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The influence of sustainable energy demands on energy efficiency: Evidence from China

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ABSTRACT

Recently, there has been a high level of energy demand worldwide, which has piqued regulators and researchers' interest in producing efficient energy. Therefore, this research investigates the impact of multiple energy demands on China's energy efficiency (renewable energy production). The researchers use secondary data extracted from World Development Indicators for the period 1986 to 2019. They use time series analysis techniques, such as the ADF test for stationarity, the ARDL model to evaluate the association between the variables, and the Granger causality test to evaluate the directional nexus amongst the variables. The findings show that multiple energy demands have a positive association with energy efficiency in China. Several implications and recommendations are made by the study to facilitate future research and regulation.

Introduction

High levels of pollution and the exponential expansion of economies has led to an increased need for energy resources to perform domestic and economic activities (Dorahaki et al., 2018; Sadiq et al., 2022). The consistent use of energy has depleted resources such as oil, coal, gas, ore, and petroleum, which is a threat to sustainable development, and the enhanced use of these energy resources could cause environmental problems such as the emission of greenhouse gases (GHGs), and hazardous chemical wastes. These problems not only damage human health but also have a negative influence on the quality of natural resources. An effective instrument to mitigate these issues is efficient energy use, which implies using less energy to perform tasks, produce products and services, secure resources, reduce waste, and protect environmental quality (Nižetić et al., 2019; Tan et al., 2022; Zhao et al., 2021). Performing tasks with reduced energy has various other benefits. It helps reduce the impact of climate change, reduces air pollution, increases energy security, reduces energy price risk for consumers, and overall improves the quality of work (Sadiq et al., 2022; Shove, 2018). For instance, insulation in buildings means less heating energy can be used to attain thermal comfort, while installing natural skylight windows or florescent or light-emitting diode bulbs minimizes the energy required for lighting in contrast to traditional bulbs (Nyangon & Byrne 2021; Sadiq et al., 2022).

There are several ways to increase energy efficiency (EE), such as the adoption of more efficient technology, better production processes, reducing energy loss, and using energy resources that can be renewed, recycled or replenished (Moslehpour et al., 2021; Tronchin et al., 2018). The production and use of renewable energy is the most effective way to achieve energy efficiency. Renewable energy comes from natural resources that can be renewed, recycled, and replenished (Al Mamun et al., 2021; Gyamfi et al., 2018). Energy from solar and wind is cheaper, does not require periodic payment, and does not involve waste disposal costs. Hence, it allows maximum output with minimum input (Ode & Ayavoo, 2020; Royston et al., 2018). Renewable energy, including biodiesel, solar power, biomass, nitrous oxide, wind power etc., restricts the emission of GHGs, and leaves no harmful waste in the post-production phase. The production of renewable energy can overcome environmental issues such as carbon dioxide, heat, excessive water use, etc., thus saving the environment and improving the health of living beings (Moslehpour et al., 2022; Trotta, 2018). The production of renewable energy is an effective way to secure energy sources for sustainable development, because the same amount of energy is replenished, either spontaneously or by some effort (Iris et al., 2019; Moslehpour et al., 2022).

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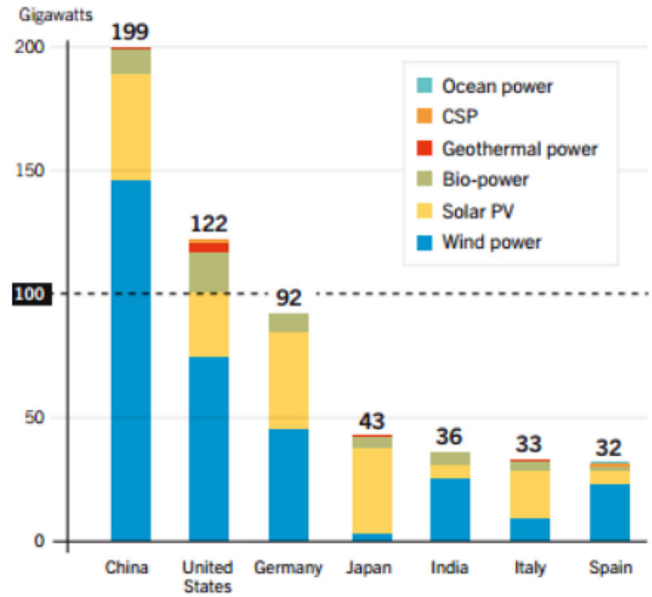

Fig. 1. Renewable power production.

This study examines the influence of multiple energy demands such as energy import (EI), energy use (EU), fossil fuel energy consumption (FFEC), renewable energy consumption (REC), and electric power consumption (EPC) on China's renewable energy production and energy efficiency. China is an upper-middle-income developing country with a large population (Khalifa et al., 2019; Liu et al., 2021). Energy production in China has increased dramatically since 1980 and has been used to perform household tasks and economic functions. The statistics show that 80% of energy is acquired from fossil fuels and 17% from hydroelectric installations. However, only 2% of power comes from nuclear energy (Clauss et al., 2021; Gökgöz et al., 2018). China has a great deal of energy potential, but much of it is not yet developed. Moreover, it is observed that energy sources are geographically far from primary industrial consumers. The northeast is rich in oil and coal, the central region of north China has coal, and the southwest is rich in terms of hydropower (Bär & Voigt, 2019; Peng & Huang, 2020). However, the Lower Yangtze area around Shanghai and the industrialized areas around Guangzhou have insufficient energy, and heavy industry is sparsely distributed near the key energy source regions outside the northeast (Liu et al., 2022; Vasques et al., 2019).

China aims to bring change to its present energy mix, away from its reliance on coal, which accounts for 70–75% of its energy, towards a reliance on renewable energy, natural gas, oil, and nuclear power, due to environmental concerns. Over the last 5 to 10 years, China has closed many coal mines to reduce overproduction, resulting in a 25% reduction in coal production (Dimian et al., 2021; Xiong et al., 2019). From 1993, China has been a net importer of oil, with a substantial proportion coming from the Middle East (Liu et al., 2022; Song et al., 2018). China is engaged in diversifying its oil import sources and has made investments in oil reserves worldwide. It is expanding its Central Asian oil imports and has invested in Kazakhstani oil reserves (Liu et al., 2018; Özer et al., 2020). Beijing also aims to increase overall natural gas production which currently constitutes 3% of the total energy consumption of the country. The city incorporated a natural gas strategy in its 5 year plan from 2001 to 2005, which aimed to increase the use of gas from 2% to 4%.China's natural gas consumption more than trebled by 2010 (Mahmood et al., 2021; Ouyang et al., 2018). China is now amongst the top countries producing renewable power. Fig. 1 shows the renewable power production of the top seven countries.

In March 2006, the National People's Congress proposed their 11th five-year plan from 2006 to 2010. This plan called for further crucial energy conservation measures and covered the development of renewable energy resources and environmental protection. By 2010, the plan proposed a 20% reduction in EU/unit of GDP, and included a shift from coal to clean energy sources such as renewable energy, natural gas, oil, and nuclear power (He et al., 2018; Kamarudin et al., 2021). Beijing also plans to boost energy efficiency and apply clean technology.

China is rich in hydropower. The example of the Three Gorges Dam illustrates its richness (Lan et al., 2022; Zhou et al., 2018). Furthermore, it is predicted that nuclear power may increase its share of electricity generation from 1% to 5% over the period 2000–2030. China's renewable energy law, which came into force in 2006, demands that renewable energy account for 10% of the country's energy by 2020 (Li et al., 2018, 2021). In 2021, China experienced its worst energy crisis, with companies in the industrial heartland advised to restrict use, people exposed to rolling blackouts, and yearly light shows cancelled, according to the Guardian (Ge et al., 2018; Huang et al., 2021a).

The current study focuses on energy efficiency and the need for a change from fossil fuel to clean energy, minimizing the use of energy in domestic and commercial areas. The objective is to analyse the influence of multiple energy demands on energy efficiency. This study bridges a literature gap by exploring the influence of energy demand on energy efficiency in detail. Numerous studies scrutinize the impact of various energy demands, such as electrical consumption, fossil fuel consumption, energy imports etc., but these studies analyse these factors separately. Godoy-Shimizu et al. (2018) address the influence of renewable energy consumption on energy efficiency but ignore other factors. This study, which addresses the influence of multiple energy demands such as EI, EU, FFEC, REC, and EPC on renewable energy production and EE simultaneously, greatly contributes to the literature. Being a hub of energy consumption, due to its large population and economic activity, China is a major source of environmental pollution from its giant industries. However, the literature is sparce on energy efficiency in China. Hence, this study which analyses China's energy consumption and efficiency removes this gap (Hussain et al., 2021).

The study is structured in five parts. The second part deals with the influence of multiple energy demands on energy efficiency from previous studies. The third part describes the data collection and analysis. The fourth part presents the results, supported by previous studies. The last part presents the conclusions, implications, and future directions.

Literature review

Countries face many environmental issues as they become more populous, with an exponential increase in economic activity (Gyamfi et al., 2018; Huang et al., 2021b; Mantikei et al., 2020). Most problems arise due to excessive energy use, which is a critical part of any society or economy. This not only causes environmental pollution but may decrease the energy resources available for future use. The concept of energy efficiency has been introduced to mitigate these issues and implies the use of the minimum energy to produce products and services, while ensuring the protection of the environment. Clean and renewable energy is encouraged, in both production and use, as part of efficient energy (Huang et al., 2021; Malinauskaite et al., 2019). The multiple demands for energy in a country are all opportunities for individuals and economists to adopt efficient energy technologies and techniques to ensure clean and renewable energy (Chien et al., 2022; Ma et al., 2019). Our study analyses the nexus between multiple energy demands such as EI, EU, FFEC, REC, EPC and EE, which are widely investigated in previous studies.

Energy import (IE) is the purchase of energy from foreign countries at the time of need to undertake domestic and economic functions such as building infrastructure and powering appliances, machines, and transport vehicles. EI may be required for several reasons, such as the ability to purchase low-cost energy in abundance, acquire clean energy, purchase high capacity energy in a minimum quantity, and address a lack of energy resources within the country (Chien et al., 2021; Gökgöz et al., 2018). Thus, the importing of energy indicates a country's demand for low-cost, clean, sustainable, or high capacity energy, or to use energy more efficiently (Chien et al., 2022; Shao et al., 2019). Zhu et al. (2020) investigate the influence of energy import on energy efficiency. Their study demonstrates that when energy resources are insufficient to meet rising domestic demand, economic entities turn to EI, and re-usable energy supplies must be developed, resulting in zero waste and cost savings. Mondal et al. (2018) examine EI demand scenarios by studying improvements in energy efficiency and GHG emission mitigation in the economy of Ethiopia. The study posits that when business organizations are allowed to import clean energy, and there is a demand for clean energy import, there is a motivation in the economy to produce renewable energy within the country to meet demand and control GHG emissions, which are objectives of efficient energy.

The energy use (EU) within a country for social and economic purposes affects the implementation of efficient energy (Ainou et al., 2022; Chang et al., 2018). Mills et al. (2019) state that societies and economies need to grow as populations increase within countries. Hence, the need for energy increases. However, the energy resources available are limited. Thus, efficient energy technologies must be applied to facilitate work using the minimum amount of energy. Molinos-Senante & Sala-Garrido (2018) investigate the status of energy consumption, energy demand, and energy efficiency. They argue that most individuals and business organizations use energy resources, causing GHG emissions and producing harmful waste that adversely affects the quality of the natural environment, working conditions and the health of living beings. Therefore, efficient energy should be encouraged to mitigate the negative influence of the energy used, because energy resources that can be renewed do not leave harmful waste, or what waste there is can be easily disposed of. Paramati et al. (2018) investigate the relationship between environmental technologies, energy demand, and energy efficiency in 28 OECD economies. Their study applies data from 1990 to 2014 and uses a panel estimation method to address cross-sectional dependence, fixed effect, and endogeneity. The study finds that various types of machinery, plants, infrastructure, and logistics are currently in use, and sufficient energy is needed to run them. It predicts that present energy resources are insufficient and will rapidly deplete in the future, resulting in the quest for energy efficiency using renewable energy sources.

Fossil fuels, such as natural gas, petroleum, coal, oil, bitumen, tar sand, and heavy oil containing carbon, are the most broadly used energy sources globally, accounting for 80% of power consumption. These materials are generated by geological processes acting on the remains of organic substances produced by photosynthesis, beginning in the archean Eon (4.0 billion to 2.5 billion years ago) (Dankiewicz et al., 2020; Martins et al., 2018). Fossil fuels are non-renewable and are expected to diminish over time. Because of their rarity, they are also costly. The increase in fossil fuel use for energy purposes motivates governments, environmental regulators, and economists to design economic and social policies in such a way as to promote energy efficiency. Chowdhury et al. (2018) investigate the energy demand, environmental impact, and energy efficiency of fossil fuels, and find many negative impacts. They are non-renewable, soon to be depleted, dangerous to produce, and cause water, land, and air pollution, oil spills, smog, acid rain, mercury emissions, and global warming. Hence, the use of fossil fuel energy must be reduced by enhancing renewable and clean energy. Sovacool et al. (2021) analyse the use of fossil fuels, energy efficiency technologies, and renewable energy production. They conducted 181 formal, semi-structured interviews at 82 institutions in the United States from 2005 to 2008. They reveal that fossil fuels cannot be recycled or completely disposed of, leaving harmful waste. Therefore, efficient energy and effective technologies must be used to overcome these issue, which do not leave any waste, and produce renewable energy.

Renewable energy is energy from renewable and sustainable biological sources such as food and non-food crops, trees, air, water, heat, and crop wastes. It is either spontaneously replenished or the materials can be recycled (Pieloch-Babiarz, 2020; Rojek-Adamek, 2021). The consumption and production of renewable energy such as biomass, biofuel, wind power, hydropower, geothermal power, and solar power are measures intended to clean the environment. For example, implementing energy efficiency, the basic objectives of which are to secure resources for future use and protect the inside and outside environments, requires renewable energy consumption and production (Bilan et al., 2020; McCauley et al., 2019). Lydeka & Karaliūtė (2021) and Pata (2018) explore the relationship between renewable energy consumption, renewable energy production, human capital, and economic performance in the Pakistani economy in short- and long-term tests, from 1990 to 2016. These tests include the augmented Dickey-Fuller generalized least squares (ADF-GLS) test for unit root, the Johansen and Juselius (JJ) co-integration test for long-term causality, and the vector error correction model (VECM) for short-run Granger causality. The study concludes that renewable energy is produced in maximum quantities in countries with a tendency to employ renewable energy such as biomass, biofuel, wind power, hydropower, geothermal power, and solar power for production and transportation. Thus, energy-efficient technologies, which need low voltage power to perform functions, are applied. The use of renewable energy cleans the environment, meets the increasing need for energy, improves the production of goods and services, and reduces costs, all characteristics of improved energy efficiency (He, Meng, Chen, Yan, & Vasa, 2021; Mazur & Duchlinski, 2020).

The use of electricity for electrical appliances, infrastructure, technology, and building management such as heating, cooling, lighting, and developing comfort, is increasing. The application of electricity as an energy source has many adverse impacts, such as the cost (production cost or monthly electricity bills), production of hazardous wastes (highly radioactive fuel rods), thermal pollution, and short circuit risks. The increase in population has resulted in a competitive modern world, with concerns about environmental issues, and growing economic activity leading to increased demand for electricity (Matuszewska-Pierzynka, 2021; Zhang et al., 2017). Hence, renewable energy should be produced to meet domestic and economic energy needs cleanly and less expensively. Dogan & Ozturk (2017) investigate electricity use, demand for energy, and energy efficiency in the economy of Los Angeles, California. The study posits that the increasing need for electricity consumption to perform business operations, administration, production, digital marketing, etc., enhances electricity demand. Nonetheless, electricity is a costly source of energy, unaffordable for firms. The production of renewable energy from biomass, biofuel, wind power, hydropower, geothermal power, or solar, could fulfil the enhanced energy need, supplying the same output from cheaper energy sources. Hence, an increased demand for electricity improves energy efficiency. Zhang et al. (2017) debate the relationship between electricity demand and energy efficiency. The study implies that rising demand for electricity to power various organizational infrastructure and technology boosts renewable energy, resource security, cost reduction, and environmental pollution reduction, improving energy efficiency.

Research methodology

This study investigates the impact of multiple energy demands on China's energy efficiency. The researchers use secondary data extracted from the World Development Indicators from 1986 to

Table 1
Measurement of variables.

S#	Construct	Instrument
01	Energy Efficiency	Renewable electricity production (% of total electricity output)
02	Energy Import	Energy import (% of energy use)
03	Energy Use	Energy use (kg of equivalent per capita)
04	Fossil Fuel Energy Consumption	Fossil fuel energy consumption (% of total)
05	Renewable Energy Consumption	Renewable energy consumption (% of total energy consumption)
06	Electric Power Consumption	Electric power consumption (kWh per capita)

Source: World Development Indicators.

2019. They use the time series analysis techniques, such as the augmented Dickey-Fuller (ADF) test for stationarity, the autoregressive distributed lag (ARDL) model to test the association between variables, and the Granger causality test to check the directional nexus between the constructs. The equation for the study is:

$$REP_t = \alpha_0 + \beta_1 EI_t + \beta_2 EU_t + \beta_3 FFEC_t + \beta_4 REC_t + \beta_5 EPC_t + e_t \quad (1)$$

where:

REP = renewable electricity production
t = time period
EI = energy import
EU = energy use
FFEC = fossil fuel energy consumption
REC = renewable energy consumption
EPC = electric power consumption.

The study takes energy efficiency as the dependant variable and measures renewable electricity production (% of total electricity output). The researchers use energy demand as the predictor of the study and measure it through several indicators such as EI (% of energy use), EU (kg/capita), FFEC (% of total), REC (% of total energy consumption), as shown in Table 1.

The study presents descriptive statistics, by year and overall, for all variables, explaining the normality of the data by providing mean, maximum, minimum values and standard deviation. The study uses a correlation test to predict strong/weal associations amongst the variables. To check the multicollinearity the study conducts a variance inflation factor (VIF) test, according to which, if the values are not greater than 5, multicollinearity is not problematic. The VIF equations are:

$$\mathrm{R}_Y^2 \to Y_{it} = \alpha_0 + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + \beta_5 X_{5it} + e_{it} \quad (2)$$

$$j = R_Y^2, \; R_{X1}^2, \; R_{X2,}^2 \; R_{X3,}^2 \; R_{X4,}^2 R_{X5}^2 \quad (3)$$

$$Tolrance = 1 - R_j^2 VIF = \frac{1}{Tolerance} \quad (4)$$

The study uses a stationarity test to evaluate the unit root. If all variables are stationary at the level, then the pooled ordinary least square (POLS) method is appropriate. However, if all variables are stationary at the first difference, the error correction model (ECM) is suitable. In contrast, if some constructs are stationary at the level and some are stationary at the first difference, the ARDL model is appropriate. This technique is used for three main reasons. Firstly, the test has a simple procedure. Secondly, it allows the cointegration relationship to be tested and estimated through the ordinary least square (OLS) method, where the model's lag order is identified. Lastly, the requirement for pretesting the variables for unit root is not required, unlike other models Therefore, the researchers use the ADF test, with the equation:

$$d(Y_t) = \alpha_0 + \beta t + \mathrm{Y} Y_{t-1} + d(Y_t(-1)) + \varepsilon_t \quad (5)$$

The stationarity of the constructs is examined individually using the ADF test, and the equations for the individual variables are:

Renewable energy production

$$d(REP_t) = \alpha_0 + \beta t + \gamma REP_{t-1} + d(REP_t(-1)) + \varepsilon_t \quad (6)$$

Energy import

$$d(EI_t) = \alpha_0 + \beta t + \gamma EI_{t-1} + d(EI_t(-1)) + \varepsilon_t \quad (7)$$

Energy use

$$d(EU_t) = \alpha_0 + \beta t + \gamma EU_{t-1} + d(EU_t(-1)) + \varepsilon_t \quad (8)$$

Fossil fuel energy consumption

$$d(FFEC_t) = \alpha_0 + \beta t + \gamma FFEC_{t-1} + d(FFEC_t(-1)) + \varepsilon_t \quad (9)$$

Renewable energy consumption

$$d(REC_t) = \alpha_0 + \beta t + \gamma REC_{t-1} + d(REC_t(-1)) + \varepsilon_t \quad (10)$$

Electric power consumption

$$d(EPC_t) = \alpha_0 + \beta t + \mathrm{Y} EPC_{t-1} + d(EPC_t(-1)) + \varepsilon_t \quad (11)$$

The researchers use the ARDL model to test the nexus between the constructs. It holds the best estimation when variables are integrated at 1(0) or 1(1). It is also appropriate for small samples (Sharif et al., 2020), and this study has 34 observations. For the application of ARDL, there should be appropriate lag selection and an appropriate lag length to solve the possible problem of endogeneity (Ahmed et al., 2021). Similarly, an appropriate lag length is needed for managing possible multicollinearity (Khan et al., 2019). The ARDL approach generates the short- and long-run results together. The equation of the ARDL model is given as:

$$\begin{aligned} \Delta REP_t = \alpha_0 &+ \sum \delta_1 \Delta REP_{t-1} + \sum \delta_2 \Delta EI_{t-1} + \sum \delta_3 \Delta EU_{t-1} \\ &+ \sum \delta_4 \Delta FFEC_{t-1} + \sum \delta_5 \Delta REC_{t-1} + \sum \delta_6 \Delta EPC_{t-1} \\ &+ \varphi_1 REP_{t-1} + \varphi_2 EI_{t-1} + \varphi_3 EU_{t-1} + \varphi_4 FFEC_{t-1} \\ &+ \varphi_5 REC_{t-1} + \varphi_6 EPC_{t-1} + \varepsilon_1 \end{aligned} \quad (12)$$

where δ_1, δ_2, δ_3, δ_4, and δ_5 represent the short-term coefficients, and φ_1, φ_2, φ_3, φ_4, φ_5, and ε_1 represent the long-term nexus. The equation for ECM for the short-run nexus is:

$$\begin{aligned} \Delta REP_t = \alpha_0 &+ \sum \delta_1 \Delta REP_{t-1} + \sum \varphi_2 \Delta EI_{t-1} + \sum \omega_3 \Delta EU_{t-1} \\ &+ \sum \theta_4 \Delta FFEC_{t-1} + \sum \mathrm{Y}_5 \Delta REC_{t-1} + \sum \mathrm{Y}_6 \Delta EPC_{t-1} \\ &+ \delta ECM_t + \upsilon_t \end{aligned} \quad (13)$$

To evaluate the association between the variables, the study conducts a Granger causality test, which is appropriate for predicting bilateral, unilateral or no relation amongst constructs. The Granger causality expressions are:

$$\mathrm{Y_t} = \beta_0 + \sum_{j=1} \beta_{1j} \mathrm{Y_{t-1}} + \sum_{h=1} \beta_{2h} \mathrm{Y_{t-p}} + \varepsilon_t \quad (14)$$

$$\mathrm{X_t} = \alpha'_0 + \sum_{s=1} \alpha'_{1s} \mathrm{Y_{t-s}} + \sum_{t=1} \alpha'_{2t} \mathrm{X_{t-m}} + \varepsilon_t \quad (15)$$

Study results

The study presents descriptive statistics by year in Table 2. The maximum renewable electricity production (REP) is 24.291% in 2019,

Table 2
Descriptive statistics (year).

	REP	EI	EU	FFEC	REC	EPC
1986	18.987	−6.556	671.21	72.225	33.954	391.352
1987	19.087	−4.354	694.422	73.236	33.970	426.554
1988	19.710	−2.968	720.341	74.235	33.990	461.798
1989	20.408	−1.166	766.995	75.709	34.084	510.620
1990	18.471	−4.566	736.852	74.832	33.258	548.954
1991	17.585	−3.098	752.629	75.432	32.931	604.694
1992	18.125	−0.442	788.129	76.469	31.678	662.637
1993	18.088	−1.37	816.163	77.045	31.249	727.107
1994	19.214	−1.919	866.834	78.428	29.472	770.28
1995	17.552	−1.637	881.654	78.986	30.537	821.081
1996	17.512	−0.695	871.756	78.935	30.183	852.741
1997	18.061	−0.071	869.359	78.994	29.740	870.617
1998	16.681	2.255	878.525	79.4	30.506	913.963
1999	16.639	0.548	898.987	79.841	29.603	992.943
2000	18.959	−0.674	928.811	80.197	28.335	1076.549
2001	17.619	1.501	984.811	81.202	26.978	1194.856
2002	15.037	3.090	1118.432	83.23	23.841	1379.485
2003	16.223	4.895	1268.133	84.796	20.161	1585.839
2004	15.593	7.858	1515.174	86.828	16.385	2039.015
2005	15.263	8.422	1630.171	87.408	14.884	2325.927
2006	17.737	8.436	1672.904	87.224	14.138	2446.369
2007	17.864	10.361	1778.434	87.636	13.432	2612.457
2008	18.623	11.446	1954.723	88.255	12.261	2943.59
2009	16.762	11.86	2086.487	88.898	11.338	3298.004
2010	19.966	14.36	2155.165	88.419	11.537	3474.988
2011	20.296	14.756	2213.759	88.237	11.522	3773.405
2012	22.609	15.022	2236.73	87.67	12.061	3927.044
2013	23.927	15.092	2236.901	87.771	12.245	3927.142
2014	23.951	15.103	2237.12	87.901	12.590	3927.201
2015	23.987	15.202	2237.25	88.23	12.864	3927.39
2016	23.990	15.299	2237.39	88.342	13.124	3927.44
2017	24.013	15.301	2237.41	88.37	13.191	3927.53
2018	24.106	15.367	2237.45	88.39	13.195	3927.61
2019	24.291	15.399	2237.478	88.402	13.213	3927.72

Source: Authors estimations.

Table 3
Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
REP	34	19.322	2.868	15.037	24.291
EI	34	5.649	7.646	−6.556	15.399
EU	34	1424.076	639.044	671.21	2237.478
FFEC	34	82.682	5.644	72.225	88.898
REC	34	22.131	9.179	11.338	34.084
EPC	34	2033.085	1404.68	391.352	3927.72

Source: Authors estimations.

Table 4
Matrix of correlations.

Variables	REP	EI	EU	FFEC	REC	EPC
REP	1.000					
EI	0.587	1.000				
EU	0.622	0.989	1.000			
FFEC	0.368	0.955	0.936	1.000		
REC	0.434	−0.967	−0.970	−0.980	1.000	
EPC	0.662	0.987	0.997	0.922	−0.953	1.000

Source: Authors estimations.

Table 5
Unit root test.

Augmented Dickey-Fuller Test (ADF)	Level	t-statistics	p-values
REP	I(1)	−6.500	0.000
EI	I(1)	−5.713	0.000
EU	I(1)	−5.476	0.001
FFEC	I(1)	−3.372	0.015
REC	I(0)	−7.548	0.020
EPC	I(1)	−5.867	0.000

Source: Authors estimations.

while the minimum REP is 15.037% in 2002. Energy import (EI) is minimum in 1986, at only −6.556%, but maximum in 2019 at 15.399%. The results indicate that the minimum energy use (EU) is 671.21 kg per capita in 1986, while the maximum EU is 2237.448 kg per capita in 2019. Fossil fuel energy consumption (FFEC) is minimum in 1986, at only 72.225%, but maximum in 2019 at 88.442%. The results indicate that the maximum renewable energy consumption (REC) is 34.084% in 1989, and the minimum in 2009 is 11.338%. Electric power consumption (EPC) is minimum in 1986, at only 391.352 kWh per capita, and maximum in 2019 at 3927.72 kWh per capita.

The study presents descriptive statistics for the mean values, standard deviation, minimum and maximum values, and observations in Table 3. The results indicate a mean value of REP of 19.322%, a mean value of EI of 5.649%, a mean value of EU of 1424.076 kg per capita, a mean value of FFEC of 82.682%, a mean value of REC of 22.131%, and a mean value of EPC of 2033.085 kWh per capita.

Table 4 gives the correlation matrix between the predictors. It only provides the direction of the association, not the significance. The results indicate that all predictors (EI, EU, FFEC, REC, and EPC) have a positive association with REP. The VIF is used to test the multicollinearity, and the results indicate that all VIF values are lower than 5, suggesting no multicollinearity issue in the model.

This study uses the ADF stationarity test to evaluate the unit root. The findings indicate that REC is stationary at the level while REP, EI, EU, FFEC, and EPC are stationary at the first difference, indicating that the ARDL model is appropriate for the study. The values are given in Table 5.

To apply the ARDL model, the co-integration amongst the constructs is examined using the ARDL bound test. The results indicate that the calculated f-statistics (5.68) are bigger than the critical values, indicating that the ARDL model could be used. Table 6 shows the values of the ARDL bound test.

The ECM results indicate that multiple energy demands (EI, EU, FFEC, REC, and EPC) have a positive association with energy efficiency (renewable energy consumption) in China. The R square value (0.446651) indicates that 44.6651% of changes in the REP are due to all selected predictors. Table 7 shows these values.

The results of the ARDL model also indicate that multiple energy demands (EI, EU, FFEC, REC, and EPC) have a positive association with energy efficiency (renewable energy consumption) in China. Table 8 shows the ARDL results.

The Granger causality results indicate that unidirectional relationships exist amongst EI and REP, EU and REP, and FFEC and REP. The results also indicate bidirectional relationships between REC and REP, while no relationship is noted between EPC and REP. The values are shown in Table 9.

Discussion and implications

The results reveal that energy import has a positive association with renewable energy production, which determines the energy efficiency within a country. These results align with the previous study by Murshed (2020), who analyse the impact of increasing energy import facilities on energy efficiency. The study implies that energy is imported because domestic energy resources are only available at a high rate due to scarcity. When the demand for energy imports increases, it becomes necessary to seek other ways to produce cheap energy. Renewable energy is cheaper than non-renewable energy and is a tool to control the excessive use and waste of energy. These results are supported by Yao et al. (2019), who reveal

Table 6
ARDL bound test.

Model	F-statistics	Lag	Level of significance	Bound test critical values	
				I(0)	I(1)
REP/(EI,EU,FFEC,REC,EPC)	5.68	4	1%	5.91	5.97
			5%	4.17	4.49
			10%	3.03	3.09

Source: Authors estimations.

Table 7
Short-run coefficients.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(EI)	0.520860	0.130242	3.999171	0.0210
D(EU)	0.676452	0.121029	5.589173	0.0023
D(FFEC)	4.701202	1.311072	3.585769	0.0328
D(REC)	1.090552	0.148634	7.337164	0.0000
D(EPC)	1.321462	0.232542	5.682681	0.0022
CointEq(−1)*	−1.284823	0.143171	−8.974045	0.0000
R-squared	0.446651	Mean dependant var		−0.050852
Adjusted R-squared	0.415255	S.D. dependant var		2.225322

Source: Authors estimations.

Table 8
Long-term coefficients.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
EI	1.188623	0.319853	3.716154	0.0022
EU	3.992114	1.044177	3.823216	0.0019
FFEC	1.185651	0.161687	7.333001	0.0000
REC	3.262038	0.743211	4.389114	0.0005
EPC	2.362782	0.923915	2.557359	0.0415
C	0.855174	0.178095	4.801786	0.0003

Source: Authors estimations.

Table 9
Granger causality test.

Null Hypothesis	F-Statistic	Prob.	Decision
EI does not Granger cause REP	4.04058	0.0072	Unidirectional
REP does not Granger cause EI	0.40206	0.8860	
EU does not Granger cause REP	4.01466	0.0099	Unidirectional
REP does not Granger cause EU	0.02800	0.2057	
FFEC does not Granger cause REP	6.18391	0.0003	
REP does not Granger cause FFEC	1.04492	0.3616	Unidirectional
REC does not Granger cause REP	4.55981	0.0024	
REP does not Granger cause REC	5.08623	0.0054	Bidirectional
EPC does not Granger cause REP	0.3521	0.1247	
REP does not Granger cause EPC	1.3251	0.1231	No

that when the energy resources are scarce, individuals and organizations move to import energy to meet domestic demand. In order to fulfil the domestic energy demand for households and economic processes, energy must be produced with resources which can be reused, leaving no waste and saving costs.

The results show that energy use positively correlates with renewable energy production, which is critical to energy efficiency. These results agree with Nižetić et al. (2019), who state that the use of energy resources is increasing rapidly both at the domestic and commercial level with increasing population and technological facilities. It is understood that energy resources taken from nature are finite, meaning technologies are introduced which use minimum energy to give maximum output in order to replenish and sustain resources. These results are in line with Jia & Lee (2018), who note that various types of machinery, plants, infrastructure, and logistics have been invented to perform economic activities, meet the requirements of the global competitive market, and undertake social or domestic activities to improve lives. Hence, sufficient energy is required to run these processes. It is feared that the available energy resources may not be enough in the coming decades as they are decreasing rapidly. Hence, there is a struggle for energy efficiency through renewable energy production. These results are supported by Gielen et al. (2019), who demonstrate that the increasing use of energy from fossil fuels enhances carbon emissions into the air, damaging the quality of natural resources, reducing the resources for future use, and affecting the health of humans. Therefore, economists encourage the production of renewable and clean energy with the intention of achieving energy efficiency and avoiding the negative social and environmental impacts of using non-renewable energy resources.

The study results reveal that fossil fuel energy consumption positively impacts renewable energy production and, thus, energy efficiency. Seyedzadeh et al. (2018) support this idea, saying that fossil fuels have been used for energy purposes in residential and commercial areas for centuries. During the combustion of fossil fuels, harmful gases are released, adding to global warming, initiating health problems, raising ocean levels, causing floods, and damaging the quality of natural resources. The increasing demand for fossil fuels motivates the production of renewable energy to save the economy. These results are supported by Mensah et al. (2019), who state that fossil fuels take years to form and cannot be re-used or recycled. As reserves of fossil fuels are limited and can be diminished with consistent use, while the demand for energy increases with increases in production and population, the use of renewable energy sources such as biomass, biofuel, wind power, hydropower, and solar power, which are not likely to be diminished, are encouraged. These results agree with Griffin & Hammond (2019), who indicate that biomass and biofuel must be encouraged for energy efficiency, to substitute for fossil fuels that cannot be recycled and leave toxic wastes that are difficult to dispose of.

Renewable energy consumption has a positive association with renewable energy production and energy efficiency. These results are in line with Saint Akadiri et al. (2019), who indicate that organizations are aware of the environmental impacts of non-renewable energy such as fossil fuels and nuclear power as well as the costs of traditional energy sources, and tend to use renewable and clean energy with minimum environmental influence. Clean energy needs to be produced at large scales to meet the demand and achieve energy efficiency. These results are similar to Chel & Kaushik (2018), who posit that non-renewable energy resources are more costly because they cannot be recycled, and there are costs associated with handling harmful waste. Therefore, firms prefer to use biomass, biofuel, hydropower, and solar power, which are renewable and do not produce waste, to reduce the cost of non-renewable energy. The demand for clean and waste-free energy leads the government to focus on forestry, agriculture, and the installation of solar panels. Thus, energy efficiency can be achieved within the economy.

The results indicate that electric power consumption positively correlates with renewable energy production, ensuring energy efficiency. These results are supported by Zhou et al. (2018), who show that a rise in electricity use to carry out operations in various business departments enhances energy demand. Moreover, due to the high cost of electricity, which business organizations cannot afford, they apply energy-efficient technologies and focus on producing renewable energy. Likewise, Shi et al. (2018) indicate that electrical energy has many disadvantages, such as the high cost of designing and establishing nuclear power stations, waste production in the form of highly radioactive fuel rods, thermal pollution, and short circuit risks. Therefore, clean and renewable energy production must be encouraged to meet energy needs in place of electricity. These results are in line with Sinha & Shahbaz (2018), who show that a rise in the demand for electricity for organizational infrastructure is a motivation for the economy to produce renewable energy for resource security, cost reduction, and reduction of environmental pollution.

The current study has both theoretical and empirical implications. The study has remarkable significance because of its contribution to green literature. It is a detailed description of energy efficiency and its social and economic significance. Technology or technological processes are taken as energy efficiency indicators in most literature concerning energy efficiency. In contrast, few studies take renewable energy production as a measure of energy efficiency. The current study analyses renewable energy production as a measurement of energy efficiency, examines the nexus between energy demand and energy efficiency, and explores the influence of energy imports, energy use, fossil fuel energy consumption, renewable energy consumption, and electrical power consumption on renewable energy production and energy efficiency. Although past studies analyse the influence of energy import, energy use, fossil fuel energy consumption, renewable energy consumption, and electric power consumption on renewable energy production and energy efficiency, their impact on renewable energy production and energy efficiency is not found. Hence, this study adds new knowledge to the literature. The study results indicate that an increase in energy imports could be costly and risky for the economy, and therefore increased energy demand must be addressed by producing renewable energy.

The current study is significant for industrialized countries, particularly emerging economies with large populations and increased use of technology and technological processes. Energy is one of the basic needs of businesses, especially in the modern era of technology. The use of energy has negative impacts as well as social and economic benefits. The increasing use of domestic, industrial, and service energy has many negative impacts on environmental quality and social well-being, besides cost. The current study clarifies that, with high energy efficiency, the environmental impacts and costs of energy can be reduced. Thus, this study could guide government authorities, environmental regulators, and economists in designing policies to protect the environment and save resources for sustainable economic development. It shows how to encourage energy efficiency and renewable energy production. This study helps upcoming researchers to investigate this area in the future and guides regulators developing regulations related to multiple energy demands and energy efficiency. The study suggests that renewable energy production and energy efficiency can be encouraged with effective management of increasing energy demand such as energy import, energy use, fossil fuel energy consumption, and renewable energy consumption.

Conclusion and limitations

Like many other emerging and populous countries, China faces many environmental issues including GHG emissions, harmful waste, and land and air pollution, which destroy the quality of natural resources and damage the health of living beings. Most environmental issues, and the resulting economic and social problems, occur due to the increasing use of unclean energy. The need for energy consumption for both economic and domestic purposes cannot be denied. However, effective management is needed to address the issues discussed, as the current study intends. This study has been conducted to explore the impact of increasing energy on renewable energy production and efficiency. The authors adopt a quantitative research method and analyse the influence of energy demand (EI, EU, FFEC, REC, and EPC) on REP and EE in the Chinese economy. The results indicate that fossil fuels and electricity, used to meet the increasing demands for energy in domestic and commercial areas, could be costly and negatively impact the environment, society, and the economy. However, increasing energy demand encourages energy efficiency. Likewise, the results highlight that renewable energy consumption in production and operational processes indicates higher energy demand than the resources available, which could be addressed by efficient energy.

The current study has some limitations, besides its theoretical and empirical implications. The study only analyses certain factors of energy demand, which limits the generalizability of the results. Addressing only energy demand as a driver of energy efficiency minimizes the study's effectiveness. Simultaneously, many other factors affect energy efficiency. Future authors are recommended to analyse more factors of energy efficiency. The study collects data about the influence of EI, EU, FFEC, REC and EPC on EE in the Chinese economy. This study may not apply to other economies, because of its focus only on China, with its particular population, geographical features, and economic conditions.

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