Economic Research-Ekonomska Istraživanja

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rero20

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To cite this article: Jianjun Zhang, Syed Muhammad Faraz Raza, Yongming Huang & Cheng Wang (2023) What affect energy poverty in China? A path towards sustainable development, Economic Research-Ekonomska Istraživanja, 36:2, 2111316, DOI: 10.1080/1331677X.2022.2111316

To link to this article: https://doi.org/10.1080/1331677X.2022.2111316

Published online: 12 Sep 2022.

ECONOMIC RESEARCH-EKONOMSKA ISTRAŽIVANJA
2023, VOL. 36, NO. 2, 2111316
https://doi.org/10.1080/1331677X.2022.2111316

What affect energy poverty in China? A path towards sustainable development

Jianjun Zhang[a], Syed Muhammad Faraz Raza[b], Yongming Huang[b] and Cheng Wang[c]

[a]School of Economics and Management, Hubei University of Science and Technology, Xianning, China; [b]China Institute of Development Strategy and Planning, and Center for Industrial Economics, Wuhan University, Wuhan, China; [c]School of Low Carbon Economics, Center of Hubei Cooperative Innovation for Emissions Trading System, Hubei University of Economics, Wuhan, China

ABSTRACT

Despite the crucial role of investment in energy under public–private partnership (I.E.P.P.P.) in abating environmental pollution and reducing energy poverty (E.P.), the existing literature offers less information about the nexus between I.E.P.P.P. and E.P. In order to identify the E.P. gap based on accessibility, affordability, and availability dimensions, this study investigates the factors influencing E.P., and examines the impact of I.E.P.P.P., globalisation (G.L.O.), output (G.D.P.), risk, technological innovation (T.I.) and renewable energy consumption (R.E.C.) on E.P. in China during the period of 1990 to 2019. The causal relationship between E.P. with its determinants is also examined. Utilising fully modified ordinary least squares (F.M.O.L.S.) econometric approach, we find that investment in energy with a public–private partnership, T.I., and gross domestic product (G.D.P.) bridge the gap for E.P., whereas R.E.C., composite risk index (C.R.I.), and G.L.O. increase the E.P. gap in China. In addition, frequency Domain Causality test reveals that unidirectional causation from I.E.P.P.P., G.D.P., T.I., G.L.O., risk, and R.E.C. to E.P. in the short run to long run.

ARTICLE HISTORY
Received 30 March 2022
Accepted 5 August 2022

KEYWORDS
energy poverty; renewable energy consumption; investment; public–private partnership

JEL CODES
Q40; Q48

1. Introduction

Many worldwide development challenges regarding climate change, inequality, and poverty have relationship with energy. Energy poverty (E.P.) is one of the concerning issues of the current era. International organisations identify E.P. as inaccessibility and difficulty in affording energy services or new kinds of energy in modern times (International Energy Agency [IEA, 2019; UNDP, 2010). As the household barely receives the essential energy resources, the I.E.A. (2019) describes E.P. E.P. usually happens with low-income households who have less ability to afford renewable

CONTACT Yongming Huang hym@whu.edu.cn

energy resources. The unavailability of modern energy in developing countries leads to health and environmental issues. Moreover, Energy-poor economies seek to minimise energy scarcity through fossil-fuel subsidies. World Bank declared that the scarcity or inaccessibility of renewable energy leads to relying on fossil solid fuels which pollute indoor air and endanger human health (World Bank, 2017).

1.1. Overview of energy situation in China

As China has undergone strong economic growth over the past more than 40 years, China is the World's leading economy. China has organised market-oriented energy measures to provide vital energy to its industrial and household sectors. China has attained 99% of electrification since 2009 and aims to acquire 100% electricity access for its households to minimise E.P. (World Bank, 2017). The Figure 1 indicates that 98.39% of electricity is accessible to the population of China in 2018, which shows the high energy availability to its households. However, electric power losses are about 6.45% in transmission and distribution, which is less effective because the populace has a high electricity supply. China has attained high electricity access percentage, while the households rely on solid fuels such as coal and firewood (Tang & Liao, 2014), which is alarming for health and the environment (World Bank, 2017). China's technology implementation is essential for reducing energy scarcity, health, and climate change risks. About 51.88% of its population have access to clean fuels and technologies for cooking.

1.2. Consumption of modern energy in China

China's overall energy consumption is enormous as energy use in terms of kg of oil equivalent per capita was 2216.28 in 2018 and 767.00 in 1990. In comparison, its renewable energy consumption (R.E.C.) scores poorly and reduced from 34.08% in 1990 to 12.23% in 2018 (see Figure 2). As mentioned above, China's efficiency in

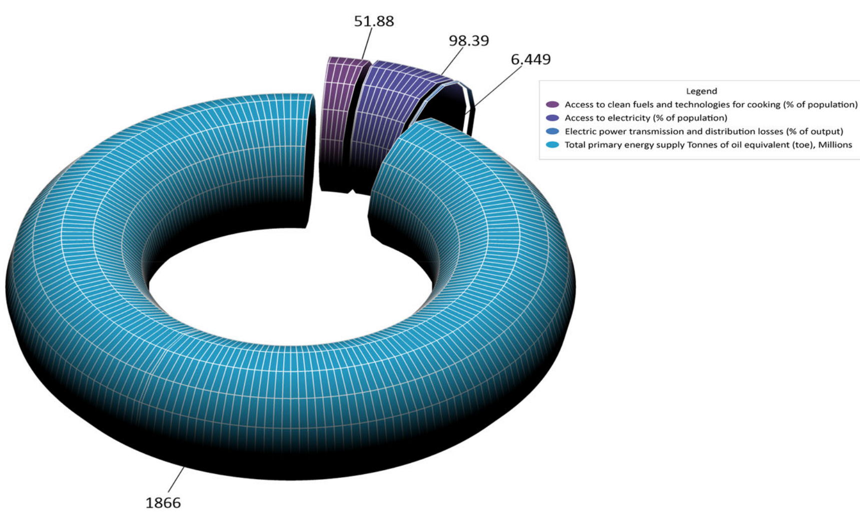

Figure 1. Energy situation in China (2018).
Source: Calculated by the authors.

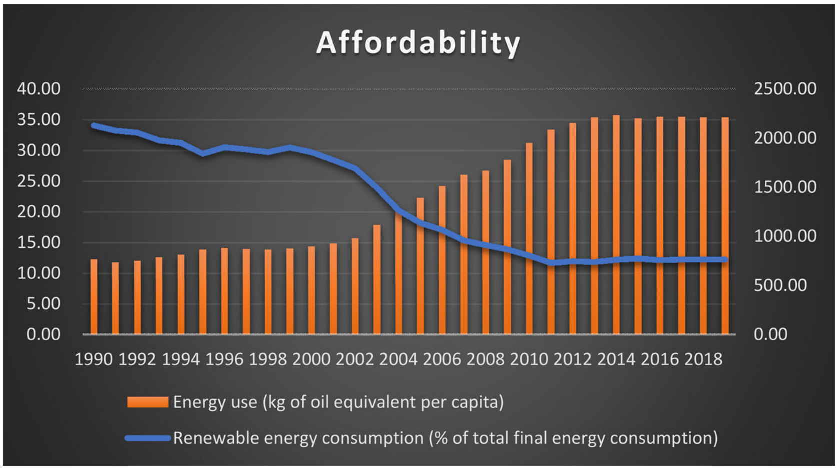

Figure 2. Affordability of energy in China (1990–2018).
Source: Calculated by the authors.

electrification still lacks renewables. China's electricity consumption per person has surpassed the average per capita of upper-middle-income countries, creating E.P. in China (World Bank, 2014). The fossil fuel subsidy to lessen E.P. may be the reason behind this renewable deficiency (One Earth, 2019). Moreover, renewable energy is the least affordable for low-income households as solid fuels are readily available at less cost. These consequences have affected the competency of R.E.C. in China. China is now implementing subsidies for renewable energy reforms to reduce energy scarcity and collaborating with the clean environment. Above all, installing solar panels on the roof of low-income households may alleviate E.P. and income poverty in China (One Earth, 2019).

1.3. Energy supply in China

China is counted as the leading energy supplier and has an ample energy supply. The total primary energy supply measured in tons of oil equivalent is from 873.64 million to 3076.09 million in 30 years. However, private participation is essential for E.P. alleviation by cutting down its costs. In China, private energy investment is substantial, and the average investment was 2178.97 million dollars annually during the past 30 years (World Bank, 2018). Figure 3 shows on and off investments in energy by private participation. It is observed that high private investments in energy occurred in some years, such as 1997, 1999, 2003, 2013 and 2016.

In contrast, it is recorded as very low in 2010 and 2018. Still, China has maintained its private participation in energy at the admired level to combat E.P. The past study favours that private investment can reduce costs, maximise benefits, and open up new projects and promotions in large projects like renewable systems (Bhide & Monroy, 2011). Energy consumption in other sectors as the ratio of total energy consumption was 53.06% in 1990, and this ratio had started to go down afterwards. It had a slight uprising interval during the period of 2012 and 2018, stable at above

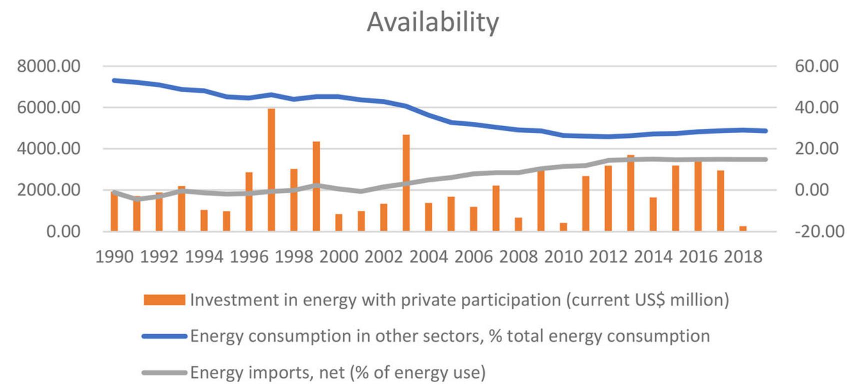

Figure 3. Availability of energy in China (1990–2019).
Source: Calculated by the authors.

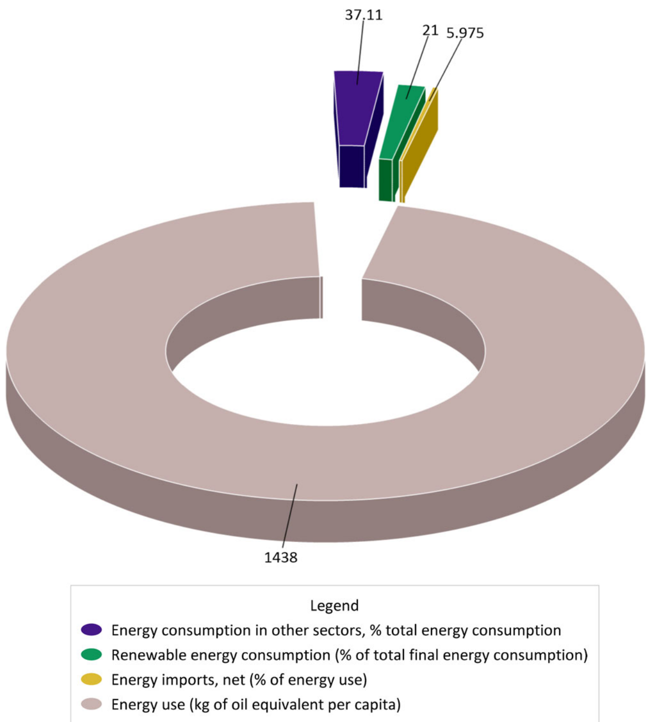

Figure 4. Average energy consumption in China (1990–2019).
Source: Calculated by the authors.

25% and recorded 28.67% in 2018. However, in Figure 4, the overall average percentage of energy consumption in other sectors was about 37.11% from 1990 to 2018.

Besides, energy import had also proliferated, witnessing an average of above 14% during the period of 2015–2019 and 14.83% in 2018 (see Figure 3). However, in Figure 4, the average net energy import is about 5.98% during the period of between 2012 and 2018. China has started implementing renewable systems to enhance R.E.C. so as to clean the environment and reduce energy scarcity. The average consumption

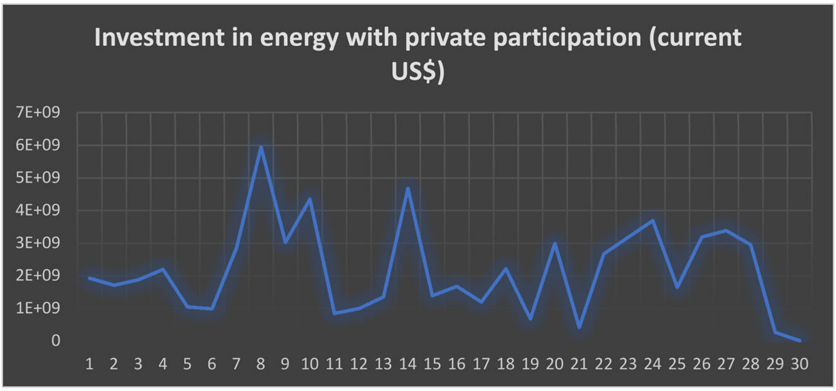

Figure 5. Investment in energy with public–private partnership (1990–2019).
Source: Calculated by the authors.

of renewable energy is 21%, and the total consumption of energy is about 1438 kg of oil equivalent (World Bank, 2018). The public–private investment in energy has shown many fluctuations in the past 30 years (see Figure 5). Its stable input can reduce energy scarcity, but need government supports. However, a massive reduction in public–private energy investment in the last three years appeared in Figure 5. The previous study favours the public–private investment providing essential energy to the energy-poor (Abbas et al., 2020).

This study aims to identify E.P. gap based on accessibility, affordability and availability dimensions. The key emphasis is on reducing energy shortages in China. Hence, we investigate the factors influencing E.P. in the case of China over the period of 1990 to 2019. The impact of investment in energy under public–private partnership (I.E.P.P.P.), globalisation (G.L.O.), output (gross domestic product [GDP]), risk (C.R.I.), technological innovation (T.I.) and R.E.C. on E.P. is examined. Moreover, this study examines the causal relationship between E.P. with its determinants such as public–private partnership (I.E.P.P.P.), G.L.O., G.D.P., risk (C.R.I.), T.I. and R.E.C. for China. Thus, in terms of energy scarcity in China, it is worthwhile to assess renewable energy effects. Besides, the study would have policy consequences for the public–private investment in energy and renewable energy, rendering it more valuable for E.P. alleviation.

Hence, this study makes several interesting contributions to the existing body of literature on environmental sustainability. First, the empirical contribution of this work lies in using comprehensive proxies for E.P. gap. This study uncovers the identification of E.P. gap based on accessibility, affordability, and availability dimensions in the case of China, which has never been identified before. This approach enables us to estimate different aspects of E.P. Most of the previous studies on E.P. suffer from narrow definition of E.P. Second, the regression model of this endeavour departs from the previous studies, which did not consider the role of G.L.O., risk and T.I. in the examination of the nexus between investment in energy and the E.P. gap. We make an important contribution to environmental sustainability by offering the first study on the impact of investment in energy on E.P. in case of China. Third, from a practical perspective, the study highlights factors which affect China's E.P. gap with the significance of benefiting the Chinese authorities to devise strategy for bridging the E.P. gap.

The remainder of the study is structured as follows. Section 2 provides a review on relevant literatures. Section 3 discusses methodology. Section 4 reports and discusses the main results and Section 5 contains our conclusions and relative policy implications.

2. Literature review

Although E.P. is one of the big issues in developing economies, there is no standard definition of E.P., with the conditions different from region to region. In assessing the E.P. threshold, no widely used approaches exist. Researchers thus prefer to use various metrics to construct the assessment method. The I.E.A. describes the incompetence of access to modern, clean energy, electricity or conventional biomass as E.P. (IEA, 2002), which is extensively accepted. Bhide and Monroy (2011) agreed with the I.E.A. statement and discussed E.P. as the central issue. Management is incompetent to access unrealistic goals like implementing electricity policies and renewable energy technologies and coping with E.P. However, in rural areas, the households relying on solid fuels such as wood and some other biomass fuels for energy supply is then evidence of E.P. Simultaneously, the energy shortage has been an issue in rural areas for both households and industries for years, as the local demand increases and the rural areas cannot meet the increased energy demand (Kaygusuz, 2011). Sesan (2012) stated that E.P. is inaccessible to modern energy sources for households in developing countries and their corresponding dependence on solid cooking biofuels.

E.P. is an issue with household economic circumstances, life, and energy prices (EPEE, 2006; Liddell et al., 2011). It has been found that the low household income intensifies E.P. (Healy & Clinch, 2004). However, in a description of E.P. or fuel poverty, basic living energy prices are above the social average, and residual income is below the authorised or professional economic poverty line (Hills, 2011). The households' incomes and the percentage spent on accessing energy or fuels are associated with the budget standard approach. The fuel poverty approach is directed to households that can bear their fuel cost less (Moore, 2012). Li et al. (2015) analysed rural household energy consumption and renewable energy systems in Zhangziying town of Beijing, and found that coal covers the most significant share of household energy usage and the requirement for household heating in winter. Renewables, such as biogas and straw gas, have simultaneously substituted coal, firewood, and L.P.G., shielding the energy scarcity and saving the atmosphere. However, a modern form of renewable energy often has good efficiency, sustainability, adequacy, and convenient access. Anyway, affordability comes first. The households are unable to afford expensive modern energy sources, and E.P. harms households' living standards. In India's urban areas, E.P. is exacerbated by the deficiencies in modern cooking and illumination fuels. Moreover, the energy scarcity is subdivided into three groups; transitional and moderate energy poor, and extremely poor in energy to access the exact energy deprivation. The findings revealed the shortfall in modern cooking and illumination fuels and the intensity of E.P. are among the extremely poor. However, the extreme energy-poor is amongst the entire population who is unable to afford the high energy costs (Nathan & Hari, 2020).

The developing countries lack research and development, technology and innovation, and other modern system aspects. The emerging nations are trying to employ renewable resources to meet sustainable energy and cover E.P., but it is hard to afford for struggling economies whose household incomes are low. The reason why reliance on solid energy is most significant lies in it covers household energy demand for living with less cost. China relies heavily on solid energy even though its rural area attained 100% electrification in 2014. Statistics indicate that 490 million Chinese citizens rely heavily on solid energy, coal and firewood for household living, i.e., cooking and heating (Tang & Liao, 2014). A nationwide household survey in 2016 shows that 30% of Chinese households depend on solid fuels. In contrast, that percentage in rural area of China is much higher (Xie & Hu, 2014). However, China still has E.P. problems in rural and urban households. The low-income households accept the contemporary energy forms but are unable to afford high energy costs (Yang & Mukhopadhaya, 2017). According to a survey, 46% of households lack modern energy, and a substantial number of households are deemed less competitive for energy prices and fall in E.P. Central China has a high E.P. rate at contemporary energy prices, while there is E.P. in Western China. Lin and Wang (2020) emphasised low-income households are suffering from E.P. and need to enact policies. Social and economic factors, such as house size, family size, schooling, occupation, and household head also affect energy scarcity. The family head is critical for getting over E.P. since men usually earn more than women. The house's ownership status is also essential for E.P. because rental status takes a more substantial and significant effect on E.P. (Abbas et al., 2020).

Household's cooking and heating reliance on solid fuel has enhanced the risk of respiratory disease and deaths in low-income countries (World Health Organization (WHO, 2007a, 2007b). E.P. is not explicitly linked with mortality but triggers associated illnesses that reflect the detrimental health consequences of E.P. (Wilkinson et al., 2007). According to previous studies, E.P. has a major impact on human being health. Solid fuel reliance has exaggerated anthropogenic pollutants and induced indoor air contamination, responsible for inadequate health standards (Lacey et al., 2017). Unreliable indices of E.P., incapability, and inadequate access to renewable energy sources damage emerging economies. China's household reliance on solid fuels such as coal and firewood is high, resulting in indoor air pollution and affecting household health (Zhang et al., 2019). China has established a market-driven modern energy source but has not solved the E.P. crisis yet. Solid or non-renewable sources still plays a significant role in China. Other determinants, including household wages, health, and environmental measures not synchronised with E.P., need further investigation in China's context.

Most industrialised economies have taken important steps to cope with environmental and economic challenges. These steps include the transformation of industrial structure from non-renewable to renewable energies (Huang et al., 2022). For such transformation, I.E.P.P.P. is considered as crucial. Also, investment in energy under I.E.P.P.P. plays a critical role in abating environmental pollution and reducing E.P.

However, the existing literature offers but less information about the nexus between investment in energy under I.E.P.P.P. and E.P. This study adds something new to the existing literature by investigating the impact of I.E.P.P.P., along with G.L.O., GDP, risk, T.I. and R.E.C. on E.P. in case of China. To our knowledge, no study till now has been conducted to examine these important determinants of E.P.

3. Methodology

3.1. Theoretical framework

Figure 6 presents the conceptual basis for the nexus proposed in this paper. The main aim of this study is to find out the impact of investment in energy under I.E.P.P.P. on E.P. in case of China. I.E.P.P.P. is the energy sector reform which would improve environmental quality by reducing carbon emissions. In green energy finance, the I.E.P.P.P. is a useful aspect as it overwhelms the contraction in public financing and enables energy facilities production. Hence, we expect a negative impact of I.E.P.P.P. on E.P.

Following Wang et al. (2022), this study uses T.I. as important explanatory variable in the model of E.P.. T.I. is the modern and revamped process to increase productivity that advances the standard of living and can strengthen long-term economic

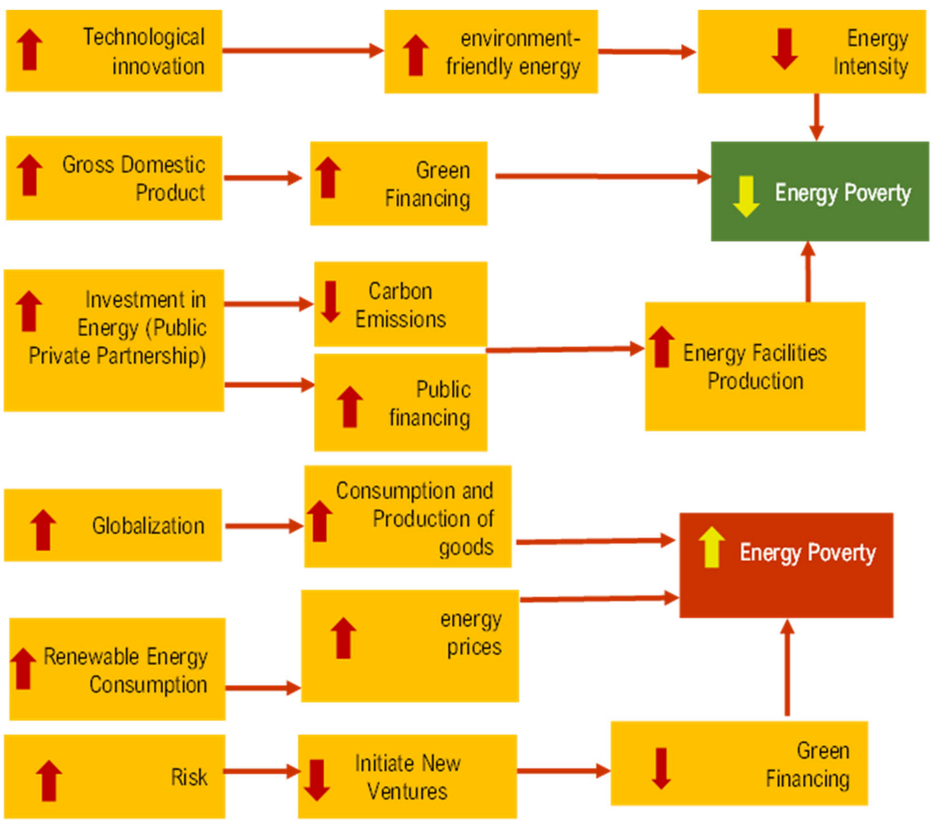

Figure 6. The theoretical framework.

Table 1. Weights for Energy Poverty Index.

No.	Indicators	W_1	W_2	W_3
1	Total Population with access to electricity (%)	0.5	0.25	0.4
2	Access to clean fuels and technologies for cooking (% of population)	0.5	0.25	0.4
3	TPES per capita (TPES pc)	0	0.25	0.1
4	TFEC per capita (TFEC pc)	0	0.25	0.1

Note: TPES is total primary energy supply. TFEC is total final energy consumption.
Source: World Bank (2020).

prosperity. T.I. in the energy sector can augment energy resources, enhance energy services quality, provide environment-friendly energy, and tackle E.P. by covering economic costs. Renewable energy as carbon-neutral forms obtained from renewables are naturally replenished on a human scale.

Following Zhao et al. (2022), this study uses G.L.O. as an important explanatory variable in the model of E.P. G.L.O. involves expanding movements and interactions of human beings, products and resources, assets, technology and cultural norms worldwide. One of G.L.O.'s consequences is it facilitates and strengthens the relations between distinct regions and communities worldwide. The World Trade Organization (WTO) defined G.L.O. into two elements. First, foreign boundaries open quickly to transfers of products, resources, finance, citizens, and thought. Second, reforms to national and international structures and policies encourage or foster those flows. G.L.O. measures include both de jure and de facto. Hence, we expect that G.L.O. will lead to reducing E.P. in China.

Following Wang et al. (2022), this study uses renewable energy as important explanatory variable in the model of E.P. Renewable energy is renowned as green energy or sustainable energy. Renewable energy reforms can hinder the quality of the atmosphere and also can reduce E.P. Hence, we expect that R.E.C. enhances E.P. in China.

To create an index to determine the extent of E.P., we constructed the 'weighted average of the four E.P. indicators' (W.A.E.P.I.). We used three different weight sets (W_1, W_2 and W_3) to represent different scenarios (Table 1).

Three weight sets are used to measure E.P.

We construct W.A.E.P.I. as follows:

$$\mathrm{WAEPI_{year}} = \sum (\mathrm{W_1{*}Access\ to\ electricity_n} + \mathrm{W_2{*}Access\ to\ modern\ fuel_n} + \mathrm{W_3{*}TFEC_{pc,n}} + \mathrm{W_4{*}TPES_{pc,n}})$$

where n = Normalised indicator (Figure 7).

We obtained the Composite Energy Poverty Index for identifying gap (C.E.P.I.) in the following way:

C.E.P.I. for a country = 100 – W.A.E.P.I.

Considering accessibility (i.e., W_1), the numbers are bigger for all years and have significantly improved from 2001.

With equal weight to all the parameters (i.e., W_2), the E.P. index reduces to a deficient number. Equal weight exaggerates the E.P. situation.

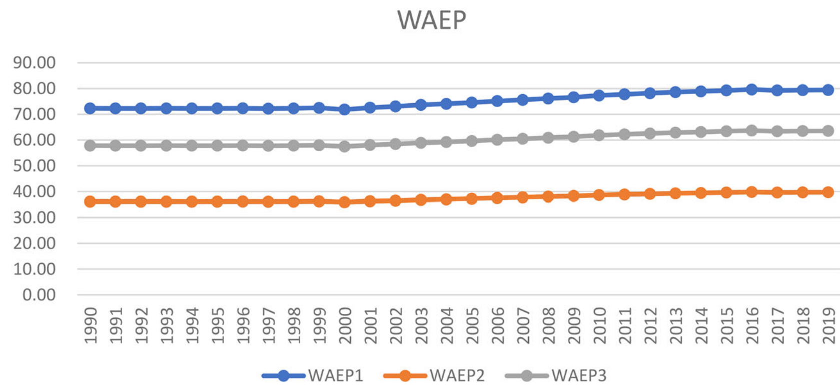

Figure 7. Weighted Average Energy Poverty Index for China.
Source: Calculated by the authors.

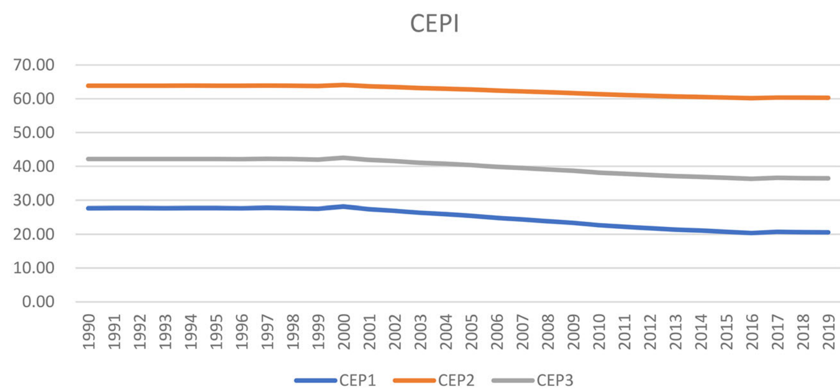

Figure 8. Composite Energy Poverty Index for Gap (CEPI) for China.
Source: Calculated by the authors.

With unequal weightage (i.e., W_3), we gave more importance to accessibility but did not ignore the role of affordability and availability, thus arriving at a balanced index (Figure 8).

With either of the weights, the most energy poor is in 1990 while the least is in 2019. Comparing these years, all terms of energy availability, accessibility, and affordability have improved.

3.2. Model specification

$$EP_t = f(GDP, IEPPP, \ REC, \ TI, \ GLO, \ CRI) \tag{1}$$

In Equation (1), E.P. is measured through three different composite energy poverty (C.E.P.) indexes for identifying gaps. All three models are given below as:

$$CEP_{1,t} = f(GDP, IEPPP, \ REC, \ TI, \ GLO, \ CRI) \tag{2}$$

$$CEP_{2,t} = f(GDP, IEPPP, \ REC, \ TI, \ GLO, \ CRI) \tag{3}$$

Table 2. Definitions and sources of data.

Variables	Definitions	Sources
CEP_1, CEP_2, CEP_3	As mentioned above, composite indexes for energy poverty are created based on methodology.	World Bank, World Development Indicators (World Bank, 2020)
GDP	Unit of GDP calculation in this research is taken as Constant US Dollars 2010.	World Bank, World Development Indicators (World Bank, 2020)
IEPPP	IEPPP attributes as an investment in energy in private-public partnership. IEPPP is the energy sector reform, and it improves environmental quality by reducing carbon emissions.	World Bank, World Development Indicators (World Bank, 2020)
REC	Renewable energy consumption aspects as carbon-neutral forms and coming from naturally replenished on a human scale. Renewable energy is renowned as green energy or sustainable energy.	World Bank, World Development Indicators (World Bank, 2020)
TI	Technological innovation is assessed as the number of patents both by residents and non-residents	World Bank, World Development Indicators (World Bank, 2020)
CRI	Composite risk index (CRI) is a compound risk value that aggregates into an index of political, Financial, and Economic risk.	https://www.prsgroup.com/explore-our-products/international-country-risk-guide/
GLO	Globalisation measures include both de jure and de facto. De jure globalisation measures policies, resources, conditions, and institutions that enable or facilitate actual flows and activities. However, De facto globalisation deals with actual flows and activities. Most of the globalisation indices focus on De facto globalization.	https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html

Source: World Bank (2020).

$$CEP_{3,t} = f(GDP, IEPPP, \ REC, \ TI, \ GLO, \ CRI) \tag{4}$$

In Equations (2) to (4) CEP_1, CEP_2 and CEP_3 index for E.P. gap measuring accessibility, availability and affordability gaps, respectively. Definitions and sources of each variable are provided in Table 2.

C.E.P. = Composite index for energy poverty showing the gap.

GDP = gross domestic product

C.R.I. = composite risk index includes financial risk, economic risk and political risk

R.E.C. = renewable energy consumption

T.I. = technological innovation

G.L.O. = globalisation

I.E.P.P.P. = investment in energy with public–private partnership

Data Time Period: 1990–2019, Country: China

3.3. Econometric techniques

3.3.1. Narayan and Popp unit root test with structural break

The Narayan and Popp (2010) structural break test units were established by Paresh Kumar Narayan and Stephan Popp for stationarity affirmation of each series. To avoid spurious regression regarding the non-stationary, orders I(0) or I(1) integrated or mixed integrated variables ought to arise. The unit root test is also central for verifying not series I(2) or higher. So with two structural breaks, we use the latest unit root assessment (Narayan & Popp, 2010). This root unit structural break test is compatible and differentiates the actual dates of splits. This newest unit root test for structural breaks includes two models to validate stationarity orders: model 1 is intercept-related and facilitates structural intercept breaks. In contrast, model 2 permits intercept and slope structural breaks. Below are the two model equations for the Narayan and Popp (2010) unit root test:

Model 1

$$X_t = K + \alpha_1 X_{t-1} + \alpha_2 t + \beta_1 D(T_B)_{1,t} + \beta_2 D(T_B)_{2,t} + \eta_1 DU_{1,t-1} + \eta_2 DU_{2,t-1} + \sum_{i=1}^{P} \delta i \Delta X_{t-1} + \varepsilon_{1t} \quad (1)$$

Model 2

$$X_t = K + \alpha_1 X_{t-1} + \alpha_2 t + \beta_1 D(T_B)_{1,t} + \beta_2 D(T_B)_{2,t} + \eta_1 DU_{1,t-1} + \eta_2 DU_{2,t-1} + \gamma_1 DT_{1,t-1} + \gamma_2 DT_{2,t-1} + \sum_{i=1}^{P} \delta i \Delta X_{t-1} + \varepsilon_{2t} \quad (2)$$

Here, X_t represents all the included variables, and Δ with (X_t, X_{t-i}) shows the first difference with ε_{it} error term in both model's equations. $\sum_{i=1}^{P} \delta_i \Delta X_{t-i}$ is the dependent variable's first difference lagged to eradicate the serial correlation. Model 1 equation reflects dummy variables in intercept as DU_1 and DU_2 progress in time T_{B1}, T_{B2} to hook promising structural breaks. Model 2 equation imitates the dummy variables as DU_i and DT_i, $i = 1,2$ progressing in time T_{B1}, T_{B2} to permit intercept and slope structural breaks. However, the unit root null hypothesis alongside the unit root alternative hypothesis refers to the t-statistics of X_{t-1}.

3.3.2. Cointegration tests

3.3.2.1. Maki (2012) cointegration test. In contrast to earlier Gregory and Hansen (2009) and Hatemi-J (2008), Maki (2012) is ideally used for cointegration while structural breaks are valued. Maki's procedure of cointegration permits multiple structural breaks, permitting up to five unforeseen structural breaks in cointegration processing. We also progress the regime approach consists of level shift with trend and regime shift with trend. This approach sanctions structural breaks in levels (υ) and regressors (δ) in level shift with trend which also refers to regime shift, while regime shift approach with trend has structural breaks (ρ), levels (υ) and regressors (δ). Furthermore, the existing test survives on the basis of the null hypothesis (support no cointegration existence) and the alternative hypothesis (support cointegration existence). The equation of Maki cointegration test with regime approach is as follows:

Equation of Level Shift with Trend

$$Y_t = \upsilon + \sum_{i=1}^{k} \upsilon i Z_{it} + \varphi \delta_t + \sum_{i=1}^{k} \varphi \delta i Z_{it} + \varepsilon_t \quad (3)$$

Equation of Regime Shift with Trend

$$Y_t = \upsilon + \sum_{i=1}^{k} \upsilon i Z_{it} + \rho t + \sum_{i=1}^{k} \rho it Z_{it} + \varphi \delta_t + \sum_{i=1}^{k} \varphi i \delta i Z_{it} + \varepsilon_t \quad (4)$$

Here, Y_t is a dependent variable, δ_t shows the series of regressors, and t specifies the time. However, structural breaks denoted by ρ, levels with υ, and ε_t with disturbance term. Z_{it} value is 0 if time periods are less than structural breaks periods ($t < TB_i$), while Z_{it} value is 1 if time periods are greater than structural breaks periods ($t > TB_i$). This Maki (2012) model will identify the structural breaks and cointegration among variables.

3.3.2.2. Bayer–Hanck cointegration test. This Byer–Hanck (2013) cointegration test is a joint integration process in which integration of series should be I(1) (Bayer & Hanck, 2013). In the collaborative integration process, it includes the outcomes of EG (Engle & Granger, 1987), J (Johansen, 1991), Bo (Boswijk, 1994) and Ba (Banerjee et al., 1998). The critical value should be less than F-statistics (F-stat > Critical value) to repudiate the null hypothesis of no cointegration. There are two steps of this cointegration test; step 1 contains EG-J values, and step 2 consists of EG-J-Bo-Ba values to deny the null hypothesis.

Step-1

$$\text{EG-J} = -2[\ln(P_{EG}) + \ln(P_J)] \quad (5)$$

Step-2

$$\text{EG}-\text{J}-\text{Bo}-\text{Ba} = -2[\ln(P_{EG}) + \ln(P_J) + \ln(P_{Bo}) + \ln(P_{Ba})] \quad (6)$$

3.3.3. Fully Modified OLS

The Phillips and Hansen (1990) development of fully modified ordinary least squares (FMOLS) enables long-term accurate and efficient estimators since it is semi-parametric. O.L.S. estimators are typically prejudiced and unreliable, F.M.O.L.S. addresses nuisance parameters and manages biased endogeneity and serial correlation. The FMOLS equation is this:

$$\beta_{i*} = (\acute{X}_i X_i) - 1(\acute{X}_i y_{i*} - T\delta) \quad (7)$$

Here, the consistent parameter indicates $\beta_i{}^*$, while the endogenous variable in the transformed form refers to y^*. However, the adjustment parameter of autocorrelation is denoted by δ and T is for the time period. Equation (7) is employed to cover biased endogeneity and serial correlation problems.

3.3.4. Frequency domain causality

Finally, we evaluate the causation interaction and assess parameter stability models using the Breitung and Candelon (2006) spectral granger-causality test. Equated with the traditional Granger causality test, this analysis's measurement approach enables the estimation of the response variable with specific time frames. This indicates that there are historical shifts in policy intervention, which means policy actions will be enacted across historical shifts. However, the method only applies to a finite time scale, so infinite horizon models are not anticipated. The equation of frequency domain causality is the following equation:

$$x_t = \alpha_1 \chi_{t-1} + \ldots + \alpha_p \chi_{t-p} + \beta_1 Y_{t-1} + \ldots + \beta_p Y_{t-p} + \varepsilon_t \quad (8)$$

In Equation (8), the linear constraint leads to a null hypothesis $M_{y \to x}(\omega) = 0$. The evaluated parameters, though, are α's and β's in time t. The lag is symbolised by p, and an error term by ε_t.

4. Results and discussions

4.1. Results

This section discusses the outcomes based on renewable energy and public–private energy investments to limit China's E.P. However, G.L.O., T.I., and GDP also reduce E.P. This study also contains the composite risk, including economic, financial, and political, all matters in energy generation to limit China's E.P. To evaluate these variables, the first step is unit root testing to measure the integration order of variables, leading us to further long-run investigation. The shock in the economy, such as economic and financial shock, is observed by structural break in the Narayan and Popp unit root test. The structural breaks of 2000 and 2008 for I.E.P.P.P. indicate economic reforms started of 2000 and 2008 respectively. During these periods, China invested billions of yuan to strengthen the energy sector. Similarly, structural breaks of 2001 and 2009 for G.L.O. indicate China's joining in the W.T.O. in 2001 and financial crises in 2009. The structural break of 1998 represents the financial crises during the period. The structural break of 2013–2014 represents the oil shock. The structural break for 1992, 2008 and 2010 represent market based economic reforms implemented by the Chinese government in 1992, the global financial crisis of 2007–2008 and the stimulus package announced by the government of China in 2010.

Table 3 shows the outcomes of the Narayan and Popp (2010) unit root test. This latest unit root test has variable integration order and two structural breaks. I.E.P.P.P. is integrated at the first difference I(1) with 2000 and 2008 structural breaks. G.L.O.

Table 3. Narayan and Popp (2010) unit root test.

	I(0)		I(1)		
Variables	Level	Trend and level	Level	Trend and level	Structural breaks
IEPPP	−1.425	−2.343	−5.760***	−6.767***	2000–2008
GLO	−4.134	−6.883***	−7.945***	−8.239***	2001–2009
TI	−2.569	−0.7031	−4.525**	−7.123***	2003–2007
REC	−4.386*	−4.162	−5.574***	−6.325***	2002–2012
CRI	−3.859	−5.987***	−9.527***	−12.648***	2002–2005
GDP	−4.042	−5.243**	−4.607**	−5.390**	2001–2008
CEP_1	−4.007	−3.595	−7.842***	−8.223***	1998–2013
CEP_2	−3.759	−2.278	−6.350***	−7.139***	2005–2008
CEP_3	−3.851	−2.780	−6.108***	−6.888***	2005–2008

Note: *, ** and *** represent significance level 10%, 5% and 1%, respectively.
Source: Calculated by the authors.

Table 4. Cointegration results.

Dependent variable (s) Maki (2012)					
CEP_1		CEP_2		CEP_3	
Level shift with trend	Trend and regime shift	Level shift with trend	Trend and regime shift	Level shift with trend	Trend and regime shift
−9.451***	−8.888***	−10.91***	−8.329***	−9.239***	−8.161***
Structural breaks					
1996–2001–2008		1993–1998–2008		1998–2005–2008	
Bayer–Hanck Test (2013)					
EG-J	EG-J-Bo-Ba	EG-J	EG-J-Bo-Ba	EG-J	EG-J-Bo-Ba
58.86**	114.51***	58.59***	114.31***	58.70***	114.38***
Critical value at 5% for each test is 10.352 and 19.761, respectively.					

Note: *, ** and *** represent significance level 10%, 5% and 1%, respectively.
Source: Calculated by the authors.

is integrated at level I(0), but more significance at first order and integrated order is taken I(1) with structural breaks 2001 and 2009. T.I. is integrated at the first difference I(1), and its structural breaks are 2003 and 2007. R.E.C., Composite risk index (C.R.I.), and Economic growth as GDP are integrated at a level but more effective at first difference. Integration order is taken at I(1) with structural breaks 2002 and 2012 for R.E.C., 2002 and 2005 for C.R.I., 2001 and 2008 for GDP. However, a composite index for E.P. CEP_1, $CEP_{2,}$ and CEP_3 are integrated at first difference I(1) with structural breaks 1998 and 2013 for CEP_1, 2005 and 2008 for both CEP_2 and CEP_3. The Narayan and Popp (2010) unit root test has shown the same orders of integration I(1) among variables, which led this research to follow the cointegration testing and F.M.O.L.S. for the long run.

Table 4 consists of two cointegration tests, i.e. Maki (2012) and Bayer–Hanck (2013) cointegration test. Maki cointegration test allows cointegration to accept the alternative hypothesis and permits multiple structural breaks. In Table 4 of Maki (2012) cointegration analysis, cointegration exists for all C.E.P.'s in both level shifts with trend and regime shift with trend. CEP_1, CEP_2 and CEP_3 are cointegrated at 1% in both level shifts with the trend and regime shift with trend. The findings also permit structural breaks of 1996, 2001 and 2008 for CEP_1, 1993, 1998 and 2008 for CEP_2, 1998, 2005 and 2008 for CEP_3. After this, Bayer–Hanck (2013) cointegration test is applied, which is the combined effect of EG (Engle & Granger, 1987), J (Johansen, 1991), Bo (Boswijk, 1994) and Ba (Banerjee et al., 1998). In the first step of EG-J, the F-statistics values of CEP_1 CEP_2 and CEP_3 are greater than 5% critical value and comprehensively reject the null hypothesis of no cointegration. In the second step of EG-J-Bo-Ba, the F-statistics significant values are greater than 5% critical value, repudiate the null hypothesis, and admit the existence of cointegration in all $CEP_{1,}$ CEP_2 and CEP_3. The results of both Maki (2012) and Bayer–Hanck (2013) expose cointegration, which permits the long run existence and refers to F.M.O.L.S. for the long run estimation.

The long run results of determinants of E.P. have been listed in Table 5. The results suggest that I.E.P.P.P., T.I., GDP, R.E.C., G.L.O. and C.R.I. are important variables influencing E.P. The overall findings of F.M.O.L.S. have shown that GDP, T.I.

Table 5. Fully Modified OLS (FMOLS).

Variables	CEP_1 Coefficients [Std.Error]	CEP_2 Coefficients [Std.Error]	CEP_3 Coefficients [Std.Error]
GDP	−0.051708***	−0.007233**	−0.020938**
	[0.016494]	[0.003162]	[0.007993]
CRI	0.000960***	0.000171***	0.000446***
	[0.000194]	[3.71E-05]	[9.39E-05]
REC	0.087942***	0.021280***	0.049908***
	[0.009921]	[0.001902]	[0.004807]
TI	−0.062185***	−0.011725***	−0.029892***
	[0.007477]	[0.001433]	[0.003623]
GLO	0.002550***	0.000445***	0.001172***
	[0.000277]	[5.31E-05]	[0.000134]
IEPPP	−0.002428**	−0.000406**	−0.001086**
	[0.001003]	[0.000192]	[0.000486]
C	2.058470***	1.885406***	1.864597***
	[0.177759]	[0.034072]	[0.086139]

Note: *, ** and *** represent significance level 10%, 5% and 1%, respectively.
Source: Calculated by the authors.

and I.E.P.P.P. have reduced E.P. in China in the long run. Nevertheless, China's E.P. has been further enhanced by its C.R.I., R.E.C. and G.L.O.

The coefficient value of the investment in energy by private-public participation (I.E.P.P.P.) for CEP_1 is −0.002, CEP_2 −0.000 and CEP_3 is −0.001, which indicates the negative influence on E.P. The improved public–private participation in energy investment has resolved China's E.P. This analysis is identical to previous research; energy investment by private–public participation provided the elemental energy requirements to the energy poor (Abbas et al., 2020).

In modern society, clean energy needs leading economies to protect the environment and limit E.P. Renewable energy refers to clean energy, and its implementation is China's leading reform to eliminate energy scarcity. The coefficient value of R.E.C. for CEP_1 is 0.087, for CEP_2 0.021 and for CEP_3 is 0.049, which positively influenced E.P. These findings support the earlier findings of Zhao et al. (2022) and Wang et al. (2022).

China's T.I. is essential to minimise the risk of energy shortages and climate change. Access to renewables and technologies for cooking contributes to their communities, comprising about 51.88% of the population (World Bank, 2018). The coefficient of T.I. for CEP_1 is −0.062, CEP_2 is −0.011 and CEP_3 is −0.029, negatively influencing E.P. These findings support the earlier findings of Zhao et al. (2022) and Wang et al. (2022).

China is now the global leader of economic interaction and G.L.O., and is seeking to extend its operations across the globe. One example is the Belt and Road Initiatives, which focuses on connecting a wide range of nations to the regions and is one of the factors for the rise in G.L.O. China and G.L.O., which has been going on for a long time, are no strangers. Chinese markets are developing new investment prospects, and the global economy appears to be turning its attention to China. The shift towards China, however, induces energy scarcity. The coefficient values of G.L.O. towards the composite index for E.P. are CEP_1 0.002, CEP_2 0.000, and CEP_3 0.001, which increase E.P. in China. China is in the midst of electrifying and introducing clean energies, and the energy shortages still take

Table 6. Frequency domain causality.

	CEP_1			CEP_2			CEP_3		
Variable(s)	0.05	1.50	2.50	0.05	1.50	2.50	0.05	1.50	2.50
GDP	9.13**	10.27***	10.26***	9.50***	10.31***	10.33***	9.36***	10.32***	10.31***
TI	5.65*	5.67*	5.62*	5.33*	5.35*	5.70*	5.46*	5.41*	5.63*
GLO	11.40***	11.49***	11.35***	11.89***	11.36***	11.52***	11.72***	11.73***	11.79***
CRI	7.25***	6.12**	6.34**	7.48***	6.35**	6.42*	7.41***	6.28**	6.21**
IEPPP	4.76*	4.64*	4.71*	4.87*	4.80*	4.73*	4.61*	4.64*	4.71*
REC	19.26***	19.23***	19.27**	11.05***	18.45***	18.43***	11.43***	18.78***	18.75***

Note: *, ** and *** represent significance level 10%, 5% and 1%, respectively.
Source: Calculated by the authors.

considerable time to be alleviated. In this situation, it's too early to anticipate G.L.O.'s assenting to limit China's E.P. These findings support the earlier findings of Zhao et al. (2022).

The coefficients of C.R.I. towards the composite index for E.P. are −0.051 (CEP_1), −0.007 (CEP_2) and −0.020 (CEP_3), which suggest that GDP has a substantial and detrimental effect on China's E.P. The results have shown that GDP has performed its role in limiting E.P. in China's long-term. These findings support the earlier findings of Zhao et al. (2022) and Shahbaz and Feridun (2012).

The GDP for CEP_1, CEP_2 and CEP_3 are 0.001, 0.0002 and 0.0004 positively influencing China's E.P. in the long run. This C.R.I. refers to economic, financial and political risks that illustrate less effectiveness in limiting E.P. The collective participation of the financial, economic, and political sectors is essential to initiate new ventures. Suppose any sector is less competitive, or in doubt, it is not easy to progress. In this scenario, China's financial, economic, and political sectors seemed reluctant to make any mutual risks to ensure minimal E.P. Abbas et al. (2020) manifested economic factors seemed effective in reducing E.P.

Table 6 explores the findings of the Breitung and Candelon (2006) frequency domain causality test. The frequency-domain causality test is proposed to inspect the causality relations from GDP, T.I., G.L.O., C.R.I., I.E.P.P.P., and R.E.C. to composite indexes for E.P. (CEP_1, CEP_2, CEP_3). The findings are shown in long ($\omega_i = 0.05$), medium ($\omega_i = 1.50$), and short run ($\omega_i = 2.50$). The indicators, GDP, T.I., G.L.O., C.R.I., I.E.P.P.P. and R.E.C., examined the unidirectional causality to CEP_1 for the short, medium, and long run. The unidirectional causality from such variables to CEP_1 applies to ***, ** and *, with a significance of 1%, 5% and 10%. In CEP_2 and CEP_3, the unidirectional causation assessed from GDP, T.I., G.L.O., C.R.I., I.E.P.P.P. and R.E.C. to CEP_2 and CEP_3 significantly in the short, medium, and long run. The Breitung-Candelon Frequency Domain Test reveals that all short-, medium-, long-term indicators significantly cause E.P. The study focuses greatly on energy investment with public–private participation, renewable energy and C.R.I. comprising financial, economic and political risks, which induced E.P. in the short, medium, and long run.

4.2. Discussions

It is evident from the results that investment in energy with P.P.P. model reduce E.P. in China. China has established a modern enterprise system to collectively participate in the government and private sectors to initiate new ventures, which has achieved three public–private participation phases. The first phase began in the 1990s with the development of power stations, and the second phase began in 2004 with a landmark issuance. However, the third and transformative stage, energy and technical advancement with public–private participation, began in 2013. To settle energy scarcity, private and public sectors jointly participate in China's market-based energy initiative (Wang et al., 2020). During the period of 1990–2019, there have been many public–private participation fluctuations, but the operative projects have perceived a reduction in energy shortages (World Bank, 2018).

GDP is negatively related to E.P. in China. In recent decades, China has witnessed a high GDP, and China's strong economic growth is taking part in the energy-generating process. China has organised a market-oriented energy system to provide energy for its household and industry sectors. In 2009, China obtained 99% electrification and in 2013 reached 100% electricity (Lin & Wang, 2020; World Bank, 2017).

China's renewable energy enactments are reluctant to limit E.P. in the long-term. It may be of inefficiency and high prices of renewable energy in China, some shreds of evidence have exposed the reasons for ineffective renewables. The I.E.A. declares that the management is incompetent to access renewables' unrealistic targets (Bhide & Monroy, 2011). China relies heavily on solid fuels, which are less expensive and readily accessible, although renewables are not feasible (Tang & Liao, 2014; Xie & Hu, 2014). Extreme poor and low-income households can't afford high energy prices (Nathan & Hari, 2020; Yang & Mukhopadhaya, 2017). Moreover, the subsidy on fossil fuels to lessen E.P. is also a hurdle behind renewables inefficiency (One Earth, 2019). Forty-six per cent of households lack modern energy like renewable energy, because of high energy rates (Lin & Wang, 2020).

Technological advancements have been affirmative to limit the E.P. in China for a long period. Technological advances in electricity contribute to reducing energy deficiency. Nevertheless, electric vehicles are one of the finest T.I.s that seek to reduce E.P. and environmental hazard. However, families with low wages cannot have the affordability of renewable energies and modern technologies. Implementing solar panels for low-income communities aims to alleviate E.P. and income poverty (One Earth, 2019).

5. Conclusion

This study focuses on public–private participation in energy investment and R.E.C. to alleviate China's E.P. We also reveals the C.R.I. based on financial, economic and political risks to limit E.P. The China-based data from 1990–2019 is taken for variables such as composite indexes for E.P. (CEP_1, CEP_2, CEP_3), GDP, T.I., G.L.O., C.R.I., I.E.P.P.P. and R.E.C. However, the composed data source is 'World Bank, World Development Indicators'. The empirical model incorporates various econometric techniques such as Narayan and Popp (2010) structural breaks unit root test, Maki (2012) and Bayer–Hanck (2013) cointegration tests, and F.M.O.L.S. Moreover, the Breitung and Candelon (2006) frequency domain causality test is applied for short, medium, and long run causation to E.P. in China. The findings reveal that Narayan and Popp (2010) unit root test has the same integration order of variables at the first difference I(1) with two structural breaks and leads to cointegration existence and F.M.O.L.S. in the long run. Maki (2012) have shown cointegration for CEP_1, CEP_2, and CEP_3. The combined effect cointegration test named Bayer–Hanck (2013) comprehensively rejected the null hypothesis of no cointegration in both EG-J and EG-J-Bo-Ba steps and admitted the cointegration existence in all CEP_1 CEP_2 and CEP_3. Both cointegration tests, Maki (2012) and Bayer–Hanck (2013), permit long-run existence.

The F.M.O.L.S. method shows that GDP, T.I., and I.E.P.P.P. negatively influence E.P. in China. However, R.E.C., G.L.O., and C.R.I. have failed to limit China's E.P. in the long run. The study greatly focuses on R.E.C. because of China's investment in renewables projects. However, the inefficiency and other factors are reluctant to limit China's E.P. in the long term. The study also emphasises China's financial, economic, and political risks, seemed unenthusiastic to make any mutual risks to ensure minimal E.P. Nevertheless, renewables and C.R.I. positively contribute to E.P. in China. In contrast, I.E.P.P.P. limits China's energy shortages in the long run. The frequency-domain causality test shows unidirectional causation from GDP, T.I., G.L.O., C.R.I., I.E.P.P.P. .and R.E.C. to CEP_1, CEP_2 and CEP_3 in the short-, medium-, and long-term.

On the basis of the findings of this study, we suggest that China should subsidise renewables to limit E.P. and ineffectiveness. Renewables and updated technologies should be low costs for low-income households as they cannot afford the high cost of living. The installation of solar panels, and electrification in low-income households, perhaps alleviate E.P. Moreover, China should improve its efficiency in electrification, which still lacks renewables. Reducing the E.P. will help the policy makers to devise strategies for improving environmental quality.

Anyway, this study only focuses on the China economy. Future research can be carried out to replicate these findings across different OECD countries. Furthermore, this study is limited to examining important variables' linear impact on E.P. A future study may be carried out to examine the interaction effect of I.E.P.P.P. and G.L.O. in affecting E.P.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work is supported by the National Social Science Foundation Project of China (No. 21BJL008).

ORCID

Yongming Huang http://orcid.org/0000-0003-0033-9277

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