, Chien F, Li L, Mohsin M (2021) Evaluating green innovation and performance of financial development: mediating concerns of environmental regulation. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-021-14499-w>
- Huang SZ, Chau KY, Chien F, Shen H (2020) The impact of startups' dual learning on their green innovation capability: the effects of business executives' environmental awareness and environmental regulations. *Sustainability* 12(16):1–17
- Iqbal S, Bilal AR, Nurunnabi M, Iqbal W, Alfakhri Y, Iqbal N (2021a) It is time to control the worst: testing COVID-19 outbreak, energy consumption and CO₂ emission. *Environ Sci Pollut Res* 28(15): 19008–19020
- Iqbal S, Taghizadeh-Hesary F, Mohsin M, Iqbal W (2021b) Assessing the role of the green finance index in environmental pollution reduction. *Stud Appl Econ* 39(3):4140
- Karpinska L, Śmiech S (2020) Conceptualising housing costs: the hidden face of energy poverty in Poland. *Energy Policy* 147:111819
- Kimanzi MK (2019) Education for sustainable development—economics students' perspectives at an institution of higher learning in South Africa. *Int J E-Bus E-Govern Stud* 11(1):53–68. <https://doi.org/10.34111/ijebe.20191114>

- Kulinska E (2017) Defining energy poverty in implementing energy efficiency policy in Bulgaria. *Econ Altern* 4:671–684
- Kyprianou I, Serghides DK, Varo A, Gouveia JP, Kopeva D, Murauskaite L (2019) Energy poverty policies and measures in 5 EU countries: a comparative study. *Energy Build* 196:46–60
- Lakatos E, Arsenopoulos A (2019) Investigating EU financial instruments to tackle energy poverty in households: a SWOT analysis. *Energy Sourc B Econ Plan Polic* 14(6):235–253
- Li W, Chien F, Hsu CC, Zhang Y, Nawaz MA, Iqbal S, Mohsin M (2021a) Nexus between energy poverty and energy efficiency: estimating the long-run dynamics. *Res Policy* 72:102063
- Li W, Chien F, Kamran HW, Aldeehani TM, Sadiq M, Nguyen VC, Taghizadeh-Hesary F (2021b) The nexus between COVID-19 fear and stock market volatility. *Economic Research-Ekonomika Istraživanja*:1–22. <https://doi.org/10.1080/1331677X.2021.1914125>
- Li W, Chien F, Ngo QT, Nguyen TD, Iqbal S, Bilal AR (2021c) Vertical financial disparity, energy prices and emission reduction: empirical insights from Pakistan. *J Environ Manag* 294:112946
- Lin B, Wang Y (2020) Does energy poverty really exist in China? From the perspective of residential electricity consumption. *Energy Policy* 143:111557
- Lowitzsch J, Hanke F (2019) Consumer (Co-) ownership in renewables, energy efficiency and the fight against energy poverty—a dilemma of energy transitions. *Renew Energy Law Polic Rev* 9(3):5–21
- Maxim A, Mihai C, Apostoae CM, Popescu C, Istrate C, Bostan I (2016) Implications and measurement of energy poverty across the European Union. *Sustainability* 8(5):483
- Muposhi A (2019) Emergence of green marketing capitalism in South Africa: implications for green economy agenda. *Int J Bus Manag Stud* 11(1):1–15
- Okushima S (2017) Gauging energy poverty: a multidimensional approach. *Energy* 137:1159–1166
- Othman Z, Nordin MFF, Sadiq M (2020) GST fraud prevention to ensure business sustainability: a Malaysian case study. *J Asian Bus Econ Stud* 27(3):245–265
- Pachauri S, Mueller A, Kemmler A, Spreng D (2004) On measuring energy poverty in Indian households. *World Dev* 32(12):2083–2104
- Phan LTC, Quang Thanh N (2019) Influence of new countryside construction program on household welfare: evidence from the Mekong River Delta of Vietnam. *AgBioForum* 21(3):1–14
- Phimister E, Vera-Toscano E, Roberts D (2015) The dynamics of energy poverty: evidence from Spain. *Econ Energy Environ Policy* 4(1):153–166
- PNIEC (2019) Energia e clima: pubblicato il piano nazionale (Pniec). Available from <https://www.ambientesicurezzaeb.it/energia-e-clima-pubblicato-il-piano-nazionale-pniec/>
- Primc K, Slabe-Erker R (2020) Social policy or energy policy? Time to reconsider energy poverty policies. *Energy Sustain Dev* 55:32–36
- Primc K, Slabe-Erker R, Majcen B (2019) Constructing energy poverty profiles for an effective energy policy. *Energy Policy* 128:727–734
- Robinson C, Lindley S, Bouzarovski S (2019) The spatially varying components of vulnerability to energy poverty. *Ann Am Assoc Geograph* 109(4):1188–1207
- Romero JC, Linares P, López X (2018) The policy implications of energy poverty indicators. *Energy Policy* 115:98–108
- Sadiq M, Hsu CC, Zhang Y, Chien FS (2021) COVID-19 fear and volatility index movements: empirical insights from ASEAN stock markets. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-021-15064-1>
- Sokolowski J, Lewandowski P, Kielczewska A, Bouzarovski S (2020) A multidimensional index to measure energy poverty: the Polish case. *Energy Sourc B Econ Plan Polic* 15(2):92–112
- Streimikiene D, Lekavičius V, Baležentis T, Kyriakopoulos GL, Abrhám J (2020) Climate change mitigation policies targeting households and addressing energy poverty in European Union. *Energies* 13(13):3389
- Thomson H, Bouzarovski S, Snell C (2017) Rethinking the measurement of energy poverty in Europe: a critical analysis of indicators and data. *Indoor Built Environ* 26(7):879–901
- Wang Q, Kwan MP, Fan J, Lin J (2021) Racial disparities in energy poverty in the United States. *Renew Sust Energ Rev* 137:110620
- Wu B, Liu S, Wang J, Tahir S, Patwary AK (2021) Assessing the mechanism of energy efficiency and energy poverty alleviation based on environmental regulation policy measures. *Environ Sci Pollut Res*: 1–13
- Xueying W, Sadiq M, Chien F, Ngo TQ, Nguyen AT (2021) Testing role of green financing on climate change mitigation: evidences from G7 and E7 countries. <https://doi.org/10.1007/s11356-021-15023-w>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.