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Role of the sharing economy in the achievement of energy efficiency and sustainable economic development: Evidence from China

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ABSTRACT

Globally, the sharing economy is considered a significant factor in achieving energy efficiency and sustainable economic development (SED) which needs regulatory and academic focus. This article investigates the impact of the sharing economy, including sharing economy users and sharing economy values, on efficient energy use and SED in China. The research uses exports, population growth, and foreign direct investment (FDI) as control variables. The article uses secondary data extracted from Statista, the sustainable development solution network, and World Development Indicators (WDI), from 1986 to 2020. The research applies the nonlinear autoregressive distributed lagged (NARDL) model to examine the associations among the variables. The results reveal that sharing economy users, sharing economy values, exports, population growth, and FDI have a positive association with efficient energy use and SED in China. This article guides policymakers establishing policies related to the achievement of SED and energy efficiency using the sharing economy. Governments, in particular, are recommended to actively encourage the growth of the sharing economy and create governance structures that support this growth.

Introduction

Sustainable economic development is a type of development the primary objective of which is to protect the environment and ensure human wellbeing. It is the process of human development where resources are used with the aim of fulfilling the needs of humans with little or no damage to the environment. The aim is to meet the needs of the present without jeopardizing future generations (Plat et al., 2019). Economic practices such as the use of machinery, plants, transport, logistics, infrastructure, and using poor quality material for production, have impacts on the environment and can potentially damage it (Song, Cao & Wang, 2019). When an economy makes rapid progress in the present, because of these practices, they put adverse pressures on the environment through greenhouse gas (GHG) emissions, climate change, harmful waste, smoke, water pollution, and land pollution. These environmental issues damage natural resources, living creatures including animals, birds, and fish, and the health of people living in the environment (Song et al., 2019). Natural resources, including living creatures on land, in air, and under water, provide raw materials, other operational resources and meet basic human needs. So, if natural resources are damaged, and the health of living creatures is destroyed as a result of economic practices, sooner or later, social wellbeing is decreased and economic development is stopped, and it becomes difficult for a country to survive (Ashraf et al., 2021). Therefore, there is a need to integrate environmental preservation into economic development, and this is termed sustainable economic development (Nikpay, 2020; Radchenko et al., 2020; Sigalat-Signes et al., 2020; Wang et al., 2020; Wawrzyniak & Doryń, 2020; Yilmaz, 2022; Maheswaranathan & Bhavan, 2022).

Energy consumption is a necessary element of society and the economy, as it is used to carry out numerous social and economic activities, including heating, cooling, lighting, transportation of goods and people, home appliances, machines, plants, technologies used for production, manufacturing, and construction, and providing economic services (Yuan & Zhang, 2020; Hieu, Tai & Hung, 2021; Nazir, Mahmood & Hameed, 2022). Firstly, naturally available energy sources are not numerous and of limited quantity. If they are used consistently, they are likely to diminish. Secondly, the excessive use of energy sources such as fossil fuels and nuclear power emits harmful

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gasses, such as GHGs, and other toxic wastes detrimental to the ecological balance. With the resultant climate change and deteriorating natural resources, it becomes difficult to maintain consistency in a country's development and economic growth (Caffaro et al., 2019). With energy efficiency, energy consumption can be reduced to a level at which it is possible to preserve natural energy resources and minimize the negative environmental impacts. Energy efficiency assures energy for future use. It protects the environment and its elements, including natural resources, livings creatures, and humans, while ensuring resources and labor for future economic purposes. Thus, energy efficiency contributes to sustainable economic development (Darity Jr, Addo & Smith, 2021; Malakauskas & Lakštutienė, 2021; Peternel & Grešš, 2021; Rauf et al., 2018; Tiberius, Schwarzer & Roig-Dobón, 2021; Zhu et al., 2021; Hussain, Yu & Wan, 2021; Treptow, 2022; Harun, Fauzi, Kasim & Wider, 2022).

The sharing economy is a business model in which individuals or firms share resources, including financial, physical, technological, information, and human resources (Šiuškaitė, Pilinkienė & Žvirdauskas, 2019). The major benefits of this sharing are reduced costs, access to resources, equal rights to benefit from resources, and challenging financial distress (Govindan, Shankar & Kannan, 2020a). Implementing a sharing economy properly within a country is useful for promoting energy efficiency within the country and sustainable economic development. When there is an increase in the number of sharing economy users or the value of the sharing economy, energy consumption can be reduced by the optimal use of energy or the sharing of technologies which run on renewable energy at a large scale. This constitutes an increase in energy efficiency (Frenken, 2017). Moreover, the optimal use of resources, reduced energy use, easy access to resources, cost reduction, and effective financial management lead the economy towards sustainable development (Jelinkova et al., 2021). The revenue generation from a sharing economy increases over time, and some statistics related to this revenue generation are given in Fig. 1.

The current study examines the impacts of sharing economy users, sharing economy value, exports, population growth, and FDI on the efficient use of energy and sustainable economic development in the Chinese economy. China is an upper-middle-income country with a population of 1411,787,240 people, as of 2020, and a nominal GDP of $19.91 trillion, estimated for 2022 (Ma et al., 2018). China, to its credit, is concentrating on sustainability in economic development while the per capita output is hardly more than one-third of the so-called developed economies. A relatively impoverished country, it has deliberately shifted its focus from the quantity to the quality of economic growth (Ma et al., 2018). China is the biggest emitter of GHGs, and struggles for energy transition, ecologically friendly improvement in transportation, and reduction of energy use (Ma, Yuan & Yang, 2021). As the biggest energy consumer globally, China's struggle to enhance energy efficiency is significant to world energy and climate concerns (Yu & Shen, 2019).

Fig. 1. Sharing economy revenues in ChinaSource: World Economic Forum.

China uses 22% of global energy, and accounts for 29% of world carbon emissions from fossil fuel burning, as of 2018. However, China has become an energy efficiency heavyweight due to its progress in implementing obligatory energy efficiency laws over recent years (Hoa et al., 2022). China has achieved significant progress in terms of technical energy efficiency. Without the gains in energy efficiency achieved since 2010, China would have consumed 25% more energy in 2018 than it did. China's economy has evolved from energy-intensive enterprises, mostly heavy industries, to service-providing companies, resulting in structural changes which have helped reduce energy demand. The industrial sector accounts for most energy savings (Song, Chen & An, 2018). Innovation-based energy efficiency programmes, such as digital labeling of the energy being used, and reinforcement of the required TOP 10,000 scheme in the industrial sector, have been praised by the world community for their significant achievements in technological energy efficiency. These significant regulations place China's energy efficiency programmes well ahead of the world average (Zhao, Guo & Zhao, 2019).

China has seen technological advancement in an industrialized economy with great expansion, a large transportation system, and a large population, so energy consumption is greater than other world economies. The large energy consumption, especially from fossil fuel combustion, emits a significant amount of GHGs (Ge et al., 2018). The resultant environmental deterioration prevents the country from achieving sustainable economic development. The economy still needs to find ways to encourage energy efficiency and sustainable economic development. The present study helps meet this need, by examining the impacts of sharing economy users, sharing economy value, exports, population growth, and FDI on efficient use of energy and sustainable economic development. Although energy efficiency and sustainable economic development are not new subjects in the literature, the present study makes a great contribution with the removal of some gaps. 1) In past literature, authors either discuss the efficient use of energy or sustainable economic development as a consequence of sharing capital. The present study enhances the scope of the literature with the addition of sharing economy impacts on efficient use of energy and sustainable economic development. 2) Past literature explores the sharing economy and its impacts on sustainable economic development and energy efficiency without considering its dimensions. Two dimensions of the sharing economy, sharing economy users and sharing economy value, are examined here. 3) Like previous studies, this research sheds light on sharing economy benefits and examines exports, population growth, and FDI effects on efficient use of energy and sustainable economic development. 4) This is one of the first studies to explore the role of sharing economy users, sharing economy value along with exports, population growth, and FDI on efficient use of energy and sustainable economic development in China (Jia-Jia et al., 2022; Mamghaderi, Khamooshi & Kwak, 2021; Nikolaou, 2022; Şerban, Pelinescu & Dospinescu, 2022; Ye, Chen & Li, 2022; Yu et al., 2022).

The paper has the following structure. Following the introduction, the second part presents the review of the literature on the nexus of sharing economy users and sharing economy value along with exports, population growth, FDI, and efficient use of energy and sustainable economic development. The next section discusses the methods, secondary data collection and analysis of the relationships. These relationships between the variables are discussed and compared to previous studies. Finally, the study implications, a short conclusion, and the limitations are presented (Al-masaeed et al., 2021; Mattayaphutron, Tam & Jariyapan, 2021; Saifan et al., 2021).

Literature review and theoretical framework

Consideration of the conditions that lead to the formation of a sharing economy and how they align with the tenets of sustainable development is necessary in order to comprehend the relationship between them. The sharing economy is characterized as a complex of economic, technological, environmental and social changes. The following list based on the work of (Gold, 2003; Lyaskovskaya, 2021; Zhu & Liu, 2021) indicates the necessary prerequisites for the emergence of a sharing economy.

Technological Prerequisites	Social Prerequisites
Industry 4.0 and digitalization of the economy The transition of producers and consumers to digital information technologies Development of online services and digital platforms The emergence of two-way reputation assessment systems Development of payment systems New capabilities of digital devices (smartphones) and the use of the application Development of social networks	Changing the culture of consumption Changing attitudes towards ownership Consumer crisis Growing inequality Rational consumption basis Expanding social connections Population growth and urbanization Migration growth Life expectancy growth Increasing population density Striving for sustainable development of society Developing a sense of community involvement and altruism
Environmental Prerequisites	**Economic Prerequisites**
Environmental crisis Growth of anthropogenic load Responsible attitude to the environment Responsible production and consumption	Economic crisis Pandemic situation New business models The downward trend in transaction costs Monetizing passive assets Development of financial literacy Development of flexible forms of lending Venture fund investments

The present idea of the sharing economy, which represents a significant shift in the technological and technical aspects of consumption and production was, in the opinion of a majority of researchers, brought about by the digitalization of many spheres of life. The connections between digitalization and the new phase of industrialization are widely acknowledged as the most important aspects of the shift to the digital world, including big data, augmented production, robotization, cloud computing, 3D printing, storage of data etc. Digitalization has had the greatest influence on consumption techniques, affecting millions of families worldwide, rather than how goods and services are created. New sharing economy business models have emerged as a result of these shifts, demonstrating a new level of socially and ecologically conscious behavior engrained in sustainable purchasing. These new models of business, featuring responsible and sustainable consumption, coincide with the socially conscious, economic and ecological objectives of sustainable purchasing, made possible by analysis of the conditions that led to the birth of the sharing economy (Lyaskovskaya & Khudyakova, 2021). Additionally, the sharing economy is presented in various studies as an economic benefit that facilitates environmentally friendly consumption of shared goods, and acts as a stepping stone to a strong and sustainable society (Boar, Bastida & Marimon, 2020; Curtis & Lehner, 2019). The connections between the sharing economy and the long-term health and growth of national economies, and the implications for the attainment of sustainable development goals, are highlighted by these arguments (Curtis & Mont, 2020; Mi & Coffman, 2019).

Sustainable economic development is the act of developing an economy the purpose of which is not only to achieve economic or financial goals but also to protect the natural environment and ensure the social welfare of the population. It is a developmental process in which resources are utilized to fulfill present economic needs, leaving room for the fulfillment of the needs of the future (Hidayat, 2021). The economic practices of production, transportation, creating technology, and building infrastructure, because of the excessive use of energy, may create hurdles to the development and welfare of future generations, as they could destroy the environment or its elements (Ren, Hao & Wu, 2022). Energy efficiency refers to the performance of social and economic practices in such a way that energy consumption can be reduced and its negative environmental impacts controlled. Effectively implemented energy efficiency is useful in providing a secure environment and high-quality natural resources in abundance (Wu, Hao & Ren, 2020). The sharing economy has many social aspects, which promote the optimal use of resources, provide access to, or the right to use, resources, encourage equality, reduce costs, and help in financial management (Cheng, 2016). In previous research, the relationships between sharing economy users, sharing economy value, exports, population growth, and FDI and the efficient use of energy and sustainable economic development are analysed. The present study examines the impacts of sharing economy users, and sharing economy value, exports, population growth, and FDI on efficient use of energy and sustainable economic development in the light of previously conducted literature (Faran et al., 2021; Handoyo et al., 2021; Jeffrey, 2021).

The number of users involved in the sharing economy affects the country's energy efficiency. (Jin et al., 2018) review sharing economy impacts on the efficient use of energy in an economy, and suggest that, when the number of individuals, firms, or economic units linked in a sharing economy increases, the ecologically friendly technologies that some people own are shared and used by others. More energy efficient technologies improve energy efficiency. Jabbour et al. (2020a) examine sharing economy users and the efficient use of energy, taking evidence from the Brazilian economy's natural resource intensive industries. The information about the sharing economy and efficient energy use comes from case studies of two medium-sized manufacturing companies operating in B2B and B2C contexts in the Brazilian economy. The research shows a positive relationship between sharing economy users and efficient energy use. The conclusion of this qualitative study implies that, if the

number of people who have a facility can share their resources among themselves, the energy resources can be used efficiently. The reason is that, with sharing, technologies can be kept running at all times, and can be used elsewhere, meaning the energy consumed in the down-time can be saved (Al-Shammari, 2021; Jermsittiparsert, 2021; Josaiman, Faisal & Talib, 2021).

Through the framework of sharing economy users, Leung, Xue and Wen (2019) examine sustainable eco-system and sustainable economic development. The study examines the sharing economy through news media discourse and frame analysis. The information on the sharing economy users' impacts on sustainable eco-system and sustainable economic development is collected from 340 online news articles relating to these factors published between 2011 and 2017 by thirteen US news outlets. The findings reveal positive relationships between sharing economy users, sustainable eco-systems and sustainable economic development. Conducting a qualitative study, Gazzola et al. (2019) state that the disparity in access to resources, human capital, and technology shrinks as the number of people ready to participate in sharing strategies, resources, and technologies grows. This provides equal prospects of success for all business divisions, contributing to long-term economic development. Similarly, the review based study conducted by Mont et al. (2020) investigates the relationship of sharing economy users with sustainable economic growth. The study implies that, with an increase in sharing economy users, the number of ecologically friendly economic practices grows. It does not allow firms to have negative impacts on the environment. The protection of the environment and natural resources enables the economy to stand on a sustainable foundation (Ibrahim, 2021; Jedrzejczyk & Brzezinski, 2021; Jin, 2021; Khoma & Vdovychyn, 2021).

The value created by the sharing economy helps promote the efficient use of energy. In empirical research Pouri and Hilty (2018a) investigate the relation of sharing economy value to efficient energy use. The study states that sharing economy value increases the resources and technologies used to transition from fossil fuel energy to renewable energy. Using renewable energy for running processes reduces the pressure on fossil fuels and saves the environment from GHG emissions. There is a positive relationship between sharing economy value and efficient energy use. The qualitative study presented by Laukkanen and Tura (2020a) considers increases in sharing economy value and indicates that economic entities save money by sharing resources, technologies, and information, rather than paying the full amount. The money saved can be invested in social and environmental activities that reduce energy use and maintain production. Melo, Macedo and Baptista (2019) explore the impacts of sharing economy value on the efficient use of energy. An increase in sharing economy value leads to a reduction in the number of practices based on energy sources. For example, sharing vehicles reduces transport activity and helps energy efficiency.

Through qualitative research, Govindan, Shankar and Kannan (2020b) shed ample light on the sharing economy's value and sustainable economic development. The authors examine the barriers to sharing economy execution in small and medium-sized enterprises operating in the Indian economy, using a literature review and the opinions of literary experts. The study posits that if the barriers to a sharing economy are overcome and it is effectively executed, money and resources, even after meeting the needs of the present generation, could be saved for future consumption. In this way, the sharing economy leads to sustainable economic development. Ma et al. (2019) claim that an increase in the value of the resources, techniques, and information shared among individuals, firms, or a circle of businesses helps address environmental issues such as water pollution, GHG emissions, and soil issues. This, combined with the assurance of environmental purity, enough resources, and a healthy workforce, results in sustainable economic development.

Rehman and Noman (2021) suggest that exports are the greatest source of earning foreign exchange and increasing the funds of state-owned and private firms, which they can use to carry out ecological programmes. One of the greatest consequences of such programmes is making optimal use of energy sources to ensure efficient energy use, which they evidence using system GMM analysis. Applying FMOLS, DOLS and PMG, Rahman, Nepal and Alam (2021) explain that an increase in exports has many benefits for the selling country. It encourages the production of the products to be exported, increases financial resources, assists in getting information, and imports better quality ecologically friendly technologies. These benefits are helpful for higher economic performance, improving social and environmental development, and promoting sustainable economic development.

Mohsin et al. (2019), consider the role of population growth in the efficient use of energy, on the basis of the hybrid error correction model, regression coefficients, and platykurtic distribution analysis. They suggests that in states where the population growth rate is high, governments focus on improving the skills and knowledge of people. The human resource increase and improved abilities enable ecological technology and production processes. These people can employ energy-efficient resources and technologies and add to energy efficiency. So, there is a positive relationship between population growth and efficient energy use. Vo (2021) explores the contribution of population growth to sustainability in economic development through GMM estimation, arguing that the size of the population determines the labor force, and an increased population necessitates a huge production of goods and services. This leads to improved productivity in the economy and increases natural and manufactured resources, all of which contribute to the economy's long-term viability.

Pan et al. (2020), using a slacks-based measure for data envelopment analysis show that FDI has a positive impact on the efficient use of energy. An increase in investment from foreign sources facilitates acquiring information from investors and having good relations. The quality information can bring ecologically friendly changes to the production and marketing processes. This change helps overcome the use of fossil fuels which is destructive to the environment, without any negative impact on the volume or quality of products and services. So there is a positive relationship between FDI and efficient energy use. Sauvat and Gabor (2021) state that sustainable economic development requires social progress and environmental development. Investment from foreign the domestic sources improves the financial resources of a country, and economic enterprises can implement business strategies to enhance social and environmental development and put the economy on the path to sustainable economic development.

Reviewing the existing literature, this study makes a considerable contribution by examining the impacts of sharing economy users, sharing economy value, exports, population growth, and FDI on sustainable economic development and efficient energy use. The sharing economy is a business concept in which resources and information are shared. This concept of analysing sustainable economic development and efficient energy use has been used as a whole, with no division into its dimensions. The present study, which considers sharing economy users and sharing economy value, and their impacts on sustainable economic development and efficient energy use, addresses this gap. This study analyses sharing economy users and sharing economy value, along with exports, population growth, and FDI, and their impacts on sustainable economic development and efficient use of energy in China, where less attention has been previously focused. This study also has great significance for developing countries like China, as sustainable economic development and efficient energy use are needed in any economy. Because of the expansion of economic practices and rapidly increasing use of energy for technologies, economies may face environmental problems, resulting in social disturbance and hurdles to economic development.

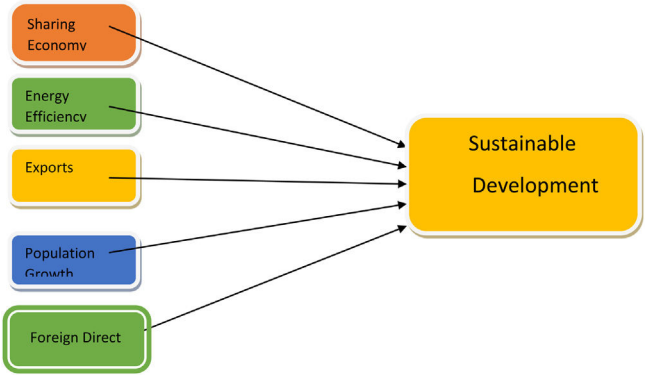

Fig. 2. Conceptual framework between sharing economy, energy efficiency, exports, FDI, population growth and sustainable development.

Research methods

Conceptual framework

The conceptual framework of the study is presented in Fig. 2, below. It shows that the study investigates the impact of efficient energy use, sharing economy users, sharing economy values, population growth, exports and FDI on SED in China.

The article uses secondary data extracted from Statista, the sustainable development solution network, and WDI, from 1986 to 2020. The research applies the NARDL model to examine the associations among the variables. The equations for both predictive variables are given as:

$$SED_{it} = \alpha_0 + \beta_1 SEU_{it} + \beta_2 SEV_{it} + \beta_3 EXP_{it} + \beta_4 POPG_{it} + \beta_5 FDI_{it} + e_{it} \quad (1)$$

$$EEu_{it} = \alpha_0 + \beta_1 SEU_{it} + \beta_2 SEV_{it} + \beta EXP_{it} + \beta_4 POPG_{it} + \beta_5 FDI_{it} + e_{it} \quad (2)$$

where;

SED = sustainable economic development
EEU = efficient energy use
i = country
t = time period
SEU = sharing economy users
SEV = sharing economy value
EXP = exports
POPG = population growth
FDI = foreign direct investment.

The article uses the sustainable development index as the SED measure and energy use (kg of oil equivalent per capita) as the efficient energy use measure, the predictive variables. The research takes sharing economy as the predictor, measured as sharing economy users (in millions) and sharing economy values (in billion US dollars). Finally, the research uses exports, measured as exports of goods and services (% of GDP), population growth, measured as annual percentage growth, and FDI, measured as FDI net inflows (% of GDP), as the control variables. The measurements and variables, with sources, are given in Table 1.

The research applies descriptive statistic analysis to examine the details of the variables, including mean values, minimum values, standard deviations, and maximum values. It employs a correlation matrix to show the directional associations among the variables. Finally, the stationarity of the variables is examined using the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, proposed by Dickey and Fuller (1979) and Phillips and Perron (1980), respectively. The equation used is:

$$d(Y_t) = \alpha_0 + \beta_t + YY_{t-1} + d(Y_t(-1)) + \varepsilon_t \quad (2a)$$

Following (Marques, Fuinhas & Tomás, 2019; Yanto, 2022), the ARDL bound test is used to examine the co-integration, which is a necessary part of applying the ARDL model. A basic requirement for applying the ARDL model is that some variables should be stationary at I(0) and others should be stationary at I(1). The ARDL model controls for the effects of autocorrelation and heteroscedasticity in the results. Finally, the ARDL model provides the long-run and short-run associations among the variables. The ARDL equations for both predictive variables are:

$$\Delta SED_t = \alpha_0 + \sum \delta_1 \Delta SED_{t-1} + \sum \delta_2 \Delta SEU_{t-1} + \sum \delta_3 \Delta SEV_{t-1} + \sum \delta_4 \Delta EXP_{t-1} + \sum \delta_5 \Delta PG_{t-1} + \sum \delta_6 \Delta FDI_{t-1} + \varphi_1 SED_{t-1} + \varphi_2 SEU_{t-1} + \varphi_3 SEV_{t-1} + \varphi_4 EXP_{t-1} + \varphi_5 PG_{t-1} + \varphi_6 FDI_{t-1} + \varepsilon_t \quad (3)$$

$$\Delta EEU_t = \alpha_0 + \sum \delta_1 \Delta EEU_{t-1} + \sum \delta_2 \Delta SEU_{t-1} + \sum \delta_3 \Delta SEV_{t-1} + \sum \delta_4 \Delta EXP_{t-1} + \sum \delta_5 \Delta PG_{t-1} + \sum \delta_6 \Delta FDI_{t-1} + \varphi_1 EEU_{t-1} + \varphi_2 SEU_{t-1} + \varphi_3 SEV_{t-1} + \varphi_4 EXP_{t-1} + \varphi_5 PG_{t-1} + \varphi_6 FDI_{t-1} + \varepsilon_t \quad (4)$$

It is the researchers' intention to include an analysis of the asymmetric nexus among exports, PG, FDI, and SED and exports, PG, FDI, and EEU. Thus, nonlinear functions are established:

Table 1
Measurements of variables.

S#	Variable	Measurement	Source	Expected sign	Reference
01	Sustainable Economic Development	Sustainable development index	Sustainable Development Solution Network		
02	Efficient Energy Use	Energy use (kg of oil equivalent per capita)	WDI	Positive	(Rebelatto et al., 2019), (Nurunnabi et al., 2020)
02	Sharing Economy	Sharing economy users (in millions) Sharing economy values (in billions of US dollars)	Statista Statista	PositivePositive	(Pouri & Hilty, 2018b) (Govindan, Shankar & Kannan, 2020c), (Shih, 2019)
03	Exports	Exports of goods and services (% of GDP)	WDI	Positive	Rahman et al. (2021)
04	Population Growth	Population growth (annual%)	WDI	Positive	(Rehman et al., 2022), Kurniawan and Managi (2018)
05	Foreign Direct Investment	FDI, net inflows (% of GDP)	WDI	Positive	(Mukhtarov et al., 2021)

$$SED = f\,(SEU,\ SEV, EXP^{+},\ EXP^{-},\ PG^{+},\ PG^{-},\ FDI^{+},\ FDI^{-}) \tag{5}$$

$$EEU = f\,(SEU,\ SEV,\ EXP^{+},\ EXP^{-},\ PG^{+},\ PG^{-},\ FDI^{+},\ FDI^{-}) \tag{6}$$

Thus, the empirical model is developed:

$$SED_t = \alpha_0 + \beta_1 SEU_t + \beta_2 SEV_t + \beta_3 EXP_t{}^{+} + \beta_4 EXP_t{}^{-} + \beta_5 PG_t{}^{+} + \beta_6 PG_t{}^{-} + \beta_7 FDI_t{}^{+} + \beta_8 FDI_t{}^{-} + e_t \tag{7}$$

$$EEU_t = \alpha_0 + \beta_1 SEU_t + \beta_2 SEV_t + + \beta_3 EXP_t{}^{+} + \beta_4 EXP_t{}^{-} + \beta_5 PG_t{}^{+} + \beta_6 PG_t{}^{-} + \beta_7 FDI_t{}^{+} + \beta_8 FDI_t{}^{-} + e_t \tag{8}$$

Eqs. (3) and (4) are the ARDL model for examining the nexus among the variables. The researchers also analyze the nonlinear association of exports, PG, FDI, and SED and exports, PG, FDI, and EEU. The equations for the partial sum of positive and negative changes in exports, PG, and FDI are:

$$EXP^{+} = \sum_{i=1}^{t} \Delta EXP_i^{+} = \sum_{i=1}^{t} \max(\Delta EXP_i 0) \tag{9}$$

$$EXP^{-} = \sum_{i=1}^{t} \Delta EXP_i^{-} = \sum_{i=1}^{t} \min(\Delta EXP_i 0) \tag{10}$$

$$PG^{+} = \sum_{i=1}^{t} \Delta PG_i^{+} = \sum_{i=1}^{t} \max(\Delta EI_i 0) \tag{11}$$

$$PG^{-} = \sum_{i=1}^{t} \Delta PG_i^{-} = \sum_{i=1}^{t} \min(\Delta PG_i 0) \tag{12}$$

$$FDI^{+} = \sum_{i=1}^{t} \Delta FDI_i^{+} = \sum_{i=1}^{t} \max(\Delta EU_i 0) \tag{13}$$

$$FDI^{-} = \sum_{i=1}^{t} \Delta FDI_i^{-} = \sum_{i=1}^{t} \min(\Delta EU_i 0) \tag{14}$$

By including the positive and negative changes in exports, PG and FDI, the article establishes the nonlinear ARDL equations:

$$\Delta SED_t = \alpha_0 + \sum \delta_1 \Delta SED_{t-1} + \sum \delta_2 \Delta SEU_{t-1} + \sum \delta_3 \Delta SEV_{t-1} + \sum \delta_4 \Delta PG_{t-1}^{+} + \sum \delta_5 \Delta PG_{t-1}^{-} + \sum \delta_6 \Delta EXP_{t-1}^{+} + \sum \delta_7 \Delta EXP_{t-1}^{-} + \sum \delta_8 \Delta FDI_{t-1}^{+} + \sum \delta_9 \Delta FDI_{t-1}^{-} + \varphi_1 SED_{t-1} + \varphi_2 SEU_{t-1} + \varphi_3 SEV_{t-1} + \varphi_4 PG_{t-1}^{+} + \varphi_5 PG_{t-1}^{-} + \varphi_6 EXP_{t-1}^{+} + \varphi_7 EXP_{t-1}^{-} + \varphi_8 FDI_{t-1}^{+} + \varphi_9 FDI_{t-1}^{-} + \varepsilon_t \tag{15}$$

$$\Delta EEU_t = \alpha_0 + \sum \delta_1 \Delta EEU_{t-1} + \sum \delta_2 \Delta SEU_{t-1} + \sum \delta_3 \Delta SEV_{t-1} + \sum \delta_4 \Delta PG_{t-1}^{+} + \sum \delta_5 \Delta PG_{t-1}^{-} + \sum \delta_6 \Delta EXP_{t-1}^{+} + \sum \delta_7 \Delta EXP_{t-1}^{-} + \sum \delta_8 \Delta FDI_{t-1}^{+} + \sum \delta_9 \Delta FDI_{t-1}^{-} + \varphi_1 EEU_{t-1} + \varphi_2 SEU_{t-1} + \varphi_3 SEV_{t-1} + \varphi_4 PG_{t-1}^{+} + \varphi_5 PG_{t-1}^{-} + \varphi_6 EXP_{t-1}^{+} + \varphi_7 EXP_{t-1}^{-} + \varphi_8 FDI_{t-1}^{+} + \varphi_9 FDI_{t-1}^{-} + \varepsilon_t \tag{16}$$

Research findings

This research applies descriptive statistic analysis to examine the details of the variables under study. Table 2 provides the basic statistics of all series, including the mean values, minimum values, standard deviations, and maximum values. The results indicate that the mean value of SED is 77.102%, while the average value of EEU is 1456.358 Kg. The mean value of SEU is 38.078 million people, while the average value of SEV is 217.673 billion dollars. Finally, the mean value of EXP is 21.338%, while the average value of PG is 0.841%, and the average value of FDI is 3.023%. The values are given in Table 2.

Table 2
Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
SED	35	77.102	2.797	65.092	83.091
EEU	35	1456.358	748.073	671.21	2948.243
SEU	35	38.078	4.352	30.859	45.297
SEV	35	217.673	12.414	197.079	238.268
EXP	35	21.338	6.753	8.712	36.035
PG	35	0.841	0.387	0.226	1.610
FDI	35	3.023	1.533	0.623	6.187

Table 3
Matrix of correlations.

Variables	SED	EEU	SEU	SEV	EXP	PG	FDI
SED	1.000						
EEU	0.434	1.000					
SEU	0.366	0.953	1.000				
SEV	0.361	0.953	1.000	1.000			
EXP	0.317	0.333	0.517	0.517	1.000		
PG	0.175	0.780	0.919	0.920	−0.707	1.000	
FDI	0.583	0.253	−0.054	−0.048	0.480	−0.214	1.000

Table 4
Unit root test.

ADF PP Series	Level	First difference	Level	First difference
SED	−3.902***	−7.102***	−2.903***	−6.012***
SEU	−2.091***	−8.672***	−3.001**	−5.195***
SEV	−0.876	−4.103***	−0.810	−4.218***
EXP	−1.201	−5.106***	−1.110	−4.192***
PG	−4.102***	−7.197***	−5.092***	−6.764***
FDI	−5.900***	−5.102***	−5.198***	−7.281***

Table 5
Bound test of nonlinear ARDL.

	F-statistic	Lower Bound	Upper Bound	Decision
Linear ARDL	0.762	4.128	4.789	No Co-integration
Asymmetric ARDL	6.872	6.121	6.512	Co-integration

The article employs a correlation matrix to show the directional associations among the variables. The results reveal that sharing economy users, sharing economy values, exports, population growth, and FDI have positive associations with efficient energy use and SED in China. These associations are given in Table 3.

The stationarity of the variables is examined using the ADF and PP tests. The results indicate that SED, SEU, PG, and FDI are stationary at a level, while SEV and EXP are stationary at first difference. These results are given in Table 4.

The ARDL bound test is used to examine the co-integration, which is necessary for applying the ARDL model. The results show that the calculated f-statistic value is 6.872, which is larger than the lower and upper bound, and indicates that co-integration exists. These results are given in Table 5.

The results of the nonlinear ARDL model for SED reveal that sharing economy users, sharing economy values, exports, population growth, and FDI have positive associations with SED in China. The results show that the asymmetric effects of EXP, PG, and FDI also have positive associations with SED. The R square indicates that 54.2% of changes in SED are due to SEU, SEV, EXP, PG, and FDI. These associations are given in Table 6.

Table 6
Nonlinear ARDL results for SED.

Variable	Coefficient	Std. Err.	t-statistic
C	1.092	0.391	2.793
SED (−1)	1.912	0.493	3.878
SEU (−1)	2.089	0.529	3.949
SEV (−1)	1.937	0.712	2.721
EXP-P (−1)	2.677	0.271	9.878
EXP-N (−1)	2.966	0.912	3.252
PG-P (−1)	3.121	1.102	2.832
PG-N (−1)	0.917	0.201	4.562
FDI-P (−1)	0.981	0.331	2.964
FDI-N (−1)	0.611	0.109	5.606
Adj. R Square	0.542		
F-statistics	50.201		
Prob.(F-statistics)	0.004		

Table 7
Nonlinear ARDL results for EEU.

Variable	Coefficient	Std. Err.	t-statistic
C	2.093	0.576	3.634
EEU (−1)	4.902	1.823	2.689
SEU (−1)	3.067	1.102	2.783
SEV (−1)	0.549	0.192	2.859
EXP-P (−1)	1.903	0.372	5.116
EXP-N (−1)	2.674	1.019	2.624
PG-P (−1)	4.673	1.722	2.714
PG-N (−1)	1.983	0.629	3.153
FDI-P (−1)	1.874	0.528	3.549
FDI-N (−1)	1.772	0.405	4.375
Adj. R Square	0.530		
F-statistics	47.192		
Prob.(F-statistics)	0.001		

The results of the nonlinear ARDL model for EEU reveal that sharing economy users, sharing economy values, exports, population growth, and FDI have positive associations with EEU in China. The results show that the asymmetric effects of EXP, PG, and FDI also have positive associations with SED. The R square indicates that 53.0% of changes in EEU are due to SEU, SEV, EXP, PG, and FDI. These associations are given in Table 7.

Discussion

The study results indicate that sharing economy users have a positive impact on the efficient use of energy. These results are supported by Khalid et al. (2018), who show that, when sharing economy users increase in some regions, there is optimal use of energy sources, because of the significant decrease in the number of technologies, transport vehicles, and other logistics being used. So, an increase in sharing economy users encourages efficient energy use. These results are also supported by Na and Kang (2018), who show that, when a greater number of people or firms indulge in sharing of resources or technologies, they can perform their operational and production processes using minimum factors of production but still have maximum outcomes. This reduces the overall use of energy resources used in a region. The results indicate that sharing economy users positively impact sustainable economic development. This is in line with Laukkanen and Tura (2020b), who show that, with an increased number of people willing to be involved in sharing strategies, resources, and technologies, the differences in access to resources, human capital and technologies decreases. This creates equal success opportunities for business units and thus contributes to sustainable economic development. These results are in line with Hu et al. (2019), who reveal that an increase in the number of users in a sharing economy divides the burden of the cost of resources, and encourages improved economic practices, including innovation, improved productivity, reduced use of energy sources, enhanced employment, and improved living standards for people. Thus, sharing economy users enhance sustainable economic development.

The results show that sharing economy value positively impacts efficient use of energy. This result matches Henni, Staudt and Weinhardt (2021), who state that an increase in sharing value means that the economic entities sharing of resources, technologies, information, etc. save the costs accrued in down-time or acquiring resources. The capital saved can be used in social and ecologically friendly practices that minimize energy use for the same productivity. These results match Filipović, Radovanović and Lior (2019), who show that an increase in sharing economy value leads to a greater number of individuals using the sharing economy for their daily tasks and firms getting their desired outcomes using energy-efficient material, machinery, and instruments. So, increased sharing economy value brings efficiency in energy usage. The results indicate that sharing economy values positively impact sustainable economic development. This result is in line with Geissinger et al. (2019), who show that an increase in the value of the resources, techniques, ideas, and information shared by individuals, groups, or a circle of firms, can help overcome environmental concerns such as water pollution, air pollution, GHG emissions, soil pollution, and dirty water. With the assurance of environmental quality and abundant resources, a healthy labor force creates sustainability in economic development. These results are also supported by Jabbour et al. (2020b), who reveal that in countries where the sharing economy is encouraged, a large amount of quality resources can be made available for future use, because of efficient allocation of resources, the saving of finances, and reduced environmental issues. Thus, increased sharing economy value assures sustainable economic development.

The results show that exports positively impact the efficient use of energy. This result matches Waheed, Sarwar and Mighri (2021), who reveal that, in order to raise international marketing for domestic goods and services, a country needs to improve the products and services they present in the international market. Such an improvement in goods and services is possible if domestic enterprises take care of ecological performance. So, exports increase the efficient use of energy. The results state that exports have a positive impact on sustainable economic development. This result agrees with Akalpler and Hove (2019), who examine the role of exports in sustainable economic development. Countries making progress in exports have higher foreign exchange, improved quality products and services, large volumes of production, and innovative technologies. These are all essential factors in sustainable economic development. The results show that population growth positively impacts the efficient use of energy. This result agrees with Mullan and Haqq-Misra (2019), who suggest that, in a country with a large stable population, education and training facilities increase. With an increase in environmental awareness and ways to mitigate it, efficient use of energy increases. The results indicate that population growth positively impacts sustainable economic development. This result matches Dong et al. (2018), who show that the increased population of a country determines the volume of human capital. With an increased population, there is a requirement to increase the provision of basic needs. This results in increased productivity, so there are increased natural and manufactured resources and high sustainability in the economy. The results show that FDI positively impacts the efficient use of energy. This result matches Muhammad and Khan (2019), who show that an increase in FDI inflow helps improve resources, human capital, management, and technology, which leads to more efficient use of energy within a country. The results reveal that FDI has a positive impact on sustainable economic development. This result matches Mukhtarov et al. (2021), who show that, for high sustainability in economic development, consistency in human capital development, business management, and economic practice is needed. This consistency is possible with an increase in FDI.

Conclusion, implications, and limitations

The authors wrote this study intending to find the influences of sharing economy users and sharing economy value on efficient use of energy and sustainable economic development. The study also has the objective of analysing the impacts of exports, population growth, and FDI on efficient energy use and sustainable economic development. Quantitative information regarding sharing economy users, sharing economy value, exports, population growth, FDI, efficient use of energy, and sustainable economic development are collected for the Chinese economy. In light of the empirical analysis, the results show positive relationships between sharing economy users, sharing economy value, exports, population growth, and FDI with efficient use of energy and sustainable economic development. The results indicate that, when the number of sharing economy users increases in a country, the total use of technologies and energy required can be reduced, and the resultant efficient use of energy and reduction in environmental issues contribute to sustainable economic development. Similarly, an increase in sharing economy value reduces overall costs, and even with limited financial resources, energy-efficient resources and technologies can be used. So, there is high energy efficiency, and the economy sees sustainable development. The results indicate that an increase in exports, population growth, and FDI improve financial resources, technological processes, skilled human capital, and management, so there is an acceleration in energy efficiency and sustainable economic development.

Implications

This article guides policymakers establishing policies related to the achievement of sustainable economic development and energy efficiency using a sharing economy. The study guides governments and economic or regulatory authorities to form policies to encourage sharing economies along with effective management of exports, population growth, and FDI so that efficient use of energy can be developed and sustainable economic development can be achieved. From a practical standpoint, the conclusions made here serve as a knowledge base for those who design strategy, policy, and tools with the intention of inspiring current and potential users of sharing economies, and subsequently enhancing performance in the sustainability area. There is a need for ongoing and coordinated efforts by all sectors to enhance the sharing economy's technology, governance, and operation while preserving its core components. Governments, in particular, should actively encourage the growth of shared economies and create governance structures that support this growth.

Despite making significant theoretical and empirical contributions, the present study has some limitations. If future authors pay attention to the same subjects, these limitations can be overcome. Firstly, although the authors select two subjects, efficient use of energy and sustainable economic development, they do not detail the contributing factors except for an analysis of the sharing economy, putting limits on the study's completeness, clarity, and validity. So, it is recommended that future authors include more factors of efficient energy use and sustainable economic development. In addition, the need for efficient use of energy and sustainable economic development is a nation-based issue. So, the data collected from a single economy cannot be used to present generalized findings. Future authors should collect data on economies other than China.

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