Environmental Science and Pollution Research (2023) 30:35996–36011
https://doi.org/10.1007/s11356-022-24695-x

RESEARCH ARTICLE

Exploring the nexus between energy consumption, income inequality and poverty, economic growth, and carbon dioxide emission: evidence from two step system generalized method of moments

Hayat Khan[1] · Liu Weili[2] · Itbar Khan[3] · Jianfang Zhang[4]

Received: 29 May 2022 / Accepted: 6 December 2022 / Published online: 21 December 2022

Abstract
The concern of environmental degradation, poverty, and income inequality remains a priority in achieving sustainable development goals. Countries are trying to reduce income inequality, alleviate poverty, and reduce environmental degradation which needs special attention. Consequently, this study explores the effect of income inequality, poverty, and energy consumption on carbon dioxide emission in the Belt and Road Initiative countries from 1996 to 2018. By employing the generalized method of moments, the findings show that income inequality, poverty, and energy consumption significantly increase carbon dioxide emission and lead to environmental degradation, while access to electricity significantly raises environmental quality. Economic growth positively affects carbon dioxide emission; however, the environmental Kuznets curve is valid. Income inequality exerts a moderating effect on carbon dioxide emission via per capita economic growth that reduces environmental degradation in the Belt and Road Initiative countries. The results of this study give important policy implications for the Belt and Road Initiative countries.

Keywords Income inequality · Poverty · Economic growth · Energy consumption · Environmental Kuznets curve · Carbon dioxide emission

Introduction

The continued concerns for achieving sustainable development have grown over the past years as the quality of the environment begins to decline due to increased economic activities. Poverty reduction and environmental change are important agendas for achieving sustainable development targets. Most countries around the world struggle to reduce poverty and provide a clean environment for future generations. Therefore, it is a challenge for countries that how to increase economic growth, reduce income inequality and poverty, and attain higher environmental quality. An increase in production to raise economic growth and living standard consumes a large amount of energy which in turn releases a high amount of carbon dioxide emission and degrades the quality of the environment (Padhan et al. 2019). Poverty alleviation through economic development and attaining environmental quality are the main concern of countries in sustainable development, especially in developing countries. The Belt and Road Initiative countries are mostly developing and emerging economies that also focus to alleviate poverty through the increase in economic activities. Encouraging economic activities to raise economic growth and alleviate poverty upsurges the level of production and industrialization which in turn raises the energy demand and thus increases carbon emissions and lowers sustainable development (Danish 2019). Economic growth may alleviate poverty in developing countries but may also

Responsible Editor: Eyup Dogan

✉ Liu Weili
liuweili83@yahoo.com

Hayat Khan
drhayatkhankhilji@gmail.com

Itbar Khan
khanitbar321321@gmail.com

[1] School of Economics and Management, Zhejiang University of Science and Technology, Hangzhou, China

[2] China Center for Special Economic Zone Research, Shenzhen University, Shenzhen, China

[3] Business School of Xiangtan University, Hunan, China

[4] China National Institute of Standardization, Beijing, China

create environmental problems (Grunewald et al. 2017). The reason for high carbon emissions is poverty and misuse of environmental resources by impoverished people for better survival (Masron and Subramaniam 2019). Some researchers argue that poverty is a major determinant of environmental degradation, especially in developing countries, because poverty is united with high population growth rates and poor environmental policies, which increase pressure on available resources and reduce environmental quality (Koçak et al. 2019). It is believed that poverty lowers the buying power of goods and services, and a decline in the buying power, in turn, reduces productivity and enhances the quality of the environment (Jin et al. 2018; Khan 2019); (Dhrifi et al. 2020). Income inequality raises carbon emissions, whereas poverty also exerts a detrimental effect on pollution (Khan et al. 2020). The level of environmental degradation is measured as per capita carbon emission, and carbon emission is considered the most pollutant contributor to the environment (Houghton 1996). It has been argued that increased economic growth reduces environmental quality because economic growth increases emissions through production and damages environmental quality; however, increased incomes may reduce poverty (Grunewald et al. 2017). The EKC (environmental Kuznets curve) hypothesis holds that an increase in per capita income increases pollution, but further increases in per capita income levels reduce emissions at a certain level (Grossman and Krueger 1991); (Panayotou 2003); (Selden and Song 1994). Economic growth is helpful in poverty alleviation while economic growth is itself a harmful factor in rising carbon emissions and environmental degradation; therefore, the relationship between economic growth and environmental quality is proven (Franklin and Ruth 2012). Environmental consequences should be considered, and policies should be inclusive when rising economic growth to reduce poverty and income inequality (Kraay 2004) (Fig. 1) shows the relationship between variables.

The current study intends to inspect the Belt and Road Initiative countries' income inequality, poverty, energy consumption, economic growth, and environmental quality association. The Belt and Road Initiative originated in China but belong to the world. They are involved in different regions, countries, cultures, and lifestyles. The aim of the Belt and Road Initiative's origination is to initiate peaceful economic cooperation and development among countries. The principles of the Belt and Road Initiative are extensive consultants, shared benefits, and joint contributions and so on. It focuses on policy coordination, connectivity of infrastructure, unimpeded trade, financial integration, and closer people-to-people ties. It has turned ideas into actions and vision into reality, and the initiative itself into a public product widely welcomed by the international community. There is a large number of countries in the Belt and Road Initiative project, including developing, developed, emerging, and less

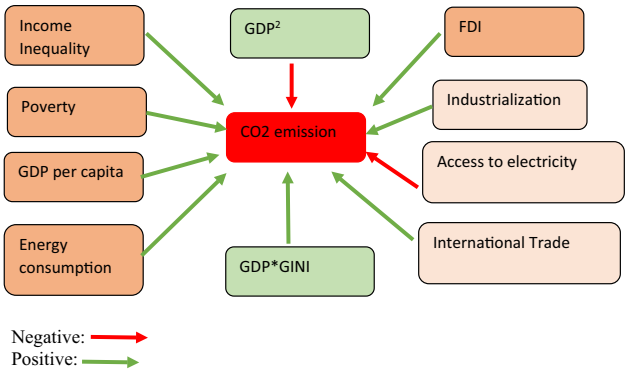

Fig. 1 The relationship between variables. Negative: red arrow. Positive: green arrow

developed countries with different economic, trade, institutions, income levels, and environmental quality. The low-level or developing countries are still in combat to upsurge economic growth, reduce income inequality and poverty, and also reduce carbon emissions. However, an increase in economic activities through production raises energy demand and thus raises carbon emissions. These countries may not have attained renewable energy to use for production and economic activities and still be contingent on nonrenewable energy sources. It is, therefore, important to give policy suggestions for the sample countries on increasing economic activities through production to reduce poverty and income inequality as well as achieve sustainable development and higher environmental quality. This study uses both poverty and income inequality, economic growth, and energy consumption to examine their effect on carbon emission.

Limited studies have been conducted linking both poverty and income inequality along with closely related factors such as industrialization, economic growth, energy consumption, and carbon emission. As emerging and developing economies, it is very important to investigate the environmental impacts of countries along the "Belt and Road Initiative." This study also assumes that the relationship between income inequality and carbon dioxide in countries along the "Belt and Road Initiative" be conditional on the level of economic growth. Consequently, this study uses the interaction between income inequality and economic growth to test this hypothesis. Likewise, this study also considers the squared term of GDP per capita to inspect the environmental Kuznets curves of the sample countries. This helps to determine the impact of economic growth on carbon emissions when selected BRI countries reach a certain level of development. The environmental Kuznets curve hypothesis suggests that when a county grasps a certain level of development reducing carbon emissions, economic growth has a positive impact on emissions in the preliminary phase of development. To the best of our knowledge, no such examination

has ever been conducted on selected BRI countries in past research. The current study is new and the first of its sympathetic to consider the impact of both poverty and income inequality along with closely related factors such as energy consumption and economic growth on carbon emissions in selected Belt and Road Initiative countries. Panel data were collected from 1996 to 2018 and examined using dynamic panel methods. The analysis results show that poverty, economic growth, income inequality, energy consumption, and industrialization significantly increase the level of carbon dioxide emissions in countries along the "Belt and Road Initiative"; nonetheless, electricity harms carbon emissions, in that way reducing carbon emissions. The results further validate the environmental Kuznets curve hypothesis, and the interaction term of income inequality and economic growth significantly reduces environmental degradation.

Literature review

Various approaches in the preceding literature have been identified by which income inequality affects carbon dioxide emissions and the environment. Several researchers have examined the influence of income inequality on carbon emission along with other related variables for different countries and regions but achieved mixed results. Poverty has also been examined in such association and its effect on the quality of the environment has been debated in the prevailing studies. Some researchers argue that poverty causes environmental damage, especially in developing countries, where poor environmental policies reduce environmental quality by increasing pressure on available resources in these countries (Koçak et al. 2019), while some other researchers believe that poverty lowers buying power and reduces people's affordability to buy food and acquire services and thus a decline in the buying power, in turn reducing productivity and enhancing the equality of environment (Jin et al. 2018; Khan 2019); (Dhrifi et al. 2020). Similarly, other factors are also included in such associations such as a rise in population, industrialization, energy use, and economic growth. Several researchers believe that rising economic growth through production and industrialization increases the energy demand; however, the increase in economic activities, energy consumption, and industrialization leads to increased carbon emissions and decreased environmental quality (Danish 2020). This study lists some previous studies that have examined the impact of income inequality and other related factors on environmental quality. The studies were conducted on different countries' samples with different periods and methods. For example, Baloch et al. (2020) used the Driscoll-Kraay regression estimator to study the impact of income inequality and poverty on carbon emissions in a sample of sub-Saharan African countries from 2010 to 2016 and found that income inequality exacerbated carbon emissions and poverty also increases pollution in sub-Saharan Africa. Similarly, Mahalik et al. (2018) used ARDL to investigate the association between income inequality and environmental quality at various country levels in the BRICS. The results showed that income increased emissions in Brazil, India, and China while reducing emissions in South Africa. The impact of coal use increases emissions in India, China, and South Africa, but has no impact on Brazil. Oil production contributes to Brazil's carbon emissions while reducing emissions from South Africa, China, and India. Similarly, Hailemariam et al. (2020) conducted another study in OECD countries. The authors examine the impact of income inequality on environmental quality by incorporating economic growth into the model and using panel data techniques. The findings suggest that an increase in income inequality increases carbon dioxide emissions, while the nonlinear relationship between carbon emissions and economic growth validates the environmental Kuznets curve. In terms of marginal emission propensity, the Gini index reduces the carbon emissions of sample countries.

Similarly, Guo et al. (2020) investigated the impact of income inequality on carbon emissions in countries in the income groups and found a negative correlation between the variables, while they found a positive correlation between income inequality and reduced risk in countries with lower income. They further show that income inequality does not affect emissions in high- and middle-income countries. This study further validates the determinantal impact of income inequality in upper-income countries. Zhao et al. (2021) used a nonlinear ARDL model to study the relationship between income inequality and carbon dioxide emissions in BRICS countries. The results of this study show positive and negative changes in income inequality and its positive impact on carbon dioxide emissions in Russia, Brazil, and China, and negative changes in income inequality. Furthermore, Padhan et al. (2019) examined the linkage between economic growth, energy consumption, wealth inequality, and carbon emissions in the next 11 countries from 1971 to 2013. Econometric techniques include panel unit root tests and Westerlund cointegration. The results show that economic growth, energy consumption, and income inequality increase carbon dioxide emissions. Within the framework of the EKC hypothesis, Demir et al. (2019) investigated the impact of income inequality on environmental quality in Turkey. By collecting data from 1963 to 2011 and using the ARDL model to analyze the data. The results show a negative relationship between income inequality and carbon emissions, suggesting that income inequality reduces environmental degradation in the sample countries.

Another study by Liu et al. (2019) in 30 Chinese provinces between 1996 and 2014 investigated the effects of income inequality and carbon emissions. The results show

that economic growth raises carbon emission levels; however, the environmental Kuznets curve is valid in the study. Another study conducted by Chen et al. (2020) investigated the relationship between income distribution and carbon emissions within the framework of the environmental Kuznets curve. Using simultaneous quantile regression, the study found that an equal distribution of income improves environmental quality in developed countries, while income inequality barely affects emissions levels. Similarly, Cetin et al. (2018) used a cointegration approach from 1960 to 2013 to study the impact of Turkey's trade openness, energy consumption, and economic growth on carbon dioxide emissions. The findings confirm a structurally disrupted long-term relationship between energy consumption, economic growth, trade, and carbon dioxide emissions. The results further show that carbon emissions are determined by energy consumption, financial development, trade, and economic growth. Their research also validated the environmental Kuznets curve hypothesis. Chukwuma et al. (2022) demonstrate forensic accounting in predicting financial performance and growth of mobile communication in Nigeria. The authors used the OLS regression model and found that there was a statistically significant association between forensic accounting instruments and financial performance. On the other hand, Robeena and Sumaira 2022a, b) studied the effect of trade openness and financial development in south Asian countries from 1980 to 2017 using the dynamic panel and static models. The findings show that financial development proxy by stock market development indicator significantly rise economic growth while trade openness, inflation, and interest rate significantly reduce economic growth. Similarly, Sumaira and Bibi (2022) examine the effect of banking sector growth on economic growth in four countries of south Asian for the period of 1980 to 2017. The authors employed fixed effect, difference GMM, and system GMM model and found that banking sector development increases economic growth. The authors argue that broad money, domestic credit to the private sector, and private sector credit by banks significantly lead to higher economic growth. Robeena and Sumaira 2022a, b studied the role of FDI and financial development on economic growth in different income-grouped countries and in the global panel from 1998 to 2018 using dynamic panel models. The authors found that FDI positively affects economic growth in lower-middle-income, upper-middle-income, and global-income countries. The findings further reveal that banking sector development has negative effect on the global panel, high-income and upper-income countries' growth, while this effect is insignificant in lower middle income. Likewise, Jamil (2022a, b) explore the monetary policy performance under the control of exchange rate and consumer price index. The authors found that stabilizing the effect on the trend and price of the exchange rate stabilizes the countries' output. The findings further show that monetary policy control and the price level do not affect exchange rate and production. Moreover, Jamil (2022a, b) studied the effect of the exchange rate regime on a county's economic growth using a generalized method of moments. The variables used in the study were per capita GDP, GDP growth, foreign trade, and inflation. The authors argue that post-Bretton woods transition from fixed to flexible management was found and there was a strong association between the exchange rate regime and the countries' growth rate. Bibi and Sumaira (2022) examine the effect of both bank-based and stock market–based financial development on economic growth in south Asian countries from 1980 to 2017. The authors employed static and dynamic models and found that both banks and stock markets significantly and positively contribute to economic growth in the sample countries.

From the literature review organized above, we conclude that there is a large number of studies which have examined the effect of income inequality along with other variables on carbon dioxide emission for a different sample of countries with different econometric models and data samples. We conclude that this different sample of countries has different characteristics such as the regions are different, economic growth levels, cultures, and lifestyles, and thus the effect of income inequality on carbon dioxide emission can be varied across countries. The Belt and Road Initiative countries are also developing and emerging economies with unique characteristics to other countries. The aim of the Belt and Road Initiative countries' origination is to initiate peaceful economic cooperation and development among countries. The principles of the Belt and Road Initiative are extensive consultants, shared benefits, and joint contributions and so on. It focuses on policy coordination, connectivity of infrastructure, unimpeded trade, financial integration, and closer people-to-people ties. It has turned ideas into actions and vision into reality, and the initiative itself into a public product widely welcomed by the international community. There is a large number of countries in the Belt and Road Initiative project, including developing, developed, emerging, and less developed countries with different economic, trade, institutions, income levels, and environmental quality. The low-level or developing countries are still in combat to upsurge economic growth, reduce income inequality and poverty, and also reduce carbon emissions. However, an increase in economic activities through production raises energy demand and thus raises carbon emissions. These countries may not have attained renewable energy to use for production and economic activities and still be contingent on nonrenewable energy sources. It is, therefore, important to give policy suggestions for the sample countries on increasing economic activities through production to reduce poverty and income inequality as well as achieve sustainable development and higher environmental quality. Such examination in the literature has not been attempted which investigates the effect of

income inequality, poverty, energy consumption, and related variables along with the interactive effect of income inequality and economic growth on carbon dioxide emission which is our research gap to investigate this association for the belt and road initiative countries.

Methodology

Variables and empirical model specification

This study uses balanced panel data to examine the impact of income inequality and poverty, economic growth, and energy consumption on carbon dioxide emissions in 40 countries from the Belt and Road Initiative between 1996 and 2018. Data for all variables used in this study come from the World Bank database, the World Development Indicator. This indicator data is used by numerous studies in environment-related research, such as Holtz-Eakin and Selden (1995), Martínez-Zarzoso and Maruotti (2011), and Khan et al. (2022b). The variables used in the study are CO2 emission (metric tons per capita), GINI which represents income inequality is the GINI index which is a measurement of the income distribution of residents in a country. The 0 indicates perfect equality, while the 100 represents perfect inequality. Likewise, poverty (POVT) is used in the model which is measured as a headcount ratio of $1.90/day percent. GDP per capita represents economic growth, energy consumption is measured as kilogram of oil equivalent per capita, foreign direct investment (FDI) is taken as the net inflow of foreign direct investment, industrialization (IND) is measured as industry value-added, ACCT is access to electricity (access to electricity (%)), international trade (TO) as a percent of GDP, INF is inflation (consumer prices (annual)), while urbanization (URB) is taken as the urban population as percent of the total population.

The selection of these variables aims to alleviate poverty, minimize income inequality, acquire renewable energy sources and reduce fossil fuels, control pollution and reduce urbanization, increase sustainable economic growth, and manage inflation and trade to reduce carbon dioxide emission and attain sustainable development in the selected sample countries of the Belt and Road Initiative.

Carbon dioxide emission taken as metric tons per capita is the dependent variable that has been considered a major factor of global warming and greenhouse gas emission. The GINI coefficient is used to measure income inequality which is used by Torras and Boyce (1998) and Liu et al. (2020) to support that a change in the level of income inequality affects the environmental pollution of a country. The theory postulates that a rise in income inequality promotes the level of carbon emission. The maximum value is 1 while the minimum value is 0; when it reaches the maximum value, that indicates that one person receives all the income while the minimum value shows that there is equal income distribution. However, these cases rarely occur in reality; a larger GINI coefficient generally illustrates large income inequality. Income inequality influences environmental quality positively or negatively. The positive effect of income inequality can be the reason that poor people in the countries and the people of poor countries may depend on the use of abundant natural resources to fulfil basic needs. The natural resources can be the use of fossil fuels and other food wastes as the technological innovation and the living standard in these low-level countries are low and that is why these counties and the people use natural resources and they do not have enough modern technology or to use the renewable energy and another environmentally friendly way to fulfil their needs. For example, in developing countries, low-level cities are mostly related to environmental degradation as the people in these countries still use traditional ways to acquire food and they also use traditional transportation systems the food and restaurants also use the traditional way. The people who work in these small factories are also low-income people in developing countries and most of the way of life is traditional as well the activities are traditional which are being performed to get food and basic standard. That is why income inequality can be related to environmental degradation, especially in developing countries included in the panel however if there is equal distribution of income can rise environmental quality.

Poverty is considered a major determinant of environmental degradation, particularly in underdeveloped countries. With increased population, there is a rise in poverty, and poor policies of environment rise stress on available resources and degrade environmental quality. As Zhao et al. (2021) argue, poverty reduces carbon dioxide emission in China and Russia in the short run as an increase in poverty lowers the buying power and affordability of buying goods and services and a decline in the buying power, in turn, reduces productivity and protect the quality of environment (Jin et al. 2018; Khan 2019); (Dhrifi et al. 2020).

Likewise, it has been argued in previous research that a rise in economic growth raises carbon emission and degrades environmental quality. Those countries which are mostly focusing on rising economic growth to raise the living standard will have lower environmental quality. An increase in economic activities such as production, industrialization, trade, and so on consumes a large amount of energy which leads to environmental degradation, especially in low-income countries. Thus, increase in economic growth is harmful to the quality of the environment. Apergis and Li (2016), Krueger and Grossman (1995), and Bai et al. (2020) argue that carbon emission is affected by per capita income and is a vital factor to affect the level of emission of a country. Some studies in the previous literature use the

squared term of GDP per capita to demonstrate the environmental Kuznets curve ((Stern 2004); (Mader 2018). The environmental Kuznets curve hypothesis shows that when a country reaches a certain level of development, economic growth reduces emissions while economic growth has a positive impact on carbon emissions at the initial stage of development in a country. Based on previous research, this study also adds the quadratic function of economic growth to examine the nonlinear effect of per capita growth on carbon dioxide emissions.

Likewise, energy consumption is also related to environmental quality, as increased energy consumption increases carbon emissions. Energy is used for production to boost economic growth, but this leads to increased carbon emissions and reduced environmental quality. Energy is the combination of renewable and nonrenewable energy. Understandably, renewable energy consumption reduces carbon dioxide emissions while nonrenewable energy use increases emissions. The sample countries have not yet reached fully utilized renewable energy sources, and they are also still not dependent totally on fossil fuels; thus, we use energy consumption in total to find its effect on carbon dioxide emission. Khan et al. (2021a, b, 2022a) and Tsuji et al. (2002) also indicate that increase in energy use raises carbon dioxide emissions that worsen environmental quality. In this regard, this study also included energy consumption in the model to study its impact on carbon emissions.

Similarly, several researchers have examined the impact of foreign direct investment on carbon emissions in previous studies. The impact of FDI on carbon emissions can be negative or positive, depending on the countries' level of FDI inflows. The impact of FDI on carbon dioxide emissions has two phenomena. The first phenomena are the pollution haven hypothesis, while the second is the pollution halo effect hypothesis. The halo effect shows that an increase in FDI inflows improves environmental quality by reducing a countries carbon emissions, while the haven effect shows that an increase in FDI in a country increases emission levels and reduces environmental quality. In the former perspective, it is stated that energy-intensive companies prefer to build in countries where the environmental regulations policies are weak (Walter and Ugelow 1979) (Copeland and Taylor 1994). However, the later perspectives indicate that foreign direct investment brings advanced technologies and management that are environmentally friendly and enhance the quality of the environment (Birdsall and Wheeler 1993) (Liang 2008). We add foreign direct investment to the model to test its effect on environmental quality in the belt and road countries.

Past studies argue that a rise in industrialization affects environmental quality where the greater degree of industrialization raises the level of production which in turn increases carbon dioxide emission and reduce environmental quality (Ghisellini and Ulgiati 2020) (Canh 2019) (Khan et al. 2022b) (Nguyen et al. 2018). Access to electricity is also needed for economic growth; however, it affects the quality of the environment and brings changes to carbon dioxide emissions as it allows the use of energy-intensive products that release emissions (Dagnachew et al. 2018).

International trade is also added to the model to examine its effect on carbon emissions. Trade can affect environmental quality positively or negatively as Antweiler et al. (2001) indicates that trade can affect the environment through composition, trade, scale, technology, and technique effects. A rise in the economic scale of a country with a rise in trade openness leads to the degradation of the environment referred to as the scale effect. The technical effect refers to comparative advantage in dirty or clean industries in the global specialization. The composition and technique effect of trade on environmental quality is positive and that is the rise in the environmental quality of a country.

Inflation may also influence the level of carbon dioxide emission as inflation increases the production cost leading to an increase in the prices of renewable energy sources and other technology that are friendly to the environment. An increase in urban population is also related to increasing carbon dioxide emissions (Li et al. 2019). Urbanization transfers rural to urban transition and moves an agricultural economy to an industrial economy ((Muhammad et al. 2020). When there is an increase in urbanization, the emission level will increase as inhabitant production and improvement in living standards as well as industrialization. However, it has also been argued that agglomeration in population due to the rise in urbanization enhances the energy use effectiveness and contributes to achieving economy of scale (Solarin and Lean 2016). Several studies in preceding literature show that if there is an increase in urbanization, it will upsurge the level of emission (Nguyen et al. 2018) (Canh 2019) (Ghisellini and Ulgiati 2020) (Khan et al. 2022b).

By following the empirical studies of Baloch, Khan et al. (2020), Baek and Gweisah (2013), and Liu et al. (2020), the following empirical model is constructed to investigate the influence of poverty, income inequality, economic growth, and energy consumption on carbon emission in the selected belt and road initiative countries.

$$CO2_{it} = \beta_0 + \beta_1 GINI_{it} + \beta_2 POVT_{it} + \beta_3 GDP_{it} + \beta_4 ENR_{it} + \beta_5 FDI_{it} + \beta_6 IND_{it} + \beta_7 ACCT_{it} + \beta_8 TO_{it} + \beta_9 INF_{it} + \beta_{10} URB_{it} + \varepsilon_{it} \quad (1)$$

where CO2 is carbon dioxide emission which is the dependent variable, GINI is income inequality, POVT is poverty, GDP is per capita gross domestic product, ENR is energy consumption, FDI is foreign direct investment, IND is industrialization, ACCT is access to electricity, TO is international trade, INF is inflation, and URB is urbanization.

$$CO2_{it} = \beta_0 + \beta_1 GINI_{it} + \beta_2 POVT_{it} + \beta_3 GDP_{it} + \beta_4 (GDP)^2_{it} + \beta_5 ENR_{it} + \beta_6 FDI_{it} + \beta_7 IND_{it} + \beta_8 ACCT_{it} + \beta_9 TO_{it} + \beta_{10} INF_{it} + \beta_{11} URB_{it} + \varepsilon_{it} \quad (2)$$

Table 1 Variables description

Variables	Descriptions
CO2	Carbon dioxide emissions are taken as a metric ton per capita
GINI	GINI (income inequality index)
POVT	Poverty, headcount ratio at $1.90/day percent
GDP	Per capita Gross domestic product
ENR	Energy consumption measured as kg of oil equivalent per capita
FDI	Foreign direct investment net inflow of FDI
IND	Industrialization measured as industry value-added
ACCT	Access to electricity percent
TO	International trade % GDP
INF	Inflation, Consumer prices (annual)
URB	Urban population as percent of the total population

Table 2 Descriptive statistics

Variable	Mean	Std. Dev	Min	Max
CO2	4.320	3.403	0.001	15.04
GINI	34.07	5.521	23.7	49.9
POVT	5.129	10.06	0.001	81.6
GDP	3.837	4.107	-17.93	17.03
ENR	1895.96	1209.98	281.77	5167.01
FDI	4.064	5.524	-40.329	54.23
IND	29.919	8.117	14.303	58.88
ACCT	93.070	17.507	6.90	100.00
TO	91.328	38.781	25.306	220.406
INF	10.229	39.463	-18.108	1058.37
URB	3.280	9.790	1161	8.240

$$CO2_{it} = \beta_0 + \beta_1 GINI_{it} + \beta_2 POVT_{it} + \beta_3 GDP_{it} + \beta_4 (GDP)^2_{it} + \beta_5 ENR_{it} + \beta_6 FDI_{it} + \beta_7 IND_{it} + \beta_8 ACCT_{it} + \beta_9 TO_{it} + \beta_{10} INF_{it} + \beta_{11} URB_{it} + (GDP * GINI) + \varepsilon_{it} \quad (3)$$

We introduced the quadratic term of the per capita income into the model in Eq. 2 to verify whether the EKC hypothesis is effective in the extended model. The model can be rewritten as Eq. 2. We also add the interaction term between per capita income and GINI. The model can be stated as Eq. 3. The variables' description is given in Table 1, and the descriptive statistics and correlation matrix of the study variables are presented in Table 2 and Table 3, respectively. Collected data was first analyzed through descriptive statistics. Descriptive statistics represent graphical or numerical methods used to summarize the data in meaningful ways thus allowing for a simpler interpretation of the data. Statistics measures attempted to describe data by identifying the central position within the data set. Measures of central tendency were also complemented by measures of spread such as the standard deviation, maximum and minimum values. The measures of spread show how to spread out or how similar or dissimilar the data are. The descriptive statistics were also summarized through tabulations which were also complemented by discussions. However, descriptive statistics only serve to describe the data. They do not allow for conclusions or inferences to be drawn from the data. This means descriptive statistics have to be augmented by other data analysis approaches. The min is simply the lowest observation, while the max is the highest observation. Obviously, it is easiest to determine the min and max if the data are ordered from lowest to highest.

Econometric techniques

This study employed both static and dynamic models including OLS, fixed effect estimator, two-step difference GMM, and two-step system GMM models for analysis. The use of static models in panel data might produce several econometric problems such as the problem

Table 3 Correlation

	CO2	GINI	POVT	GDP	ENR	FDI	IND	ACCT	TO	INF	URB
CO2	1.000										
GINI	−0.16	1.000									
POVT	−0.476	0.169	1.000								
GDPPC	−0.02	0.104	−0.034	1.000							
ENR	0.941	−0.225	−0.530	−0.053	1.000						
FDI	0.088	−0.035	−0.114	0.228	0.025	1.000					
IND	0.132	0.083	0.162	0.136	0.099	−0.159	1.000				
ACCT	0.383	−0.134	−0.460	−0.016	0.445	0.007	−0.123	1.000			
TO	0.107	−0.393	−0.229	0.029	0.200	0.215	−0.173	0.282	1.000		
INF	0.010	−0.023	0.133	−0.020	0.031	−0.041	0.111	0.015	0.016	1.000	
URB	0.039	0.317	0.169	0.124	−0.020	−0.116	0.433	−0.040	−0.384	−0.017	1.000

of autocorrelations in the regression model in presence of lagged dependent variable. Likewise, there may be a correlation in the fixed effect time-invariant in the error term with explanatory variables and may exist the issue of endogeneity between the dependent variables and the explanatory variables. In such situations, the use of instrumental variables needs to be adopted to eliminate the endogeneity issues such as the use of IV estimation. However, using the fixed-effect IV estimator feeble instruments may also be biased same as the ordinary least square regression model. Consequently, the generalized method of moments estimators is a good fit in panel data analysis, and it has been considered the most efficient estimator (Weili et al. 2022). GMM model has two types, namely, the difference and system GMM estimators. In the difference GMM estimator, the first difference between the dependent and independent variables is used to deal with specific country effects, and the first difference lagged dependent variables are instrumented with previous levels. In such a case, it removes the problem of autocorrelation; however, the lagged levels maybe be considered as poor instruments using the first difference and thus may decline the efficiency. To increase the model efficiency, Arellano and Bover (1995) and Blundell and Bond (1998) developed the system GMM estimator which is considered more efficient than the different GMM models. There are two system equations in the system GMM where one equation is a difference while the other remains at the level (Kurul 2021). After that, construct the second equation variable to its specific first-order difference and measure the variable in the difference by its specific lag level. Discussion of the advantages of the generalized method of moments, it is been also considered suitable in panel data with short period T and large N (number of countries). Arellano and Bover (1995), Blundell and Bond (1998), and Arellano and Bond (1991) recommend and further validate what Blundell and Bond (1998), Baltagi (2008), and Roodman (2009a, b) have studied. It is also called AB testing. This test examines the AR2 (second-order correlation) associated with the perturbation term in the generalized method of moment (GMM). Certain situations can lead to ineffective lag as an instrument. Therefore, Arellano and Bond (1991) point out that this test is more important than the test (AR1) because it already tests the availability of automated communications, especially at the surface. Furthermore, Arellano and Bond (1991) show that the AB test is very important in GMM because GMM estimators have consistency that depends on the E $E(\Delta_{\varepsilon i,t-2}) = 0$ condition. According to Arellano and Bond, (1991) and Blundell and Bond (2000), this test relies on false assumptions without an automatic connection and is tested for residues in differences. The AR1 test of AB in the first difference usually refutes the erroneous assumption due to $\Delta\varepsilon i,t\text{-}1 = \varepsilon i,t\text{-}\ \varepsilon i,t\text{-}1$ where both have $\varepsilon i,t\text{-}1$. This assumption may be valid if the EIT is not consistently relevant or does not follow a random walk to reduce the appropriate details of the modified dynamic model for panel data.

This is why AB, AR2 test is more important than the first difference because its autocorrelation detects the relationship levels. Furthermore, Roodman's (2009a) Sculpture states that this test may not be reliable for small dynamics for dynamic panels, but no alternative test has been discovered for this purpose. In our study, we have implemented the AB second-order autocorrelation test. AR1 and AR2 tests with the corresponding *p* value will be accepted sequentially, and it will be established that there is no serial automatic relationship in the second sequence in terms of error. If the AR (2) value is greater than the critical level, then it means that we will accept that there is no serial relationship.

Consequently, this study employed an ordinary least square model, fixed effect estimator, and generalized method of moments. However, the main focus of this study is on the system GMM especially the two-step system GMM model as it is preferred as the most efficient estimator while analyzing panel data.

Results and discussions

Table 4 presents the direct impact of poverty and income inequality on carbon dioxide emission where column 1 shows the list of variables, column 2 presents the OLS model results, column 3 presents the results of the fixed effect model, while columns 4 and 5 show the results of difference and system GMM models, respectively. As we mentioned in the methodology, our main focus is GMM and especially the two-step system GMM model as it is considered the most efficient estimator. The lagged dependent variables are positive and significant. The Arellano and Bond (1991) test for first- and second-order serial correlations in the first-order difference error and the Sargan test for over-identification restrictions are described. We found that the test of Arellano and Bond (1991) fulfil the requirements and accepted the null hypothesis that the error in the first-order difference regression does not show the second-order serial correlation AR (2), which evidence the fitness of the models. The over-identified restriction also rejects the null hypothesis and validates the model fitness and evidence of the correctness of the used tools.

In the given table below, the results of the impact of income inequality on carbon emissions are significant and positive both in the difference and system GMM models, as shown by the coefficients. The results show that rising income inequality raises carbon dioxide emissions in the sample countries, leading to environmental degradation. Specifically, the coefficient values indicate that if income

Table 4 The direct effect of poverty and income inequality on carbon emission

Variables	OLS	Fixed effect	Difference GMM	System GMM
GINI	0.023***	−0.008***	0.010***	0.010***
	(0.006)	(0.003)	(0.0001)	(0.0003)
POVT	0.002	−0.004*	0.0001***	0.033***
	(0.005)	(0.002)	(0.0002)	(0.0004)
GDP	−0.004	0.001***	0.0281***	0.0001***
	(0.011)	(0.003)	(0.0001)	(0.001)
ENR	0.002***	0.002***	0.002***	0.003***
	(4.580)	(5.780)	(3.420)	(2.760)
FDI	0.0462***	0.006**	0.063***	0.001***
	(0.008)	(0.003)	(0.0002)	(0.000)
IND	0.013*	0.021***	0.013***	0.013***
	(0.006)	(0.005)	(0.0003)	(0.0002)
ACCT	−0.014**	−0.009*	−0.001***	−0.081***
	(0.006)	(0.005)	(0.000)	(0.0008)
TO	−0.006***	−0.006***	0.005***	0.008***
	(0.001)	(0.000)	(0.0001)	(7.230)
INF	−0.000	0.000**	0.010***	0.004***
	(0.000)	(0.000)	(2.710)	(9.800)
URB	6.851	4.500***	5.430***	8.360***
	(5.631)	(9.851)	(0.001)	(8.301)
L.co2			0.001***	0.001***
			(0.0001)	(0.002)
Constant	-0.063	0.870		3.376***
	(0.684)	(0.560)		(0.082)
Observations	587	587	529	566
R-squared	0.906	0.835		
Number of id		37	36	37
AR1			−2.81(0.061)	−2.97(0.014)
AR2			−1.84(0.065)	−1.08 (0.279)
Sargan test			705.92(0.012)	486.80(0.941)

Note: Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

inequality in the BRI countries rises by 1%, the level of carbon dioxide emission will be increased by 0.01%. Our findings are reinforced by Baloch et al. (2020) and Magnani (2000). They also state that income inequality raises pollution; however, You et al. (2020) argues that emission can be reduced in high-income countries with higher economic growth as an improvement in income inequality. Baek and Gweisah (2013) illustrate that a high level of inequality raises emissions both in the short and the long run. Boyce (1994) gives the power-weighted social decision rule and argues that environmental degradation depends on the level of income distribution between poor and rich societies. Rich-class people are likely to affect the environmental decisions that lead to environmental degradation. Likewise, income inequality raises consumption competition which is associated with a rise in the use of energy, and thus a rise in energy use increases carbon dioxide discharge where the high amount of consumption is termed as the Veblen effect. This effect means that rich people are using luxurious items to show their rich status which is linked to the degradation of environmental quality. Likewise, Jorgenson et al. (2017) indicate that income inequality increases working hours while an increase in working hours raises the consumption of energy that, in turn, increases carbon emission. Our findings can be attributed to some or all of these reasons; however, energy consumption and economic growth are also related to increased carbon emissions in our study. Thus, it can be concluded that income inequality, energy consumption, and economic growth all together raise carbon emissions in the Belt and Road Initiative countries that lead to environmental degradation. Our findings can be explained that income inequality increases emission which may be the reason that unequal income distribution reduces the low-income people's affordability to purchase environmentally friendly products as well the lack of awareness in poor people due to low education as poor people cannot get enough

education. On the other hand, rich people can use luxury items with rising carbon emissions and worsening environmental quality.

The results on the impact of poverty on carbon emissions indicate that the estimated coefficient is significant and positive which illustrates that a rise in poverty leads to increase carbon emissions and degrading environmental equality in the sample countries. Specifically, the values of the coefficients specify that if there is a 1% increase in the level of poverty in selected sample countries will increase emissions by 0.001 and 0.003% correspondingly shown by difference and system GMM estimators. Baloch et al. (2020) and Masron and Subramaniam (2019) also found similar results which reinforce our findings. They further indicate that impoverished people in countries misuse environmental resources for their survival which raises the level of emission and degrades the quality of the environment. As confirmed by our findings, both poverty and income inequality increase carbon emissions and degrade environmental quality. The Belt and Road Initiative countries should reduce income inequality and alleviate poverty because it causes degradation. It is also proved by the effect of industrialization on carbon emissions. Countries on the Belt and Road Initiative are increasing industrialization to raise economic growth to eradicate poverty, thus increasing energy consumption which leads to environmental degradation. Jin et al. (2018) also indicates that an increase in industrialization raises economic growth which in turn can alleviate poverty while also worsening the quality of the environment. The Belt and Road Initiative countries need to alleviate poverty; however, some of the economic activities should be reduced as these are related to carbon emissions.

Economic growth also significantly increases carbon dioxide as the coefficients are positive and significant in both models. The results show that a rise in economic growth in countries along the Belt and Road Initiative increase carbon dioxide discharge. More specifically, the results indicate that if there is a 1% increase in economic growth in the Belt and Road Initiative, countries will raise carbon dioxide emissions by 0.028 and 0.001%, respectively. Sharif et al. (2019) and Zafar et al. (2021), Khan et al. (2021a, b, 2022a), and Okere et al. (2021) reinforce our results. This positive effect on carbon emission can be the reason that the sample countries are mostly emerging and developing countries that are focusing on boosting economic growth and enhancing living standards even at the cost of the environment. These countries also need to reduce poverty and income inequality, and a rise in economic growth can achieve this objective. In this way, these countries increase economic growth through production and industrialization; however, increase in these factors raises energy demand while an increase in energy use leads to higher carbon emission discharge which is harmful to environmental quality.

Similarly, the system and difference GMM estimators on the impact of energy consumption on carbon emissions show that both coefficients are positive and significant, indicating that energy consumption in countries along the "Belt and Road Initiative" significantly increases carbon dioxide emissions.

Likewise, the difference and system GMM estimators on the effect of energy consumption on carbon emission indicate that both coefficients are positive and significant which illustrates that energy consumption in the Belt and Road Initiative countries significantly increases carbon dioxide emission. The estimated coefficient values show that if there is a percent rise in the use of energy, it will increase carbon dioxide by 0.002 and 0.003%, respectively, shown by the difference and system GMM models in the selected Belt and Road Initiative countries. These results can be linked with the higher production level in the sample countries which are focusing to raise economic growth, while a rise in production and industrialization increases economic growth and raises energy demand and thus leading to high carbon dioxide emissions. The sample countries can lower carbon emissions by using renewable energy sources as a substitute for energy from fossil fuels in production and accelerating economic activities that can in turn help alleviate the level of poverty, reduce emission levels, and attain sustainable development.

The effect of foreign direct investment on carbon dioxide emission is also positive and significant which indicates that a rise in the inflow of FDI in the selected Belt and Road Initiative countries leads to a rise in carbon dioxide emission which harms the environment. The difference and system GMM estimators' results illustrate that a percent rise in FDI inflow in the Belt and Road Initiative countries increases carbon emission by 0.06 and 0.001%, respectively. Similarly, the effect of industrialization on carbon emission is positively significant in both estimators shown by its coefficient values. The coefficient values show that a percent increase in industrialization level in the selected sample countries will increase carbon dioxide by 0.013%. Industrialization is related to economic growth where industrialization uses a high amount of energy where Belt and Road Initiative countries may not have acquired yet renewable energy. Thus, a rise in industrialization to increase economic growth leads to rising carbon emissions and environmental degradation.

Access to electricity in the Belt and Road Initiative countries negatively and significantly affects the level of carbon dioxide emission shown by the estimated coefficient in the difference and system GMM model. The findings confirm that a rise in access to electricity in the selected countries significantly reduces carbon emissions and leads to a higher quality of the environment. The coefficient values illustrate that a percent rise in access to electricity in the selected countries will reduce the level of emission by 0.001 and

0.08%, respectively, shown by the difference and system GMM models.

The coefficients of international trade indicate that a rise in international trade in the selected Belt and Road Initiative countries significantly increases carbon dioxide emissions. The estimated values indicate that if there is 1% rise in trade will be an upsurge in carbon dioxide discharge by 0.005 and 0.008%, respectively, in difference and system GMM models. Khan et al. (Khan et al. (2021a, b, 2022a) found that trade openness negatively affects carbon emissions. Danish Khan (2019) found that trade openness does not affect carbon emissions in his sample countries. On the other hand, Faisal et al. (2020) achieved the opposite results and argues that a high level of trade increases the emerging countries' environmental quality.

The effect of inflation in the model on carbon emission is positive and highly significant shown by the estimated coefficients in difference and system GMM models. The results illustrate that a rise in the inflation level in selected countries leads to high carbon emissions. More specifically, the values of the coefficients indicate that a percent increase in inflation will increase carbon dioxide emission in selected countries of the Belt and Road Initiative by 0.01 and 0.004%, respectively, shown by difference and system GMM models. Likewise, urbanization also exerts a significant and positive effect on carbon emission indicated by the estimated coefficients both in difference and system GMM models. The results confirm that a rise in urbanization leads to high carbon emission discharge in the sample countries. More specifically, the results indicate that if there is a percent increase in urbanization in the Belt and Road Initiative countries, carbon dioxide emissions will rise by 5.4 and 8.3%, respectively.

Table 5 presents the quadratic term results of the difference and system GMMs models on the impact of poverty, income inequality, and economic growth on carbon dioxide emissions in selected BRI countries. The results show that the estimated coefficient of income inequality is significant and positive in both estimators, suggesting that income inequality in the sample countries leads to increased CO2 emissions. More specifically, the coefficient values indicate that a percentage increase in income inequality would increase carbon dioxide emissions by 0.003% and 0.049% in selected countries shown by the results of difference and system GMM estimators, respectively. Our findings are consistent with the theory of Boyce (1994) who postulate that higher income inequality worsens environmental quality because income inequality creates rank differences among people that harm the environment. Likewise, our findings are also similar to the results of Uzar and Eyuboglu (2019) for Turkey and Hao et al. (2016) and Liu et al. (2019) for China. However, Demir et al. (2019) found opposite results to our findings.

Likewise, poverty in the sample countries raises carbon dioxide emissions, as the estimated coefficient of poverty is positive and significant in both models, indicating that poverty increases carbon dioxide emissions. More specifically, the coefficient values show that for every one percentage point increase in poverty in countries along the Belt and Road Initiative, carbon dioxide emissions increase by 0.001 percentage points. Masron and Subramaniam (2019) reinforces our research that poverty increases carbon emissions and reduces environmental quality.

The coefficients of economic growth estimated by the difference between GMM and the system GMM model are positive and significant, indicating that higher economic growth leads to higher carbon emissions in the sample countries. Specifically, the coefficient values indicate that 1% economic growth would increase carbon dioxide emissions by 0.012% and 0.001% in selected countries as shown by the difference and system GMM models, respectively.

Likewise, the results of the square term of economic growth indicate that it negatively and significantly affects carbon emissions. The coefficients are negative both in difference and system GMM models confirm the U-shape association between economic growth and carbon dioxide. Thus, the environmental Kuznets curve is validated in this result shown by the negative coefficients in both estimators. The results further illustrate that economic growth rise emission levels at the initial stage of the countries' economic development; however, it reduces carbon emissions when it reaches higher economic growth. Uzar and Eyuboglu (2019) also indicate that the environmental Kuznets curve is valid in Turkey. Furthermore, our findings are also in line with Liu et al. (2019) and Azam et al. (2021).

The positive effect of income inequality on carbon dioxide in sample countries can be linked to the economic growth level as economic growth is presumed to be a driver of living standards, and increases in economic growth are also believed to reduce income inequality; a reduction in income inequality can improve the quality of the environment shown by the results of this study. To test these hypotheses, we employ the interaction term between income inequality and economic growth in our model. The interaction term of income inequality and economic growth shows that income inequality has a moderating effect on carbon dioxide emissions through per capita economic growth. Likewise, the results on the interaction terms between inequality and economic growth indicate that the coefficients are negative which means that income inequality as a moderating effect via economic growth on carbon emission reduction.

The estimated coefficient values for the impact of energy consumption on CO2 emissions in the difference and system GMM models are negative and significant, suggesting that increased energy consumption increases

Table 5 The nonlinear effect of poverty, income inequality, and economic growth on carbon emission

Variables	OLS	Fixed effect	Difference GMM	System GMM
GINI	0.014*	−0.008**	0.003**	0.049***
	(0.008)	(0.003)	(0.001)	(0.0005)
POVT	0.003	−0.003	0.001***	0.001***
	(0.005)	(0.002)	(0.000)	(0.001)
GDP	−0.076	0.009	0.012*	0.001***
	(0.054)	(0.016)	(0.006)	(0.0001)
GDP^2	−0.003**	−0.001***	−0.001***	−0.0003***
	(0.001)	(0.000)	(8.72)	(1.230)
GDP*GINI	0.002	−0.0001	7.840	−6.240***
	(0.001)	(0.0004)	(0.000)	(9.140)
ENR	0.002***	0.002***	0.001***	0.002***
	(4.560)	(5.740)	(1.480)	(4.490)
FDI	0.049***	0.007**	0.006***	0.065***
	(0.008)	(0.003)	(0.001)	(0.000)
IND	0.013*	0.022***	0.015***	0.085***
	(0.006)	(0.005)	(0.000)	(0.000)
ACCT	−0.013**	−0.008	−0.009***	−0.006***
	(0.006)	(0.005)	(0.001)	(0.000)
TO	−0.006***	−0.006***	−0.003***	0.001***
	(0.001)	(0.000)	(0.000)	(9.940)
INF	0.0002	0.000***	0.001***	0.014***
	(0.001)	(0.000)	(0.000)	(9.810)
URB	6.821	4.530***	2.970***	3.650***
	(5.741)	(9.761)	(1.321)	(0.001)
L.co2			0.252***	0.001***
			(0.003)	(0.002)
Constant	0.172	0.763		0.001***
	(0.704)	(0.560)		(0.002)
Observations	587	587	529	566
R-squared	0.908	0.838		
Number of id		37	36	37
AR1			−2.00(0.045)	−3.03(0.002)
AR2			−0.90(0.369)	−1.74 (0.082)
Sargan test			167.47(0.900)	493.47(0.900)

Note: Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

CO2 emissions in selected countries. Specifically, the coefficient values show that for every 1% increase in energy consumption in selected BRI countries, carbon emissions increase by 0.001% and 0.002%. The results indicate that high energy use is harmful to the quality of the environment; however, the use of renewable energy may be useful to reduce pollution. Khan et al. (Khan et al. (2021a, b, 2022a) and Khan et al. (2020) argue that renewable energy use raises environmental quality by lowering the level of carbon emission discharge while Ali et al. (2017) indicate that energy from nonrenewable sources degrades environmental quality.

The effect of foreign direct investment on carbon emission is positive and significant shown by the coefficients in difference and system GMM models. The results illustrate that foreign direct investment in the sample countries leads to environmental degradation. The coefficient values show that if there is a percent rise in the inflow of foreign direct investment in the sample countries will increase emission levels by 0.006 and 0.06%, respectively. Similarly, a rise in industrialization in the sample countries will lead to environmental degradation as the coefficients of industrialization in the models are positively significant which shows that industrialization raises carbon dioxide emission. This can

be the reason that countries are increasing industrialization to increase economic growth which in turn raises energy demand while the high amount of energy use increases carbon emission and lowers the quality of the environment.

On the other hand, access to electricity in the sample countries exerts a negative and significant effect on carbon dioxide emission as the coefficients values are negative and significant in both models. The results of the study show that the electricity supply in the countries is associated with higher environmental quality, where each percent increase in electricity supply will reduce carbon dioxide emissions by 0.009% and 0.006%, respectively, shown by difference and system GMM estimators.

The impact of international trade on CO2 emissions is significant and positive, indicating that the level of trade in countries has increased CO2 emissions. The estimated coefficient values indicate that if international trade increases by 1%, carbon dioxide emissions will increase by 0.001%, and thus, the increase in carbon dioxide will reduce the quality of the environment. Likewise, rising inflation levels in the sample countries lead to a high discharge of carbon dioxide. The coefficient values indicate that a percent increase in inflation would increase CO2 emissions by 0.01% and 0.01% in selected countries shown by difference and system GMM models, respectively. Again, the impact of urbanization on carbon emissions is significant and the estimated coefficients are positive. More precisely, the values of the coefficient indicate that a percentage increase in urbanization in selected countries would increase CO2 emissions by 2.9% and 3.6%.

Conclusion

This study uses panel data to investigate the impact of poverty and income inequality on carbon dioxide emission in the Belt and Road Initiative countries from 1996 to 2018 considering other closely related factors that include energy consumption, economic growth, foreign direct investment, industrialization, and access to electricity. The data for all variables were collected from the World Bank database, and the World Development Indicator, and employed OLS, fixed effects, difference GMM, and two-step system GMM estimators for analysis. The results show that income inequality, poverty, economic growth, energy consumption, and industrialization significantly increase carbon emissions, while electricity supply reduces emissions in the sample countries. The results further validate the environmental Kuznets curve hypothesis, and the interaction term of income inequality and economic growth significantly reduces environmental degradation. The findings confirm that a high level of poverty and income inequality in the sample countries is linked to environmental degradation. This can be the reason that the sample countries are rising economic activities to enhance the living standard, reduce income inequality, and alleviate poverty; however, rising economic activities through increased production raises unequal energy demand resulting in higher carbon dioxide discharge and in turn leads to environmental degradation.

Recommendations

The countries' policies should be devised to raise economic growth by using renewable energy as a substitute for nonrenewable energy in production to alleviate poverty as energy consumption in our findings are harmful to environmental quality. The countries should alleviate poverty without the cost of environmental quality by taking other possible ways. On the other hand, economic growth itself is the main driver of environmental degradation in the sample countries. This study can also suggest not alleviating poverty only with increased economic growth but may use other alternative ways such as short-term employment and financial support to the poor people to reduce poverty and lower the harmful impact of economic growth and poverty on the quality of the environment. The governments of the sample countries should also tackle the unequal distribution of income and provide policies that the high-class rich people should not use their income to produce pollution. For this purpose, a strong institutional framework in the sample countries might be required to provide such policies for the different levels of people to reduce emissions. Likewise, it is suggested that the use of nonrenewable energy sources in production should be reduced and government may invest in renewable energy sources as it is considered environmentally friendly. Innovations may also be helpful to enhance energy efficiency and acquire renewable energy consumption which can be used as a substitute for nonrenewable energy for production. In short, it is suggested that government should not only focus on rising economic growth through production and industrialization by using a high amount of energy to alleviate poverty while using alternative ways and making changes to the production process such as the use of renewable energy sources. Likewise, the government should also take part to reduce the unequal distribution of income which can be helpful reduce carbon emissions and raising environmental quality.

Our study is limited to sample countries and target variables. Future researchers could conduct such research by incorporating institutional quality variables that aid in institutional policymaking. Future research could also include technological innovations, as innovations increase energy efficiency, access to renewable energy sources, and make production processes more efficient, which in turn helps reduce the harmful effects of industrialization and

economic growth on environmental quality. It is also recommended that such studies be conducted in other countries, such as developing and developed countries to draw useful recommendations, as these countries may differ in their levels of the income distribution, economic growth, poverty levels, and environmental quality.

Acknowledgements The authors are thankful to the journal editor and anonymous reviewers for their useful comments and suggestions that improved the quality of this paper

Author contribution Conceptualization and formal analysis were performed by Hayat Khan, idea and structure of the study were arranged by Liu Weili, formal writing were done by Itbar Khan, and proofreading were done by Jianfang Zhang.

Data availability Data used in the analysis are available upon reasonable request from the corresponding author.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

References

Ali S, Anwar S, Nasreen S (2017) Renewable and non-renewable energy and its impact on environmental quality in South Asian Countries. Forman J Econ Stud 13:177–194

Antweiler W, Copeland BR, Taylor MS (2001) Is free trade good for the environment? Am Econ Rev 91(4):877–908

Apergis N, Li J (2016) Population and lifestyle trend changes in China: implications for environmental quality. Appl Econ 48(54):5246–5256

Arellano M, Bond S (1991) Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Rev Econ Stud 58(2):277–297

Arellano M, Bover O (1995) Another look at the instrumental variable estimation of error-components models. J Econom 68(1):29–51

Azam M, Liu L, Ahmad N (2021) Impact of institutional quality on environment and energy consumption: evidence from developing world. Environ Dev Sustain 23(2):1646–1667

Baek J, Gweisah G (2013) Does income inequality harm the environment? empirical evidence from the United States. Energy Policy 62:1434–1437

Bai C, Feng C, Yan H, Yi X, Chen Z, Wei W (2020) Will income inequality influence the abatement effect of renewable energy technological innovation on carbon dioxide emissions? J Environ Manag 264:110482

Baloch MA, Khan SU-D, Ulucak ZŞ, Ahmad A (2020) Analyzing the relationship between poverty, income inequality, and CO2 emission in Sub-Saharan African countries. Sci Total Environ 740:139867

Baltagi BH (2008) Forecasting with panel data. J Forecast 27(2):153–173

Bibi R, Sumaira (2022) The effect of financial development on economic growth: evidence from south Asian developing countries. J Environ Sci Econ 1(1):1–17

Birdsall N, Wheeler D (1993) Trade policy and industrial pollution in Latin America: where are the pollution havens? J Environ Dev 2(1):137–149

Blundell R, Bond S (1998) Initial conditions and moment restrictions in dynamic panel data models. J Econom 87(1):115–143

Boyce JK (1994) Inequality as a cause of environmental degradation. Ecol Econ 11(3):169–178

Blundell R, Bond S (2000) GMM estimation with persistent panel data: an application to production functions. Econ Rev 19(3):321–340

Canh NP (2019) Global emissions: a new contribution from the shadow economy. Int J Energy Econ Pol. http://econjournals.com/index.php/ijeep/article/download/7244/4344. 10.32479/ijeep.7244

Cetin M, Ecevit E, Yucel AG (2018) The impact of economic growth, energy consumption, trade openness, and financial development on carbon emissions: empirical evidence from Turkey. Environ Sci Pollut Res 25(36):36589–36603

Chen J, Xian Q, Zhou J, Li D (2020) Impact of income inequality on CO2 emissions in G20 countries. J Environ Manage 271:110987

Chukwuma OV, Ugwu JI, Babalola DS (2022) Application of forensic accounting in predicting the financial performance growth of MTN mobile communication in Nigeria. J Environ Sci Econ 1(1):67–76

Copeland BR, Taylor MS (1994) North-South trade and the environment. Q J Econ 109(3):755–787

Danish (2019) Effects of information and communication technology and real income on CO2 emissions: The experience of countries along Belt and Road. Telematics and Informatics, 45

Danish MSS, et al (2020) A systematic review of metal oxide applications for energy and environmental sustainability. Metals 10(12):1604

Dagnachew AG, Lucas PL, Hof AF, van Vuuren DP (2018) Trade-offs and synergies between universal electricity access and climate change mitigation in Sub-Saharan Africa. Energy Policy 114:355–366

Demir C, Cergibozan R, Gök A (2019) Income inequality and CO2 emissions: empirical evidence from Turkey. Energy Environ 30(3):444–461

Dhrifi A, Jaziri R, Alnahdi S (2020) Does foreign direct investment and environmental degradation matter for poverty? Evidence from developing countries. Struct Chang Econ Dyn 52:13–21

Faisal F, Tursoy T, Pervaiz R (2020) Does ICT lessen CO2 emissions for fast-emerging economies? An application of the heterogeneous panel estimations. Environ Sci Pollut Res 27(10):10778–10789

Franklin RS, Ruth M (2012) Growing up and cleaning up: the environmental Kuznets curve redux. Appl Geogr 32(1):29–39

Ghisellini P, Ulgiati S (2020) Circular economy transition in Italy. Achievements, perspectives and constraints. J Clean Prod 243:118360

Grossman GM, Krueger AB (1991) Environmental impacts of a North American free trade agreement, National Bureau of economic research Cambridge. Mass, USA

Grunewald N, Klasen S, Martínez-Zarzoso I, Muris C (2017) The trade-off between income inequality and carbon dioxide emissions. Ecol Econ 142:249–256

Guo Y, You W, Lee CC (2022) CO2 emissions, income inequality, and country risk: some international evidence. Environ Sci Pollut Res 29:12756–12776. https://doi.org/10.1007/s11356-020-09501-w

Hailemariam A, Dzhumashev R, Shahbaz M (2020) Carbon emissions, income inequality and economic development. Empir Econ 59(3):1139–1159

Hao Y, Liu Y, Weng J-H, Gao Y (2016) Does the environmental Kuznets curve for coal consumption in China exist? New evidence from spatial econometric analysis. Energy 114:1214–1223
Holtz-Eakin D, Selden TM (1995) Stoking the fires? CO2 emissions and economic growth. J Public Econ 57(1):85–101
Houghton Ed (1996) Climate change 1995: The science of climate change: contribution of working group I to the second assessment report of the Intergovernmental Panel on Climate Change, Vol 2. Cambridge University Press
Jamil MN (2022a) Impact the choice of exchange rate regime on country economic growth: which anchor currency leading the 21st century. J Environ Sci Econ 1(1):18–27
Jamil MN (2022b) Monetary policy performance under control of exchange rate and consumer price index. J Environ Sci Econ 1(1):28–35
Jin G, Fu R, Li Z, Wu F, Zhang F (2018) CO2 emissions and poverty alleviation in China: an empirical study based on municipal panel data. J Clean Prod 202:883–891
Jorgenson A, Schor J, Huang X (2017) Income inequality and carbon emissions in the United States: a state-level analysis, 1997–2012. Ecol Econ 134:40–48
Khan H, Khan I, Kim Oanh LT, Lin Z (2020) The dynamic interrelationship of environmental factors and foreign direct investment: dynamic panel data analysis and new evidence from the globe. Math Problems Eng 2020:2812489. https://doi.org/10.1155/2020/2812489
Khan H, Weili L, Khan I (2021a) Environmental innovation, trade openness and quality institutions: an integrated investigation about environmental sustainability. Environ Dev Sustain 24:3832–3862. https://doi.org/10.1007/s10668-021-01590-y
Khan H, Weili L, Khan I (2022a) Institutional quality, financial development and the influence of environmental factors on carbon emissions: evidence from a global perspective. Environ Sci Pollut Res 29:13356–13368. https://doi.org/10.1007/s11356-021-16626-z
Khan H, Weili L, Khan I (2022b) The role of institutional quality in FDI inflows and carbon emission reduction: evidence from the global developing and belt road initiative countries. Environ Sci Pollut Res Int 29(20):30594–30621. https://doi.org/10.1007/s11356-021-17958-6
Khan H, Weili L, Khan I, Khamphengxay S (2021b) Renewable energy consumption, trade openness, and environmental degradation: a panel data analysis of developing and developed countries. Math Problems Eng 2021:6691046. https://doi.org/10.1155/2021/6691046
Khan M (2019) Does macroeconomic instability cause environmental pollution? The case of Pakistan economy. Environ Sci Pollut Res 26(14):14649–14659
Koçak E, Ulucak R, Dedeoğlu M, Ulucak ZŞ (2019) Is there a trade-off between sustainable society targets in Sub-Saharan Africa? Sustain Cities Soc 51:101705
Kraay A (2004) When is growth pro-poor?: cross-country evidence (Vol. 3225). World Bank Publications. https://doi.org/10.1596/1813-9450-3225
Krueger AB, Grossman G (1995) Economic growth and the environment. http://arks.princeton.edu/ark:/88435/dsp01xg94hs03x
Kurul Z (2021) Türkiye'de Doğrudan Yabancı Yatırım Girişleri ve Yurtiçi Yatırım İlişkisi: Doğrusal Olmayan ARDL Yaklaşımı. Sosyoekonomi 29(49):271–292
Li K, Fang L, He L (2019) How population and energy price affect China's environmental pollution? Energy Policy 129:386–396
Liang F (2008) Does foreign direct investment harm the host country's environment? Evidence from China. Available at SSRN: https://doi.org/10.2139/ssrn.1479864
Liu J, Liu Y, Wang X (2020) An environmental assessment model of construction and demolition waste based on system dynamics: a case study in Guangzhou. Environ Sci Pollut Res 27(30):37237–37259
Liu Q, Wang S, Zhang W, Li J, Kong Y (2019) Examining the effects of income inequality on CO2 emissions: Evidence from non-spatial and spatial perspectives. Appl Energy 236:163–171
Mader S (2018) The nexus between social inequality and CO2 emissions revisited: challenging its empirical validity. Environ Sci Policy 89:322–329
Magnani E (2000) The Environmental Kuznets Curve, environmental protection policy and income distribution. Ecol Econ 32(3):431–443
Mahalik MK, Mallick H, Padhan H, Sahoo B (2018) Is skewed income distribution good for environmental quality? A comparative analysis among selected BRICS countries. Environ Sci Pollut Res 25(23):23170–23194
Martínez-Zarzoso I, Maruotti A (2011) The impact of urbanization on CO2 emissions: evidence from developing countries. Ecol Econ 70(7):1344–1353
Masron TA, Subramaniam Y (2019) Does poverty cause environmental degradation? Evidence from developing countries. J Poverty 23(1):44–64
Muhammad S, Long X, Salman M, Dauda L (2020) Effect of urbanization and international trade on CO2 emissions across 65 belt and road initiative countries. Energy 196:117102
Nguyen CP, Nguyen NA, Schinckus C, Su TD (2018) The ambivalent role of institutions in the CO2 emissions: The case of emerging countries. Int J Energy Econ Policy 8(5):7
Okere KI, Onuoha FC, Muoneke OB, Oyeyemi AM (2021) Towards sustainability path in Argentina: the role of finance, energy mix, and industrial value-added in low or high carbon emission—application of DARDL simulation. Environ Sci Pollut Res 28(39):55053–55071. https://doi.org/10.1007/s11356-021-14756-y
Padhan H, Haouas I, Sahoo B, Heshmati A (2019) What matters for environmental quality in the Next Eleven Countries: economic growth or income inequality? Environ Sci Pollut Res 26(22):23129–23148
Panayotou T (2003) Economic survey of Europe. Econ Growth Environ 45–72. https://doi.org/10.18574/nyu/9781479862689.003.0018
Robeena, Sumaira (2022a) The relationship between trade openness, financial development and economic growth: evidence from Generalized method of moments. J Environ Sci Econ 1(1):58–66
Robeena B, Sumaira (2022b) The effect of foreign direct investment and financial development on economic growth: evidence from global income countries. J Environ Sci Econ 1(1):36–51
Roodman D (2009a) How to do xtabond2: An introduction to difference and system GMM in Stata. The Stata J 9(1):86–136
Roodman D (2009b) A note on the theme of too many instruments. Oxf Bull Econ Stat 71(1):135–158
Selden TM, Song D (1994) Environmental quality and development: is there a Kuznets curve for air pollution emissions? J Environ Econ Manag 27(2):147–162
Sharif A, Raza SA, Ozturk I, Afshan S (2019) The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission: a global study with the application of heterogeneous panel estimations. Renew Energy 133:685–691
Solarin SA, Lean HH (2016) Natural gas consumption, income, urbanization, and CO 2 emissions in China and India. Environ Sci Pollut Res 23(18):18753–18765
Stern D (2004) Therise and fallofthe Environmental Kuznets Curve. World Dev 32:1419–1439
Sumaira, Bibi R (2022) Banking sector development and Economic growth in south Asian countries: Dynamic Panel data analysis. J Environ Sci Econ 1(1):52–57
Torras M, Boyce JK (1998) Income, inequality, and pollution: a reassessment of the environmental Kuznets curve. Ecol Econ 25(2):147–160
Tsuji H, Gupta AK, Hasegawa T, Katsuki M, Kishimoto K, Morita M (2002) High temperature air combustion: from energy conservation to pollution reduction. CRC Press
Uzar U, Eyuboglu K (2019) The nexus between income inequality and CO2 emissions in Turkey. J Clean Prod 227:149–157
Walter I, Ugelow JL (1979) Environmental policies in developing countries. Ambio: Technol Dev Environ Impact 8(2/3):102–109
Weili L, Khan H, Han I (2022) The impact of information and communication technology, financial development, and energy

consumption on carbon dioxide emission: evidence from the Belt and Road countries. Environ Sci Pollut Res 29:27703–27718. https://doi.org/10.1007/s11356-021-18448-5

You W, Li Y, Guo P, Guo Y (2020) Income inequality and CO 2 emissions in belt and road initiative countries: the role of democracy. Environ Sci Pollut Res 27(6):6278–6299

Zafar MW, Sinha A, Ahmed Z, Qin Q, Zaidi SAH (2021) Effects of biomass energy consumption on environmental quality: the role of education and technology in Asia-Pacific Economic Cooperation countries. Renew Sustain Energy Rev 142:110868

Zhao W, Hafeez M, Maqbool A, Ullah S, Sohail S (2021) Analysis of income inequality and environmental pollution in BRICS using fresh asymmetric approach. Environ Sci Pollut Res 28(37):51199–51209. https://doi.org/10.1007/s11356-021-14209-6