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RESEARCH ARTICLE

The Impact of Energy Consumption, Energy Efficiency, and Technological Advancements on CO2 Emissions in Belt and Road Countries

Lin Yumei[1], Anwar Shahid[1,*]

[1]School of Software, Quanzhou University of Information Engineering, Quanzhou, 362000, Fujian, P.R. China

Corresponding Author: Anwar Shahid. Email: anwarali@qzuie.edu.cn
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Abstract

Rising economic activities, industrialization, and production raise energy demand, and the increased use of energy from fossil fuels has a negative impact on environmental quality. Due to their higher energy density, fossil fuels are anticipated to dominate the future energy supply. It is possible for the usage of fossil fuels to be supplemented by the growth of renewable energy sources, investments in low-carbon automation, and the creation of an energy infrastructure. Environmental innovations and technologies may help increase energy efficiency and acquire renewable energy sources, which may lead to a reduction in energy consumption, the achievement of green energy, and an improvement in environmental quality. This study examines the impact of technological innovations on energy efficiency, energy demand, and carbon dioxide emissions in light of economic growth. From 1985 to 2019, panel data from Belt and Road initiative countries were utilized using static and dynamic panel models. The results support the significance of technological innovations in lowering energy consumption, increasing energy efficiency, and enhancing environmental quality. In addition, it was confirmed that the significant effects of energy consumption, economic growth, energy demand, and financial development on carbon dioxide emissions degrade environmental quality. According to the results, increased economic activity is the result of an increase in energy demand, while technological innovations and well-established financial institutions were found to be beneficial in reducing energy consumption, increasing energy efficiency, acquiring renewable energy sources, and boosting environmental quality. The results of this study have significant policy implications and recommendations for the sample countries.

Keywords: Energy consumption; Energy efficiency; Technology innovations; economic growth; Environmental sustainability

1. Introduction

Increased production and industrialization to boost economic growth have a negative impact on environmental quality, Paramati, Shahriar, and others (2022). This increased use of energy from fossil fuels in economic activities contributes to air pollution, health risks, and global warming Shahzad, Paramati, and others, 2022). Because of their higher energy density, fossil fuels are expected to become the dominant source of energy in the future. To reduce their reliance on fossil fuels, emerging and developing economies, including those participating in the Belt and Road Initiative, must invest in low-carbon technology, renewable energy sources, and energy infrastructure. Because it is critical to increase energy efficiency, reduce energy consumption, and acquire

renewable energy sources, new technologies and innovations in environmental-related activities may be capable of resolving the issue of environmental degradation. Aside from the effects of energy consumption and technological advancement on energy demand and energy efficiency, a variety of other factors play a role. Strong climate regulations improve energy efficiency. Geller, Harrington, et al. (2006) provide examples of how technological advances anticipate this gap and increase energy efficiency. Energy efficiency is the most important factor in reducing power intensity in the manufacturing industry Liddle and Parker (2016). Energy consumption and energy efficiency improvements are also linked to per capita economic growth. However, economic expansion, according to Parker and Liddle (2016), increases energy consumption when fossil fuels are used in production. As a result, increased energy consumption in economic activity raises emissions and degrades environmental quality Khan et al. (2021); Bai, Feng et al. (2020); Krueger and Grossman (1995). According to Shabaz et al. (2013a) and Fakher (2019), economic development has significantly contributed to the rise in carbon emissions.

In addition to affecting energy consumption, energy efficiency, and environmental quality, financial institutions also have an impact on energy consumption. Green financing that finances renewable energy sources can improve environmental quality. Nevertheless, financial organizations that assist polluting businesses might result in environmental harm. Shahbaz et al. (2013b) illustrate that a rise in trade liberalization enhances the quality of the environment. According to Nasir and Rehman (2011), trade liberalization has a significant and positive relationship with CO_2 emissions in Pakistan. To quantify the alternative impact of commerce on CO_2 emissions, technology, size, and compositional effects on the environment are taken into account (Antweiler et al., 2001; Ertugrul, Cetin et al. (2016). Antweiler, Copeland et al. (2001) state that the effects of commerce on the environment may be broken down into five categories: composition, trade, scale, technology, and technique. The term "scale effect" refers to the degradation of the environment that occurs when a nation's economic might increases concurrently with an increase in the openness of its trade markets. In the context of global specialization, "technical effect" refers to the competitive advantage enjoyed by "dirty" industries as opposed to "clean" ones. Trade has a beneficial effect on environmental quality, both in terms of its substance and its techniques, which results in an overall improvement in the environmental quality of a nation.

Improvements in technological innovations can overcome the issue of environmental degradation by increasing energy efficiency and acquiring renewable energy sources. Innovations bring efficient technology, which is used in production and thus raises energy efficiency, leading to sustainable economic growth; Shahbaz, Raghutla et al. (2020). An increased energy efficiency can raise environmental quality by reducing carbon dioxide emissions. Wang, Yang et al. (2012) and Su and Moaniba (2017) argue that carbon emission variations are explained by innovations. Cole (2004) argues that technological innovation helps provide information regarding environmental stress through trade, substitution, and pollution-related industries. Thus, energy consumption, trade, and financial development affect the energy consumption of a country. The energy intensity is also affected by these factors. Previous research has investigated the impact that energy has on carbon dioxide levels; however, the relationship between the two has not yet been investigated, despite the fact that the parameters in question have an impact on energy consumption, energy efficiency, and carbon dioxide emissions. It is necessary for the countries along the Belt and Road to determine how the elements in question affect energy consumption as well as energy efficiency. It is also needed to examine the effect of energy consumption, energy efficiency, and other related factors on carbon dioxide emissions. The role of technology innovations in this linkage is very important, which also needs examination; however, it has been ignored in the previous studies, especially for the Belt and Road initiative countries. Through this investigation, this study will provide important recommendations for the sample countries on how these factors affect energy efficiency, energy demand, and environmental quality. The important role of technology innovations in this investigation is highlighted, which is very important for the sample countries.

Consequently, this study is arranged based on three major objectives. A primary goal is to investigate how changes in trade, finance, technology, and the economy have affected energy consumption. The second objective is to analyze how changes in trade, economic development, and technology have affected energy efficiency. The third objective is to analyze the connection between energy efficiency, technology, energy use, and economic development. Panel data from 1985 to 2019 of the Belt and Road initiative countries is analyzed through OLS, fixed effects, and GMM models. The results showed that economic growth and financial development increase energy use, but increased technological innovation decreases energy consumption. The impact of trade and economic growth on energy intensity is negative, while financial development and technological innovation improve energy efficiency in the sample countries. Many causes, such as increased energy intensity and energy consumption, as well as increased commercial activity, economic expansion, and financial development, all contribute to an increase in the amount of carbon dioxide that is released into the atmosphere.
The remaining parts of the investigation are summarized as follows: (2) Literature review, (3) methodology, (4) Results and discussions, and (5) conclusions.

2. Literature review

Earlier studies conducted a large number of analyses on the impact of various factors on energy consumption and carbon dioxide emissions in various sample nations; however, the findings of these studies were found to be inadequate. Shan, Genc, and their co-authors investigate this question in their study, "Examining the Role of Renewable Energy Utilization and Green Innovative Technologies in Achieving Carbon Neutrality in Turkey" (2021). For data from 1990 to 2018, the STIRPAT model is used. The findings show that using renewable energy sources and technological advancements can significantly reduce CO_2 emissions, while population growth, CO_2 emissions from energy use, and economic growth all remain relatively unchanged. Chien, Ajaz, and their colleagues will look into the impact of technological innovation and the use of renewable energy sources on CO_2 emissions in Pakistan from 1980 to 2018. The study lends support to Pakistan's Environmental Kuznets Curve. The consumption of renewable energy, according to the authors' findings, reduces CO_2 emissions, and some researchers believe that technological innovation will increase renewable energy. As a result, both technological innovation and renewable energy are critical for long-term development. Radmehr, Henneberry, and their colleagues (2021) investigated the three-way relationship that exists between carbon emissions, renewable energy consumption, and economic growth in EU countries in their study. The population growth of 94,099 is geographically related to the use of renewable energy and CO_2 emissions, according to the econometric analysis. Further research has revealed a link between economic growth and carbon emissions, as well as energy consumption and carbon emissions. Furthermore, there is no two-way street in Pakistan between economic growth and the development of renewable energy sources. Chien, Ajaz, and colleagues (2021) use a quantile ARDL model to assess the role of renewable energy, technological progress, and globalization in reducing carbon emissions between 1980 and 2018. The findings lend support to the EKC theory by demonstrating a significant relationship between economic growth and rising emissions. This is demonstrated by the fact that as economies grow, so do emissions. Furthermore, they emphasize that the use of renewable energy and technological advancements both have a negative impact on the amount of carbon emissions produced.
Globalization has been discovered to be a significant contributor to the rise in CO_2 emissions measured in Pakistan. Su Qi, Su Qi, and others (2022) investigated the relationship between technological innovation, energy consumption, and CO_2 emissions in Malaysia. The data is examined using a bootstrap ARDL model, and the results show that using renewable energy sources helps to delay the deterioration of the ecosystem. The development of innovative technologies has the potential to reduce Malaysia's negative environmental impact as

well as the amount of carbon emissions produced by the country. Furthermore, the findings of their investigation demonstrated that the EKC theory was correct. Abed, Mahmoud, and others (2021) investigate the relationship between CO_2 emissions, energy consumption, and technological progress. The study, which spanned the years 1990 to 2019, relied on sample data from the G8 countries. They use the FMOLS econometric model, and the results show that there is an inverse relationship between CO_2 and technological innovation in the long run. The authors of this study go on to show that urbanization degrades environmental quality. M. N. Jamil (2022) discovered the long-run relationship between energy consumption and economic growth in emerging economies. The results, obtained using panel roots and vector error correction models, show that while oil, electricity, and gas are equal in the short run, coal is important in the long run. There is a one-way causal relationship between energy and economic growth. From 1987 to 2017, Li and Wei (2021) investigated innovation, economic growth, and CO_2 emissions. The provinces of China make up the research sample. The authors' economic model is based on a panel model, and they discover non-linear relationships between the variables studied. However, the authors point out that the effect of CO_2 on economic growth varies depending on the subsamples studied. Using the ARDL estimator, Fan and Hossain (2018) investigate the relationship between technological innovation, economic growth, and CO_2 emissions in China and India. The data range from 1974 to 2016, and the findings show that technological innovation and carbon dioxide drive long-term economic growth. However, they discovered that this effect was mixed and inconclusive in the short term. Similarly, they discovered that carbon dioxide had a long-term positive effect on growth but a short-term negative effect on growth. Cheng and Hou (2021) investigate the link between technological innovation and economic growth in 48 countries. The authors discover, using data from 1971 to 2015, that the relationship between economic growth, finance, and innovation varies by income level and time period. Fernandez et al. (2025) studied and analyzed the projection of electricity generation profiles and carbon emissions towards 2050. Sajid et al. (2025) scrutinized the long-run effects of technological innovation, green innovation, and green energy on CO2 emissions in Pakistan: an augmented ARDL approach.

The relationship between CO_2 and technological innovation and institutional quality is examined in Bakhsh and Yin et al. (2021). The authors discover that institutional quality has a moderating effect and that technological innovation modifies the relationship between CO_2 and FDI using data from 40 Asian countries from 1996 to 2016. Furthermore, the authors demonstrate that FDI and institutional quality significantly reduce environmental degradation. BRICS-inspired awe In the same authorized sample as Xie et al., the relationship between technology, economic growth, and CO_2 was examined (2021). The authors validate the EKC assumption and discover that innovation indicators increase CO_2 emissions, while only one innovation indicator decreases emissions. Similarly, a mobile cellular subscription improves the environment or quality significantly. This study looked at CO_2 emissions from high-tech exports, trade, and electricity use. Niu (2021) investigates the link between technological innovation and CO_2. The study spans the years 2009 to 2018, with a sample of 30 Chinese provinces. They discovered, using fixed effects and models, that emissions from the technological innovation curve and an increase in technological innovation lead to China's sustainable growth. From 2000 to 2019, Mikiewicz (2021) investigated the relationship between innovation, technology, and emissions in high-ranking countries. Developed and patented a CO_2 emission estimator using FMOLS and DO authimators. Some other related recent investigations are [Ouni et al. (2025) and Navendu Prakash (2025)].

Aslan, Godzbass, and others (2021) arranged for a study to be conducted on G7 countries as well as emerging market countries. The study's goal was to look into the impact of a country's financial development, energy consumption, and economic growth on carbon emissions. The authors discover a positive correlation between energy consumption and stock market-based finance in both samples using data from 1990 to 2017 and analyzing financial developments using a panel VAR model of banking and stock market indicators. They also discovered that this relationship exists in both samples. The expansion of banking and financial development has a long-term

negative impact on energy consumption. Evaluating the Impacts of Financial Development, Information and Communication Technology, and Institutional Quality on Carbon Emissions in Pakistan, Sharif is a type of et al (2020). To investigate the link, the researchers examined data from 1995 to 2018 and used a QARDL model. They discover that GDP and institutions have a positive impact on carbon emissions, whereas FD and ICT have a negative impact. Olubiyi (2020) investigated energy consumption and carbon emissions in Africa using systematic atic GMM and vector autoregressive models. The findings indicate the existence of unidirectional causal relationships between coal and mortality, fuel consumption, and per capita income, as well as coal and fuel consumption and per capita income. Similarly, there is an inverse relationship between energy consumption and temperature. Systematic GMM models show that the effects of energy use on well-being vary, with increased coal consumption lowering unemployment and reducing infant mortality.

3. Methodology

This study explores the nexus between energy consumption, energy efficiency, and carbon dioxide emissions. Dynamic panel models are utilized to conduct an analysis of panel data spanning from 1985 to 2019 in selected countries from the One Belt and One Road initiative. The following is the empirical model on the effect of technological innovations, economic growth, and financial development on energy consumption.

$$ENR_{it} = \beta_0 + \beta_1 ENR_{it-1} + \beta_2 TO_{it} + \beta_3 FD_{it} + \beta_4 GDP_{it} + \beta_5 TEC_{it} + \varepsilon_{it}, \quad (1)$$

ENR is energy consumption, which is the dependent variable in equation 1. ENR_{it-1}, is the first lag of the dependent variable that quantifies the effect of the previous year's effect on the current year's energy use. Likewise, TO is international trade, FD represents financial development, GDP is economic growth, and TEC is technological innovation.

Equation 2 shows the effect of technological innovations, economic growth, and financial development on energy efficiency. Shahbaz, Raghutla et al. (2020) argue that technology innovation raises energy efficiency, and it has been further confirmed by Sharif, Mishra et al. (2020). If there is increased energy efficiency, it can raise environmental quality by reducing carbon dioxide emissions.

$$EI_{it} = \beta_0 + \beta_1 EI_{it-1} + \beta_2 TO + \beta_3 FD_{it} + \beta_4 GDP_{it} + \beta_5 TEC_{it} + \varepsilon_{it}, \quad (2)$$

This study also adds energy intensity, which represents the energy efficiency, while it also adds energy consumption to represent the energy demand in the model. A higher intensity of energy is referred to as higher usage of energy. It's been believed that technological innovations affect all sectors, such as energy consumption, climate change, production, and economic activities Li and Just (2018); Ulucak (2020).

Equation 3 shows the effect of energy consumption, energy efficiency, technological innovation, and economic growth on carbon dioxide emissions. A large number of researchers in the preceding literature show that energy consumption and energy efficiency affect carbon dioxide emissions. Moreover, technological innovations improve energy efficiency and acquire renewable energy sources, which can reduce carbon emissions and safeguard environmental quality.

$$CO2_{it} = \beta_0 + \beta_1 CO2_{it-1} + \beta_2 EI_{it} + \beta_3 ENR_{it} + \beta_4 TO_{it} + \beta_5 FD_{it} + \beta_6 GDP_{it} + \beta_7 TEC_{it} + \varepsilon_{it}, \quad (3)$$

A large number of proxies have been used for technological innovation in previous studies, such as research and development expenditure, Maradana, Pradhan et al. (2017), and Knott and Vieregger (2018). Likewise, patent applications are also used to proxy for innovations such as Wusiman and Ndzembanteh (2020); Maradana, Pradhan et al. (2017). Besides this, some researchers used high technology export, while others used new product development and licenses to proxy for innovations. It is believed that a change in technological innovations affects the quality of the environment. For instance, the study of Su and Moaniba (2017) shows that variations in carbon dioxide emissions are explained by technological innovations. Cole (2004) argues that environmental stress can be identified with technological innovations.

Likewise, we add other variables to the model, such as financial development, economic growth, and trade. The reason for adding these variables is that they are due to the fact that they have an influence on energy consumption and efficiency due to financial institutions, economic regulations, and trade and income level Chen and Liu (2006); Koengkan (2018).

The indicators of financial development are also employed by (Khan et al., 2019; Muhammad, 2019); Alshubiri, Jamil et al. (2019), such as domestic credit to the private sector and credit to the private sector by banks. Furthermore, the literature used a large number of different proxies; however, domestic credit to private sector % GDP is largely used, and thus, we think it is a more suitable indicator. Because an increase in energy consumption results in a higher level of carbon dioxide emission, the use of energy has an impact on the quality of the environment. The expansion of the economy drives up energy consumption in manufacturing, which results in the release of a large quantity of carbon emissions and the deterioration of environmental quality. Khan et al. (2021); Tsuji, Gupta et al. (2002). The consumption of energy is also accounted for in this study's model in order to investigate the influence that it has on the environment. Both Apergis and Li (2016) and Bai, Feng et al. (2020) suggest that a country's income level influences the quality of the environment there. According to the environmental Kuznets curve hypothesis, there is a correlation between rising income and rising levels of carbon dioxide emissions. It has been demonstrated by Shabaz et al. (2013a) and Fakher (2019) that the expansion of the economy has played a substantial role in the rise of carbon emissions.

According to Shahbaz et al., increased trade liberalization leads to an improvement in environmental quality (2013b). In terms of the impact of trade openness on environmental quality, it has been demonstrated that increased trade liberalization leads to an improvement. In a similar vein, Nasir and Rehman (2011) discovered that trade liberalization in Pakistan had a significant impact as well as a positive relationship with the country's CO_2 emissions. However, to assess the alternative effect of trade on CO_2 emissions, it is necessary to consider the environmental consequences of trade in terms of both technology and size and composition (Antweiler et al., 2001; Ertugrul, Cetin et al., 2001). According to Antweiler, Copeland, and others (2001), commerce can have an impact on the environment in a variety of ways, including compositional impacts, scale effects, technological effects, and technique effects. When a country's economic scale and trade openness both expand at the same time, the phenomenon is known as the "scale effect," which refers to the environmental degradation that results from this phenomenon. The term "technical effect" refers to the competitive advantage that certain polluted industries have over "clean" businesses in the context of global specialization. This benefit stems from globalization's increased emphasis on specialized production. A country's environmental quality improves as a direct result of commerce's positive influence on environmental composition and technology, which ultimately leads to an improvement in environmental quality. Table 1 contains descriptive statistics, and Table 2 contains the correlation matrix.

Table 1. Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
ENR	974.982	230.926	281.774	167.01
EI	6.322	2.890	1.992	20.895
TO	94.256	39.479	25.306	211.5
FD	49.138	31.253	0.186	165.39
GDPC	7184.962	6651.807	462.266	38995.2
TECH	12.35	11.974	0.001	62.246
CO_2	4.481	3.421	0.001	15.047

Table 2. Correlation matrix

	ENR	EI	TO	FD	GDP	TEC	CO_2
ENR	1.0000						
EI	0.2832	1.0000					
TO	0.3580	0.1771	1.0000				
FD	0.2673	0.1509	0.2713	1.0000			
GDPC	0.6443	-0.2065	0.2383	0.2185	1.0000		
TECH	0.3101	0.0913	0.3757	0.7352	0.2672	1.0000	
CO_2	0.9402	0.2952	0.2456	0.3131	0.6422	0.3446	1.0000

Firstly, the panel unit root test is used to determine whether or not the data are stationary. Second generation known as CIPS and CADF were utilized for data stationarity checking. These tests make the assumption that each series is distributed independently across cross-sectional in the panel. They also depend on the value of the cross-sectional mean delay value as well as the first difference of the single series. It raises the regression ADF that is produced by cross-sectional common factor correlation. Each region's null-hypothesis homogeneity enables the regional distinction against heterogeneous alternatives. The objective of employing static models is to compare them with the results of dynamic models and the findings of prior studies in order to obtain effective outcomes. Compared to static models, the best estimator is the generalized method of moments. In panel data analysis, the best estimator is the two-step GMM approach. Using static models, such as OLS, generates incorrect findings due to econometric concerns such as autocorrelation problems. Fixed effect model generates the same econometric issues as the OLS estimator, since it produces unreliable and inefficient results and is as biased as OLS because of the possibility of a time-invariant correlation between the dependent and explanatory variables and the fixed effect in the error term. In light of these problems connected with the OLS and fixed effect models, the GMM estimator is the optimal solution for dealing with panel data. Weili, Khan et al (2022). There are two varieties of GMM models. The system and the different GMM estimators are these. The difference to exclude country-specific effects, the GMM model uses the first difference of dependent and independent variables and the first difference of lagged dependent variables with their previous levels. In such situations, autocorrelation issues can be eliminated; nevertheless, the lagged levels may have subpar instruments due to the usage of the first difference, which may limit efficiency. The system GMM model proposed by Arellano and Bover (1995) and Blundell and Bond (1998) can be improved to increase efficiency. Thus, the system GMM model is better than the system GMM model. There are the level and the difference equations in the system GMM models KURUL (2021). Construct the second equation's variables to the first order difference and measure the variable in difference by

its special lag level. Based on these discussions, the GMM model has several advantages when doing the panel data analysis, Arellano and Bover (1995); Blundell and Bond (1998). Consequently, this study focuses on applying the two-step system GMM models for reliable results.

4. Results and discussions

Results on the effect of explanatory variables on energy consumption, energy intensity, and carbon dioxide are given in this section. Panel data models have been employed for analysis; however, the data stationarity was first checked via second-generation panel unit root tests. The results of these tests show that all the variables are stationary in first order or at the level. Thus, it allows to apply further econometric models.

Table 3. Panel Unit Root Tests

Variables	CIPS		CADF	
	I(0)	I(1)	I(0)	I(1)
CO_2	-1.540	-4.670***	-1.302	-2.764***
FD	-1.407	-2.698***	-1.629	-2.177***
GDP	-2.734**	-4.345***	-2.062	-2.712***
ENR	-0.451***	-3.323***	-0.400	-2.228***
EI	-1.220	-3.717***	-1.114	-2.933 ***
TO	-0.923	-3.256***	-1.313	-2.293***
TECH	-2.289 **	-2.622**	-1.803	-1.848*

Table 4 shows the results of several econometric models, including ordinary least squares, fixed effect, difference, and two-step system generalized method of moments, as well as a list of variables in the first column. Columns 2 through 5 present the study's findings on the impact of technological innovations, financial development, and economic growth. The fact that the coefficient of lagged dependent variables is positive and significant indicates that the consumption of energy over the course of one year is significantly influenced by the consumption of energy over the course of the previous year.

The Arellano and Bond (1991) tests for first and second order serial correlations, as well as the Sargan tests for over-identifying retraction, are described. These tests demonstrate that the null hypothesis does not demonstrate second-order serial correlation (AR2). This means that there is no evidence that the model was specified incorrectly. Similarly, the Sargan test rejects the over-identifying restriction null hypothesis in the GMM estimator, indicating that all of our estimates were correctly specified.

The results show that the influence of trade on energy consumption is insignificant across the majority of models; however, the coefficient in the two-step difference GMM is positive and statistically significant. When we consider the results of the two-step difference GMM, we find that this effect is not statistically significant. According to the findings, there is no discernible link between economic activity and energy consumption in the countries along the Belt and Road. Because the effect of financial development on carbon dioxide is both positive and significant, this suggests that financial development leads to an increase in energy consumption. If financial development rises by one percent, energy consumption in the sample countries rises by 0.060 percent. This was demonstrated by the system GMM model. The positive and significant coefficient for this variable indicates that economic expansion is associated with an increase in energy consumption. Increases in economic growth result in 12.3 point increases in energy consumption. Both (Saidi & Hammami, 2015) and (Omri, 2013) concluded that increased economic growth leads to increased energy consumption, and our findings are similar to theirs.

Because the estimated coefficient of technology is significant and the sign is negative, it can be deduced that technological advancements in the nations represented in the sample result in a reduction in the amount of energy used. According to the findings of the two-step system GMM, a one percent increase in technology will result in a 1.7 percent increase in energy consumption.

Table 4. The effect of variables on energy consumption

	(1)	(2)	(3)	(4)
VARIABLES	ENR	ENR	ENR	ENR
TO	0.396	-0.0967	1.685***	-0.178
	(1.113)	(1.140)	(0.387)	(0.227)
FD	8.116***	8.064***	3.163***	0.060*
	(0.976)	(0.978)	(1.069)	(0.687)
GDP	5.387	6.168*	12.58***	12.36***
	(3.545)	(3.519)	(0.770)	(0.593)
TECH	3.539	3.829	-1.149**	-1.768**
	(3.356)	(3.430)	(1.482)	(0.805)
ENR_{it-1}			0.970***	0.973***
			(0.0323)	(0.0192)
Constant	1,443***	1,583***		59.70
	(205.0)	(123.4)		(78.14)
Observations	416	416	376	416
R-squared		0.159		
Number of id	37	37	37	37
AR1			-3.14	-3.04
			(0.012)	(0.002)
AR2			-0.102	-0.12
			(0.903)	(0.903)
Sargan test			489.23	489.23
			(0.031)	(0.001)

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

Table 5 shows the effect that various factors have on energy intensity. Columns 1 through 5 present the variable list, the OLS test results, the fixed effect, the difference, and the system GMM models, in that order.

The results show that trade has a significant and negative effect on energy intensity, implying that increased trade reduces energy intensity significantly. The results also show that a 1% increase in trade reduces energy intensity by 0.001 percent. The model results show that financial development has a positive effect on energy intensity, whereas economic growth has a negative effect on energy intensity, indicating that it reduces energy intensity. In particular, a one percent increase in economic growth reduces energy intensity by 0.014 percent, as shown in the two-step system GMM.

The findings show that as income increases, people use more energy-efficient equipment. However, economic growth has a positive effect on carbon dioxide and energy consumption, which is an intriguing finding that shows that rising income levels increase energy consumption and degrade environmental quality. Similarly, income is important in encouraging people to use energy-efficient equipment, which saves energy and improves environmental quality. As a result, it is possible to conclude that energy intensity, energy consumption, carbon dioxide, and economic growth are all related. Technology has a positive effect on energy intensity and shows that as technology advances, so does energy intensity. According to the findings, a 1% increase in technology

increases energy intensity by 0.001% in the sample countries.

Table 5. The effect of the variable on energy intensity

VARIABLES	(1) EI	(2) EI	(3) EI	(4) EI
TO	-0.013***	-0.017***	-0.001***	-0.001***
	(0.004)	(0.004)	(0.001)	(0.001)
FD	0.011***	0.012***	0.001**	-0.0001
	(0.004)	(0.004)	(0.002)	(0.001)
GDP	0.015	0.020	-0.012***	-0.014***
	(0.01)	(0.015)	(0.001)	(0.001)
TECH	0.030***	0.040***	0.013**	0.001***
	(0.011)	(0.012)	(0.005)	(0.004)
EI_{it-1}			0.817***	0.921***
			(0.013)	(0.020)
Constant	5.858***	6.022***		0.522*
	(0.586)	(0.524)		(0.287)
Observations	438	438	288	328
R-squared		0.080		
Number of id	39	39	37	38
AR1			-3.01	-3.00
			(0.002)	(0.003)
AR2			0.35	0.34
			(0.633)	(0.733)
Sargan test			380.30	380.20
			(0.013)	(0.012)

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

Table 6 presents the findings regarding the relationship between carbon dioxide emissions and factors such as energy consumption, trade, energy intensity, financial development, and economic growth. The data show that energy intensity has a direct and noticeable impact on the amount of CO_2 emitted. If the sample countries' energy intensity increases by one percent, the corresponding increase in CO_2 emissions will be 0.001 percent.

The predicted energy consumption coefficient is not only positive and significant, but it is also low. Higher energy consumption is associated with higher levels of carbon dioxide emissions and lower levels of environmental quality in the Belt and Road countries, according to the data. To be more specific, the findings show that for every one percent increase in energy use, carbon dioxide emissions rise by 2.3 percentage points. These findings could be related to the sample countries' higher production levels, which are geared toward increasing economic growth. Increased production and industrialization, on the other hand, are promoted to promote economic growth, raise energy demand, resulting in high levels of carbon dioxide emissions. It is possible for the sample countries to reduce their carbon emissions by switching from using fossil fuel energy to using renewable energy as an alternative in their manufacturing processes. As a result, this can aid in poverty alleviation, emission reduction, and the attainment of sustainable development. The estimated trade coefficient is both positive and statistically significant. According to the findings, increased trade in Belt and Road countries is likely to result in higher levels of carbon dioxide emissions and a decrease in the quality of the environment in those countries. The two-step GMM process, on the other hand, renders this effect completely insignificant.

The expansion of the economy reduces the amount of carbon dioxide in the atmosphere, which helps to protect the environment. According to the findings, greater economic growth is associated with a deterioration in environmental quality, and a one percent increase in economic development is associated with a 0.002 percent increase in emissions. The expansion of the economy has a positive effect on carbon dioxide, implying that it contributes to the rise in carbon dioxide concentrations in the atmosphere. A one percent increase in growth is associated with a 0.008 percent increase in emissions in the countries included in the sample. Our findings are consistent with those of previous studies conducted by Adebayo, Adedoyin, and their co-authors (2021); Sharif, Raza, and their co-authors (2019); and Okere, Onuoha, and their co-authors (2019). (2018, 2019). (2017). (2021).

Table 6. The effect of energy on carbon dioxide emissions

VARIABLES	(1) CO_2	(2) CO_2	(3) CO_2	(4) CO_2
EI	-0.039	-0.004	0.001***	0.0001*
	(0.030)	(0.007)	(0.0001)	(0.0001)
ENR	0.001***	0.0002***	9.150***	2.390***
	(8.610)	(2.410)	(9.710)	(1.130)
TO	-0.0003	0.0004**	0.0003***	8.020
	(0.001)	(0.0004)	(4.460)	(5.020)
FD	0.003**	0.002***	0.0001***	0.0002***
	(0.001)	(0.0004)	(2.860)	(2.770)
GDP	0.024***	0.004***	0.006***	0.008***
	(0.006)	(0.001)	(8.950)	(0.0001)
TECH	-0.004	0.001	-0.0008***	-0.0002***
	(0.005)	(0.001)	(6.070)	(7.550)
$CO2_{it-1}$			0.645***	0.940***
			(0.001)	(0.001)
Constant	1.787***	0.758***		-0.051
	(0.329)	(0.0691)		(0.0400)
Observations	417	383	344	383
R-squared		0.364		
Number of id	37	37	37	37
AR1			-2.310	-2.321
			(0.032)	(0.022)
AR2			-1.314	-1.34
			(0.170)	(0.180)
Sargan test			332.02	332.03
			(0.850)	(0.950)

Note: Standard errors are shown in parentheses. Significance at *** p<0.01, ** p<0.05, * p<0.1

These researchers also discovered that higher levels of economic activity result in higher levels of carbon dioxide emissions. The findings indicate that the sample countries lack a significant amount of ideas and technology to increase the use of renewable energy sources and improve energy efficiency. The findings also suggest that carbon-dioxide-emitting production activities consume a significant amount of energy derived from fossil fuels.

However, increased production and industrialization result in a higher demand for energy, which in turn results in higher carbon emissions, which is detrimental to environmental quality. These countries' production and industrialization contribute to the acceleration of their economic growth.
The technical coefficients estimated are also negative and significant. The findings show that technological advancement and adoption are beneficial in terms of lowering emissions and improving environmental quality. According to the two-step GMM model, a one percent increase in technology reduces emissions by 0.002 percent. The findings indicate that countries must increase technology and innovation in order to reduce pollution and carbon dioxide emissions. Rising innovations and technology will result in an increase in renewable energy and energy efficiency, which will improve environmental quality. A country's unique development will result in patenting and innovations. According to Ausubel (1991), spillovers and climate change necessitate increased technological innovation. Zhang, Peng, et al. (2017) demonstrate that improved levels of technological innovation can overcome environmental barriers. According to Zhou, Sandner, et al. (2016), patent applications can protect technologies from patent acquisitions. According to Wang, Yang, et al. (2012), acquiring patents reflects the performance of energy innovations and increases energy efficiency. Our findings are consistent with those of Suki et al., 2022) ; Chien, Ajaz et al (2021).

5. Conclusion

This investigation is primarily concerned with three goals. The first step is to investigate how economic growth, technological advancement, and increased commerce affect the amount of energy we use. The second goal is to investigate the impact of trade, finance, economic growth, and technological advancement on energy consumption. The third goal is to investigate the impact of factors such as energy intensity, energy consumption, technological advancement, financial development, and economic growth on carbon dioxide emissions. When these goals are investigated, it will become clear what role technological innovation plays in terms of energy consumption, energy efficiency, and environmental quality. In order to achieve this goal, panel data from 1985 to 2019 were collected and analyzed using static and dynamic panel estimators. The panel unit root test was used first to determine whether the data were stationary. According to the findings, economic expansion and financial development both increase energy consumption, whereas increasing innovation decreases energy consumption. Trade has a minor impact on energy consumption, whereas economic growth, financial development, and economic growth all have a negative impact on energy consumption, resulting in lower energy consumption. The impact of technological advancements on energy efficiency has been positive, resulting in an overall improvement in energy efficiency.
Similarly, energy intensity, energy consumption, trade, financial development, and economic growth all contribute significantly to CO_2 emissions, whereas technological innovations reduce CO_2 emissions and improve environmental quality. The findings show that financial development is related to increased energy consumption and carbon dioxide emissions in the sample countries. The findings show that the financial institutions in the sample countries did not contribute to renewable energy projects, which did not increase energy efficiency and thus increased carbon dioxide emissions. The sample countries must improve their financial systems and ensure that they contribute to environmental quality. If there are well-established financial institutions with sound environmental policies, energy efficiency, energy use, and environmental quality will improve. Similarly, economic growth increases energy consumption while decreasing energy intensity and increasing carbon dioxide emissions. The findings show that countries are only concerned with economic growth in order to raise living standards, even at the expense of the environment. The findings also confirm that these countries use fossil fuels for economic activities and production, which contributes to environmental degradation, as the results show that

energy use is high and energy efficiency is low in the sample countries. Trade openness has little effect on energy consumption while decreasing energy efficiency and increasing carbon dioxide emissions. This demonstrates that trade activities are also contributing to rising economic growth, resulting in high energy consumption, increased carbon dioxide, and decreased energy efficiency. As a result, environmental technology innovation that reduces energy consumption, increases energy efficiency, and reduces carbon dioxide emissions performs well. This is because improved environmental technology can aid in the acquisition of renewable energy consumption for use in environmentally friendly production and economic activities. Improved technological innovation can bring new machinery while reducing energy consumption. Reduced energy use reduces pollution and improves environmental quality. Similarly, improved technological innovation can boost energy efficiency by introducing less polluting technologies. Technology innovations can also be used in international trade activities, reducing pollution, and can be linked to financial institutions. As a result of the findings, environmental technology innovation plays a critical role in reducing carbon dioxide emissions by increasing energy efficiency, reducing energy use, acquiring renewable energy consumption, and thus improving environmental quality. It is recommended that countries promote renewable energy sources through environmental technology for use in economic activities while reducing carbon dioxide emissions.

Our study is limited in that it only looks at the sample countries, the variables used, and the methodology. In the next study, a different method may be used, and the study may be conducted on a different sample of countries, in order to reach a more applicable conclusion. The following study could include governance indicators that highlight its role in financial institutions, economic activities, environmental policies, and its contribution to increasing energy efficiency and environmental quality. These indicators could be incorporated into the research.

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Also, I wish to tell you that this paper has not been sent to another Journal and will not be sent until I have your decision.

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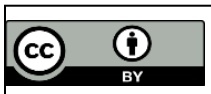

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