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The effect of technological innovations, urbanization and economic growth on environmental quality: does governance matter?

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Climate change has become a major challenge in recent decades as a result of rapid economic growth due to increased energy use and a rise in urbanization. Environmental damage induced by energy use, urbanization, and economic growth can be overcome by technological advancement and good governance. This study examines the effect of urbanization, technological innovations, and economic growth on carbon dioxide emissions in the Belt and Road initiative countries from 2002 to 2022. By using GMM model, the results show that, technological innovations and foreign direct investment raise carbon dioxide emissions however, research and development enhance environmental quality. This study also found that urbanization has a nonlinear relationship with carbon emission where effective governance exert a moderating role in this association. This study provides important policy suggestions for BRI countries.

KEYWORDS

urbanization, technological innovations, governance, environmental quality, economic growth

1 Introduction

Global warming and climate change have become important issues in recent decades Zhou, Eom et al. (2013). Economic growth harms the environment due to energy use and carbon emissions. Environmental deterioration has been increased due to rise in carbon emissions and climate change. Population expansion accelerates environmental degradation, whereas economic growth slows down environmental degradation Adem, Solomon et al. (2020). Severe weather increases with the global mean surface temperature. Throughout the past decade, global warming has been linked to winter warming and spring cooling Shao (2017). Urbanization also affects carbon emissions. Cities produce most greenhouse gas emissions and help reduce carbon emissions. Urbanization boosts the economy, energy use, and carbon emissions. Urbanization and industrial restructuring drives energy use and carbon emissions. This study examines technological innovations, urbanization and carbon emissions, which are significant issues for sustainable development and the low-carbon economy. Globalization accelerates urbanization, which affects carbon emissions. Urbanization and carbon emissions have been studied for a decade. Past studies show that urbanization raises carbon emissions. Urbanization requires rapid urban area growth, declining urban population density, and increasing the daily travel distance of urban people

Glaeser and Kahn (2004). Hence, private car use rises which in turn increasing carbon emissions. Sadorsky (2014) uses the Stochastic impacts of population, wealth, and technology regression (STIRPAT) model to analyze demographic features and pollution using data from over 80 countries collected over the past two decades. Chen, Jia et al. (2008) examined 45 major cities, argues that urbanization reduce *per capita* carbon emissions due to low population density and inadequate infrastructure and public transit utilization. Muñoz, Zwick et al. (2020) found that urbanites had the lowest carbon footprints in 2020. Zhang and Li (2020) found that urbanization reduces carbon emissions by creating economies of scale and non-fossil energy use. Few studies on urbanization investigate nonlinear effect on CO2 emissions in previous literature. According to Martínez-Zarzoso and Maruotti (2011), metropolitan population density and carbon emissions have a U-shaped relationship. According to this study, it assumes that urbanization and carbon emissions are non-linear and examines urbanization's importance.

It is also been stated by other researchers that urbanization directly impacts carbon emissions. Ali, Bakhsh et al. (2019) found that urbanization reduces carbon emissions and does not negatively affect environmental protection. Sun and Huang (2020) found an inverted U-shaped association between urbanization and carbon emissions efficiency in 30 Chinese provinces between 2000 and 2016. Analyzing the indirect consequences of urbanization on carbon emissions, particularly government policy actions, helps in reducing environmental damage. Voluntary corporate climate governance is not enough to decarbonize. National governments must combine direct and indirect climate initiatives to significantly reduce carbon emissions Lister (2018). Consequently, carbon emissions markets need more government intervention. This study evaluates effective government and urbanization-related carbon emissions. Cities produce most greenhouse gas emissions and help reduce carbon emissions. Urbanization boosts the economy, energy use, and carbon emissions. Urbanization and industrial restructuring drive energy use and carbon emissions. Globalization accelerates urbanization, which affects carbon emissions. Advancement in technology also effect the level of economic growth, and carbon emission. Technological innovations, Urbanization and carbon emissions have been studied for a decade. However, this study answers the following questions that have not been done before. How urbanization effect environmental quality? is there any nonlinear association between urbanization and carbon dioxide emission? How technological advancement response to environmental degradation? What is the effect of good governance in urbanization and carbon emissions reduction? To answer these questions, this study examines technological innovations, urbanization and carbon emissions, a significant issue for sustainable development and the low-carbon economy.

This study examines how urbanization affects the ecology of Belt and Road countries. This study examines the direct and indirect effects of urbanization on environmental quality in Belt and Road countries. This study also includes technological innovations and research and development in reducing carbon emission. The study focuses on how Belt and Road institutions promote environmental quality. This study creates these questions: Urbanization affects BRI countries' CO2 emissions? Is the BRI urbanization and CO2 emissions relationship is U-shaped? What is the effect of technological innovations and research and development in reducing carbon emission. Does governance moderate urbanization-CO2 emissions? The study is necessary because Belt and Road countries aim to address economic, social, and governance issues while taking advantage of globalization's potential. This study uses BRI countries, which are mostly emerging or developing countries. This study examines how urbanization affects carbon emissions and institution expansion (including the effectiveness of governance). This study improve technological innovations, urbanization, economic growth, institutional development, and environmental policy in the sample countries by examining the relationship between urbanization and carbon emissions.

The study is structured as follows; Part 2 discusses past research literature, Section 3 describes methodologies, Section 4 discusses the results, and Section 5 concludes the study.

2 Literature review

2.1 Technological innovations and carbon dioxide emission

Several studies have made extensive use of econometric approaches to investigate the ways in which new technologies affect carbon emissions in a variety of nations and areas. Needs in terms of approach, technology, or service are satisfied by innovations Maranville (1992). Technology has the effect of increasing productivity but also increasing carbon emissions. Suki et al. (2022) conducted research on Malaysia to investigate environmental quality and new technologies innovations. Using bootstrapped ARDL model demonstrates that the environmental effect in Malaysia can be mitigated by the use of alternative forms of energy and technological innovations. The Environmental Kuznets Curve was bolstered by this study's findings. A panel cointegration method for analysis was used by Demircan Çakar et al. (2021) to investigate the relationship between technical progress and CO2 emissions in Mediterranean countries from 1997 to 2017. The study found that the adoption of new economic strategies resulted in lower CO2 emissions. Chen et al. (2020) investigated how the introduction of new technologies influenced the CO2 emissions produced by China's transportation sector between the years 2001–2016. They discovered that the innovation signal may have an effect on the carbon dioxide emissions from the transportation sector. They also demonstrate that technological innovation indicators had similar effects across intensities, which suggests that common technology-based techniques for reducing emissions should be used together. During the years 2009 and 2018, Niu (2021) conducted research on China's thirty provinces' levels of technological innovation and CO2 emissions. Analyses using the fixed-effect model, it is possible that technological innovations will both cut carbon emissions and help the Chinese economy.

2.2 Economic growth, urbanization, and carbon dioxide emission

Economic growth and environmental quality are linked with the urbanization. Urbanization takes place when the majority of the population that is capable of working relocates to a city. The most significant socioeconomic shift occurring across the globe, particularly in less developed countries is urbanization Gu (2019). Urbanization is a direct result of economic and social advancement. The urbanization leads to the expansion of society. The growth of the regional economy is stimulated and supported by the development of cities, which serve as economic centers for their regions. China's urbanization fascinates people around the world Chen et al. (2016). Urbanization exacerbates environmental difficulties. Growing research on the relationship between urbanization and carbon emissions has an impact on low-carbon cities Xu et al. (2018). Yet, this body of literature is fragmented. Carbon emissions increase as a result of urbanization, but they also decrease. The emissions of carbon dioxide are increased with urbanization. The consequences of urbanization on the economy, land, and people, as well as carbon emissions, have been the subject of research Zhang and Xu (2017). Each component of urbanization has an effect on carbon emissions. It implies that there is a relationship similar to the Kuznets curve between economic urbanization and carbon emissions. Urbanization causes more increases in carbon emissions than economic expansion Zhang et al. (2021). Emissions of carbon dioxide rose along with the region's population, gross domestic product (GDP), built-up area, and urban road area. Long-term urbanization and carbon emissions are shown to be cointegrated through the use of heterogeneous panel cointegration. According to the findings of credible studies, urbanization in Granger leads to higher levels of carbon emissions (Wang et al. (2016). Urbanization in a region results in both direct and indirect carbon emissions from households. With each additional percentage point of urbanization, household direct and indirect carbon dioxide emissions increase by 2.9% and 1.1%, respectively; Sheng and Guo (2016) showed, with the assistance of mean group (MG), pooled mean group (PMG), and dynamic fixed effects (DFE), that rapid urbanization leads to an increase in both short-term and long-term carbon emissions. Wang et al. (2021) discovered that urbanization leads to lower levels of carbon emissions; however, industrialized economies have disconnected these two factors. According to Ma et al. (2019) China's urban agglomerations are unrelated to the country's overall economic growth. The rise in population and the spread of urbanization both work together to cut a region's carbon emissions Sun and Huang (2020). China's urban agglomerations are unrelated to the country's overall economic growth. The population, economic, and spatial effects of urbanization on carbon emissions were analyzed by Huo et al. (2021) in 30 Chinese provinces between the years 2000 and 2015. Urban population and building footprint affect carbon emissions from urban buildings.

2.3 Carbon dioxide emission, technological progress, and economic growth

The advent of the digital age has brought about profound changes in business, industry, and the economy. The growth in industrial output can be attributed to new technology, which have made production more straightforward, streamlined supply chains, and digitized business processes. The engine of economic expansion is innovation. Both economic growth and emissions of greenhouse gases are influenced by innovation. Many countries have different advantages when it comes to invention based on innovation indices, economic growth, financial sectors, and other aspects Janoskova and Kral (2019). Between the years 1996 and 2018, a spatial econometric model was utilized in order to investigate the correlation between technological innovation and carbon dioxide emissions in 96 different countries. Carbon emissions are unaffected by technological advances. Nonetheless, the results of this study demonstrated that technological advancement led to a significant reduction in emissions in high-income countries that are also large contributors to pollution. According to the data, R&D contributes to a rise in global emissions. Countries that are more globalized see a greater impact from innovation on emissions. Mensah et al. (2018) investigated the relationship between technological advancement and reduced emissions in 28 OECD countries from 1990 to 2014. While the majority of the sample nations saw higher emissions as a result of economic growth, a handful of the nations experienced decreased emissions as a result of innovation. They were unable to provide evidence in support of the environmental Kuznets curve. The use of renewable energy led to a decrease in CO2 emissions, whereas the use of nonrenewable energy led to an increase. In addition, research and development are green practices. The writers are of the opinion that innovation helps to lower carbon emissions and makes the environment better. The research also discovered that different countries have varying levels of innovation and carbon emissions. According to Santra (2017), the BRICS countries environmental innovation brought for a reduction in carbon emissions from 2005 to 2012. The findings indicate that related technologies contribute to the growth of BRICS countries. According to the findings of their research, environmentally friendly technologies can help governments cut emissions of carbon dioxide. These gadgets increase production while simultaneously lowering energy use and CO2 emissions.

Both the consumption of energy and the emission of carbon have an impact on economic growth Al-Mulali and Sab (2012). The consumption of energy leads to an increase in both economic development and CO2 emissions. Jalil and Feridun (2011) analyzed the relationship between economic growth and use of energy and found that financial development is beneficial to economic expansion. Bakhsh et al. (2021) uses the generalized method of moments estimation to investigate the connection between foreign direct investment (FDI) inflows and four indicator variables of carbon dioxide emissions in 40 Asian countries between the years 1996 and 2016. Carbon dioxide emissions are greatly cut when there is an increase in foreign direct investment. According to Aïssa et al. (2014), economic growth was spurred on by both international trade and the use of renewable energy. Raihan and Tuspekova (2023) Dynamic Ordinary Least Squares (DOLS) technique was used to analyze time series data from 1990 to 2021. According to the results of the DOLS estimation, a one-percentage-point increase in economic growth is associated with a 0.24% increase in CO_2 emissions. Furthermore, increasing the use of renewable energy by 1% is related with a reduction in CO_2 emissions of 0.81 percent over the long run, as indicated by the coefficient of renewable energy use being negative and statistically significant.

2.4 Governance and environmental quality

The quality of the public service, civil servants, and their independence from political pressures; policy formulation and implementation; and the government's credibility with respect to its policy pledges determine its effectiveness Kaufman (2011). Urbanization affects government efficiency and carbon emissions. Urbanization has improved the system, technology, and population, boosting government efficiency. Smart cities improve local government efficiency. Yet, urbanization, migration from rural to urban areas, economic and social construction, and innovation will enhance governance standards for economic systems, social mechanisms, related laws and regulations, and urban building. Governments must become more efficient. Urbanization gradually meets people's basic needs, improves living standards, and raises welfare satisfaction, which requires better government services. Urbanization and governance efficiency are poorly studied. This study assumes that urbanization improve government efficiency in formulating legislation and regulations, monitoring markets, enforcing laws, implementing policies, and providing services.

Sustainability, resource conservation, and environmental protection require government efficiency. The study found that government governance and economic welfare can reduce carbon emissions Ronaghi et al. (2020). Effective administration is still the most significant component in lowering harmful emissions, even though countries that import commodities may produce higher emissions. Consequently, governments are crucial to urbanization-related carbon emissions. Government efficiency helps governments adopt sustainable and environmental policies. Implementing sustainable policies, compliance measures, acceptable regulations, and increasing the costs of illegal activity can achieve this (Jayachandran (2015). Government efficiency may affect carbon emissions. Efficient government balances urbanization and carbon output.

Government laws effect carbon emissions and environmental quality Esty and Porter (2005). The market economy relies on government regulation, which also helps increase the efficiency of the market. Carbon emissions can be reduced through governance, which includes government approvals, tax policies, market systems, laws, and regulations. Past research has shown that countries have very different approaches to reducing carbon emissions, and that these differences, together with the fact that national decisions are the driving force behind all aspects of government Halkos and Tzeremes (2013). It is possible that the government will institute a carbon emissions mechanism in order to direct market economic activities. Businesses can cut their carbon emissions by adhering to the regulations. Carbon-defying businesses can find assistance in loopholes. Governance of the market helps to reduce market failures and increases carbon efficiency Jalilian et al. (2007, Dehdar et al. (2022) studied the effect of technology and government policies on carbon emissions in 36 OECD countries from 1994 to 2015 using OLS and quantile regression. results indicated that Gross Domestic Product (GDP), fossil fuel consumption, industrialization and taxation to GDP intensify CO_2 emissions. In contrast, urbanization (% of the total population), environmental patents, and environmental tax as a percentage of total tax reduce CO_2 gas emissions. Kazemzadeh et al. (2023) investigate the nexus between economic growth, institutional quality, urbanization and energy consumption on carbon emissions. The model results shows that model allows for exploring sufficient conditions and identifying the optimal combination of variables that increase or decrease the ecological footprint.

2.5 Economic growth, energy consumption and carbon emissions

Same like governance, technological innovations and urbanization, several other factors effect carbon dioxide emission. For instance, Kazemzadeh, (2022a) used data of 16 emerging economies from 1990 to 2014 and estimated resources, export quality and energy efficiency on ecological footprint by using quantile regression. The findings shows that According to the SBM-DEA model, Turkey and Hungary ranked higher, whereas China and India ranked lower in terms of resources and energy efficiency. According to quantile regression, resources, energy efficiency, and trade openness lower the ecological footprint. GDP, consumption of fossil fuels, and population, on the other hand, all contribute to a worsening of the environmental footprint. Weili, (2022a) studied the effect of carbon emissions, energy use and economic growth on innovations in 181 countries of the world from 1980 to 2019. The findings shows that carbon dioxide and economic growth increase technological innovations while the inflow of FDI decrease innovations output. Energy consumption also negatively affects innovation indicators except for research and development. Raihan and Tuspekova (2022) studied the nexus between energy consumption, forest and industrialization with carbon emissions in Russian. Using ARDL model, the findings shows that energy consumption and industrialization raise carbon emissions in Russia. Kazemzadeh, (2022b) explore the effect of energy transition on carbon emissions in five countries from 2006 to 2020 using panel quantile regression. The findings shows that brain drain, trade openness, and economic growth increase CO_2 emissions *per capita*. At the same time, the energy transition, energy efficiency, and urbanization mitigate the environmental degradation in this group of countries. Koengkan et al. (2023) studied energy transition and environmental degradation in 18 Latin American an Caribbean countries. Using nonlinear ARDL model and found that economic growth in both the short-and long-run have an increase of 0.6994 and 0.3192, respectively, and the variable public capital stock in the short-run has an increase of 0.0176 in CO_2 emissions. However, the positive and negative asymmetry of the variable ratio of renewable energy in the short-and long-run has a decrease of −0.1320 (on positive variations) and −0.1131 (on negative variations) in the short run and −0.0364 (on positive variations) and −0.0783 (on negative variations) in the long run-on CO_2 emissions. Moreover, Koengkan and Fuinhas (2021) studied the effect of gender inequality on environmental degradation in 14 European union countries from 1991 to 2016 using moments quantile and fixed effect model. The findings shows that gender gap pay and energy consumption increase the CO_2 emissions in the EU. However, the economic growth, globalization and urbanization deepening do not increase the environmental problem. Batool et al. (2022) investigate the relationship between economic growth (GDP), financial development (FD), and energy

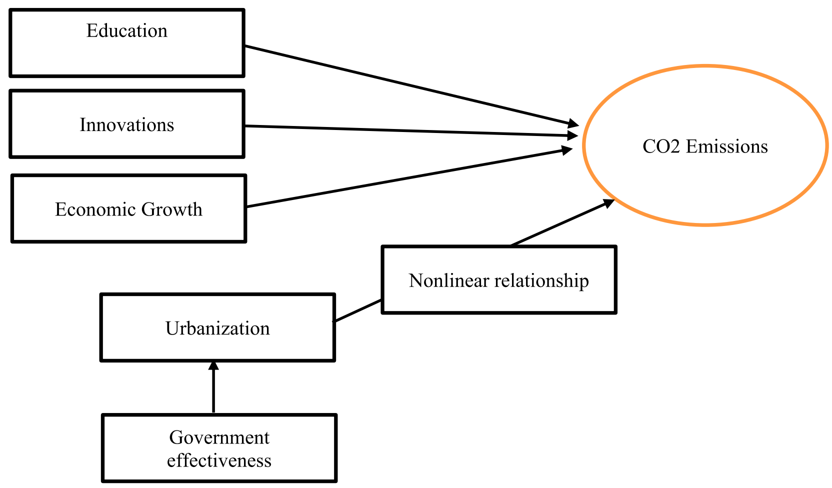

FIGURE 1
The effect of urbanization on carbon dioxide emission.

consumption (ENC) in South Asian countries for the period 1991–2020, Panel co-integration procedures are used for empirical purposes. However, the long-run results of the Pooled Mean Group (PMG) reveal that the impact of financial development (FD) and economic growth (GDP) on energy consumption (ENC) is positive and considerable. Based on the Granger causality results of the Vector Error Correction Methodology (VECM), the Conservation Hypothesis holds between economic growth (GDP) and energy consumption (ENC) in the South Asian Region in both the short and long run. Furthermore, the findings suggest that there is a two-way causal relationship between financial development (FD) and energy use. Likewise, Karimi Alavijeh et al. (2022) studied the effect of agriculture development on carbon dioxide emission in 15 developing countries from 2004 to 2020 using quantile regression. Results show that the agricultural value added is positive and significant in all quantiles except the 0.3, 0.4, and 0.5 quantiles, and it becomes more in higher quantiles. Moreover, energy consumption and trade openness are the most robust influential variables. Koengkan et al. (2022) explore the battery electric vehicles and plug in hybrid electric vehicles on carbon emissions in 29 EU countries from 2010 to 2020. The results show that BEVs and PHEVs are capable of mitigating CO_2 emissions. However, each type of technology has a different degree of impact, with BEVs being more suited to minimizing CO_2 emissions than PHEVs. We also found a statistically significant impact of economic development (quantile regression results) and energy consumption in increasing the emissions of CO_2 in the EU countries in model estimates for both BEVs and PHEVs. Angelov (2023) studied US recession in 2023 and its economic implications. The authors employed economic models to assess the livelihood of recession. Using Keynesian Cross and IS-LM model, the findings shows the significance of timely and targeted stimulus, the need for coordinated monetary and fiscal policies and the long term structural reform importance. Muhammad, (2023a) studied the Butterfly effect and its implication for resilience in complex socio ecological systems. This study aims to uncover the nonlinear dynamics, tipping points, and feedback loops that magnify or reduce the consequences of modest perturbations in complex systems by scrutinizing case studies and applying mathematical modelling. Furthermore, it investigates how understanding the Butterfly Effect might influence techniques for increasing the resilience of socio-ecological systems, such as adaptive management, scenario planning, and community participation. The study also investigates the ethical and governance implications of complex systems' unpredictability and interdependence. It emphasizes the importance of inclusive decision-making procedures that take into consideration varied viewpoints and values. Chatterjee and Bhandari (2023) studied the livelihood strategies dimensions for the inhabitants of several occupational groups at Sundarbans, associated opportunities through sustainable livelihood framework. The study concludes that with the recommendation of Mangrove regeneration at Sundarbans. Udoh et al. (2023) explore the impact of particulate emission damage, natural resources, growth in agriculture land and population growth on output per worker in Nigeria. Using ARDL model, the findings shows that output per worker increased with an increase in the explained variables used in the study. The findings shows that sustainable growth can be achieved through the reduction of human activities that deplete the environment. Asad et al. (2022) examine the manager's perception about Green Human Resource Management and its practices in the corporate sector of Khyber Pakhtunkhwa (henceforth, KP), Pakistan. The study shows that shows that on average 63 percent of the managers do green practices and 38 percent do not, 64 percent of managers do eco-friendly practices in their industries while 53 percent of managers do not, and 42 percent of managers are working to expand the sphere of green HRM practices but 57 percent of managers do not work as such to expand green HRM practices in their organization. Raihan and Voumik (2022) investigated the dynamic effects of financial development, renewable energy utilization, technical innovation, economic growth, and urbanization on carbon dioxide (CO2) emissions in India. Using time series data from 1990 to 2020 using an Autoregressive Distributed Lag (ARDL) model, this study assesses short and long-run dynamics. The results of

TABLE 1 **Variables description and Symbols.**

Variables description	Symbols		Source
carbon dioxide emissions (metric tons *per capita*)	ENV		WDI
Patent application residents	PAR	TIVT	WDI
Research and development expenditure	RD		WDI
Fixed telephone subscription per 100 people	FTS		WDI
Urbanization taken as total population	UBN		WDI
Education attainment compulsory	EDU		WDI
Per capita gross domestic product	GDP		WDI
Foreign direct investment inflow %GDP	FDI		WDI
Government effectiveness (estimate)	GVR		WGI
Labor force	LBF		WDI
saving (Net saving)	SVN		WDI

Note: WDI, and WGI, are world development indicator and world governance indicator respectively.

the ARDL short- and long-run analyses revealed that financial development, economic expansion, and urbanization have a positive and significant effect on CO2 emissions in India. In contrast, the short- and long-term coefficients for renewable energy utilization and technical innovation are both negative and statistically significant, implying that increasing these variables will result in decreased CO2 emissions. Khan and Liu (2022) studied the financial availability and innovation link with environmental and firm performance. The results show that suitable financial resources have contributed to the performance of financial instruments, but they also play a significant part in environmental performance. Muhammad, (2023b) conducted a study on Using Laplace series and partial integration in valuing environmental assets and estimating Green GDP. The study concludes with suggestions for future research to further explore the potential of the proposed method and its impact on sustainable development. Ozoadibe and Obi (2023) studied green building practices and energy facility in public libraries in Rivers State. The findings revealed that Rivers state libraries can preserve archives with renewable energy and green building practices, such as solar power, passive ventilation, native landscaping, water-efficient fixtures and regulated humidity. Muhammad, (2023c) evaluate the potential for adapting the meritocracy, pragmatism, and honesty (MPH) model to the Nigerian context with the aim of promoting economic development in the country. He results of the study suggest that adopting the MPH model in Nigeria could lead to increased economic growth, improved competitiveness, and reduced poverty and inequality. Raihan (2023a) Using the most up-to-date annual data between 1990 and 2019, this study investigated the evidence of the Environmental Kuznets Curve and the Pollution Haven Hypothesis in Bangladesh. The empirical results indicated that the country has an inverted U-shaped Environmental Kuznets Curve and the adverse impact of foreign direct investment on the environment confirmed the validity of the Pollution Haven Hypothesis in Bangladesh. Jamil and Rasheed (2023) used 260 Pakistan stock exchange-listed firms data from 2011 to 2020 and estimated impact through Regression least square method and GMM. The results of Regression least square and GMM confirmed that the Corporate social environment and environment friendly Co_2 emission have high significant positive impact on Organizational Performance. Social capital role as mediator is highly positive significance that enhances employee's social, environment Co_2 emission activity and firm outcomes; Indicate corporate social environment, eco-friendly Co_2 emission and social capital have intangible potential Capital of a firm and their significant impact on organizational performance. Raihan (2023b) conducted a review of tropical blue carbon ecosystem for climate change mitigation by considering economic significance of ecosystem services rendered by blue carbon habitats associated with governance mechanism and conservation approaches to address climate change mitigation through ecosystem. The study reviewed forms of governance and shows that there is potential for future implementation to reduce ecological issue.

3 Methodology

3.1 Empirical models

This study examines the effect of technological innovations and economic growth on carbon emissions by introducing governance and urbanization into the model in the Belt and Road countries from 2002 to 2022. This time is chosen based on the availability of data of the variables. The sample selection is based on the economics, social and institutional characteristics of the belt and road initiative countries. The data has been collected from the world bank database, world development and world governance indicator. Holtz-Eakin and Selden (1995), Martínez-Zarzoso and Maruotti (2011) and Holtz-Eakin and Selden (1995) used this indicator for data collection. Data were analyzed using STATA version 15. This study specifies the baseline model presented in Equation (1) while Equation (2) shows the nonlinear association of the variables. Equation (3) present the interaction term of governance and urbanization.

$$ENV_{it} = \beta_0 + \beta_1 TIVT_{it} + \beta_2 FTS_{it} + \beta_3 UBN_{it} + \beta_4 EDU_{it} + \beta_5 GDP_{it} + \beta_6 FDI_{it} + \beta_7 GVR_{it} + \beta_8 LBF_{it} + \beta_9 SVN_{it} + \varepsilon_{it} \tag{1}$$

$$ENV_{it} = \beta_0 + \beta_1 TIVT_{it} + \beta_2 FTS_{it} + \beta_3 UBN_{it} + \beta_4 (UBN)^2_{it} + \beta_5 EDU_{it} + \beta_6 GDP_{it} + \beta_7 FDI_{it} + \beta_8 GVR_{it} + \beta_9 LBF_{it} + \beta_{10} SVN_{it} + \varepsilon_{it} \tag{2}$$

$$ENV_{it} = \beta_0 + \beta_1 TIVT_{it} + \beta_2 FTS_{it} + \beta_3 UBN_{it} + \beta_4 (UBN)^2_{it} + \beta_5 EDU_{it} + \beta_6 GDP_{it} + \beta_7 FDI_{it} + \beta_8 GVR_{it} + \beta_9 LBF_{it} + \beta_{10} SVN_{it} + \beta_{11} (UBN^{*}GVR) + \varepsilon_{it} \tag{3}$$

ENV represent environment where CO2 is used to proxy for environmental quality. CO2 is measured in metric tons *per capita*. TIVT represent technological innovation proxy by patent application (PAR) and research and development expenditure (RD). FTS is infrastructure proxy by fixed telephone subscription/100 people. Urbanization is represented by UBN, which is measured by the proportion of the urban population in total population. EDU is education, GDP is *per capita* gross domestic product represent economic growth, FDI is foreign direct investment inflow, GVR is governance proxy by government effectiveness, LBF is labor forces while SVN is saving. To capture the nonlinear effects of urbanization on carbon emissions, this study also includes the squared term of urbanization into the econometric estimates, which is specified in Equation (2). In addition to an evaluation of the nonlinear effects of urbanization on carbon emissions, this study also addresses the interaction term between government effectiveness and urbanization. Figure 1 shows the relationship between variables. Table 1 shows the variables description, symbols and data sources.

Carbon dioxide emissions are taken as a Metric ton *per capita*. Recently, Raheem et al. (2020) and other researchers have employed this proxy Khan, (2021a). It is a widely held belief that higher levels of carbon dioxide emissions result in a decline in the quality of the environment in a given country. According to Li et al. (2019), a growth in urban population is likewise associated to an increase in carbon dioxide emission Khan, (2021b). The process of urbanization involves the movement of people from rural to urban areas and the change of an agricultural economy to an industrial economy Muhammad et al. (2020). When there is a growth in urbanization, there will also be an increase, in the number of emissions as a result of increased industrialization, production by residents, and improvements in the inhabitants' standard of living. On the other hand, some people believe that the increase in urbanization and resulting population agglomeration leads to an increase in the efficiency of energy usage and a contribution to the realization of economies of scale Solarin and Lean (2016); Canh et al. (2019); Ghisellini and Ulgiati (2020); Nguyen et al. (2018); Nguyen et al. (2018). Numerous studies in the prior literature suggest that an increase in urbanization leads to a high level of output and an increase in carbon emissions Khan, (2022b). The indicator of a region's social wellbeing is enhanced in this study effort to incorporate the component of educational attainment. This facet relates to the delivery of public services: The transformation of urban residents' energy consumption or other activity patterns is inextricably linked to the enhancement of public services, which may or may not have a direct impact on carbon dioxide emissions but is closely related to the transformation of those patterns. For example, if individuals have a better awareness of the negative consequences of carbon emissions on them, the local government is more likely to take additional actions to cut emissions. We examined how technology advancement impacts environmental quality. According to multiple studies, innovation increases emissions, however we believe this effect might be positive or negative depending on the country. Pollution control costs enable nations and businesses to innovate in order to compete on the market Dangelico and Pujari (2010). Tight environmental regulations drive cleaner production via innovation, hence boosting environmental performance. Sharif et al. (2023) contend that energy-efficient technologies and energy innovation can have an impact on climate change. Technological innovation in economics is difficult to measure due to the fact that in the past, researchers have employed proxies such as R&D expenditure Maradana et al. (2019); Knott and Vieregger (2018); Patent Applications residents Maradana et al. (2017); Wusiman and Ndzembanteh (2020); licensing; and new product development. This study employs two indicators to evaluate innovations. First, R&D expenditure as a proportion of GDP Kwon et al. (2022). Human, material, and monetary resources are needed for scientific research and experimental development Knott and Vieregger (2018). The second proxy is the number of patent applications per one thousand residents Wusiman and Ndzembanteh (2020); Rodríguez-Pose and Wilkie (2019). Innovation explains changes in emissions Su and Moaniba (2017). A proxy for the infrastructure based on the number of people per hundred having a fixed telephone line Weili, (2022b). According to the conclusions of a study, infrastructure upgrades, notably in the sector of telecommunications, stimulate economic growth Canning and Bennathan (2000). Wheeler and Mody (1992) highlighted that the success of multinational investors depends on a dependable infrastructure. As a result, the infrastructure will have an immediate impact on the number of IEDs that are introduced. The impact of infrastructure on the degree of economic activity and environmental quality.

The *per capita* gross domestic product is used as a measurement of economic growth Aritenang, 2021, Hamdaoui, Ayouni et al. (2021); Khan, (2022a). According to the research, higher levels of economic growth are associated with increased levels of pollution and carbon dioxide emissions Ozcan et al. (2018, Khan, (2021b). Similarly, previous studies have indicated that a rise in economic expansion is associated with an increase in carbon emissions and a deterioration in the quality of the environment. It has been demonstrated by Krueger and Grossman (1995) that the level of income *per capita* is a significant factor in determining the amount of carbon emissions produced. There has been a great deal of studies done in the past that demonstrated the Environmental Kuznets Curve by using the square terms of GDP *per capita* Stern (2004). The environmental Kuznets Curve demonstrates that economic growth has a positive influence on carbon emissions; however, once a country reaches a certain level of development, emissions begin to decline. This happens after a country has reached a certain level of development. In order to investigate the nonlinear influence of *per capita* growth on carbon dioxide emissions, this study incorporates the quadratic function of economic growth, which was not included in the previous research.

A sizeable number of academics investigate, too, how the effect of international direct investment on carbon emissions can be understood. The level of foreign direct investment can have either a positive or a negative impact on the amount of carbon emissions produced by a country; however, this impact is always dependent on the level of foreign direct investment. The Pollution Halo and Pollution Haven effects are the most common outcomes that can be caused by foreign direct investment. The Pollution Haven hypothesis contends that rising levels of foreign direct investment will lead to higher levels of carbon dioxide emissions and a deterioration in environmental quality. On the other hand, the Halo hypothesis maintains that increased levels of foreign direct investment will reduce carbon emissions and lead to an improvement in environmental quality. In earlier theoretical frameworks, it was hypothesized that energy-intensive businesses would prefer to construct their operations in countries that had less stringent environmental regulations Walter and Ugelow (1979). However, more recent viewpoints suggest that increased foreign direct investment brings advanced technologies as well as improved environmental management, thereby leading to an improvement in the quality of the environment Birdsall and Wheeler (1993). We include foreign direct investment in the model so that we can investigate the effect that it has on the level of environmental quality in countries along the Belt and Road.

The effectiveness of the government reflects the political independence of civil workers and the quality of bureaucracy. It demonstrates the dependability of government policy pledges and the excellence of public services. It further undermines the adaptable management of public authorities. Effectiveness of government refers to the caliber of civil officials, the formulation of policies, and their execution. Mehlum et al. (2006) suggested that resource-rich nations can leverage their abundant supply to generate rapid economic growth if their institutions function properly. Strong governance and robust institutions are required for sustained and consistent economic growth. Natural resources typically bring disputes and issues to a country and have a detrimental impact on the country, but this negative impact can be turned into a good impact by ensuring that the country's institutions are of high quality. Brewer (1993) addressed many sorts of government actions that might directly and indirectly influence the economic level of a nation via their effects on market imperfections. It can be viewed as a choice between utilization today and utilization tomorrow, as it is a strategy to build wealth through time and improve the standard of living of many people in the future. Anthony-Orji et al. (2017) discovered that long-term consumer savings positively impact economic growth. Before doing formal analysis, this study employs the cross-sectional dependence test, the second-generation panel unit root test, and the cointegration test. This study employs Westerlund panel cointegration as its cointegration test. This test accepts the no cointegration null hypothesis and demonstrates that there is no long-term connection between the variables. After conducting these early tests, we continue to formal analysis utilizing static and dynamic panel models. These estimators consist of OLS, the fixed effect model, the two-step difference, and the two-step system generalized technique of moments (GMM). The GMM model was introduced by Arellano and Bond (1991) which is regarded as the most recent application of the theme, and the majority of studies that deal with panel data focus on this estimate. To address the heterogeneity issue, the study first employs static models, OLS, and fixed effect. These static estimators are used to compare the findings of the current investigation with those of previous studies, as well as with the results of dynamic models. It will address the issue of endogeneity related with the study variables by employing GMM models Kinyondo et al. (2021). System GMM models account for grouping equation variances on a horizontal plane. The instruments indicated in the model have a changeable delay value in the difference equation. In addition, the horizontal equation and first-difference instruments are variables that are investigated. The simulation of Monte Carlo by Blundell and Bond (1998) demonstrates that the SGMM model provides the best accurate estimation of this challenge. The over-identifying restriction test was replaced with the Sargan and Hansen tests, and the sequence correlation tests of Arellano and Bond were also employed. The majority of these test findings verified our research predictions. Acceptance and effectiveness of the instruments are indicated by Hansen test values. The serial correction test determines whether or not the hypothesis is supported by the second serial correlation of residuals. In the regression results, the coefficients were confirmed and heteroskedasticity was examined. Foreign direct investment is the dependent variable in the GMM equation, which may be expressed as follows:

$$ENV_{it} = \beta_0 + \beta_1 CO2_{i,t-1} + \beta_2 Y_{i,t} + \beta_3 X_{i,t} + \varepsilon_{i,t} \tag{4}$$

In Eq. (3), ENV represent environmental degradation proxy by carbon dioxide emission, Y is the explanatory variables used in study and X represent the control variable, $CO2_{i,t-1}$ is the first lag of carbon dioxide emission is used as an explanatory variable to measure the effect of the previous year's emission on the current carbon emissions while ε is the error term. The subscripts in the equation specify (i = 1. . . N) and (t = 2002. . . 2019) index country and time respectively.

This analysis employs a Belt and Road Initiative country panel dataset. To perform this type of research, panel data is preferable to other types of data, such as time series or cross-sectional data, because panel data offers numerous major advantages Hsiao (2005). Panel data provides and enhances estimation efficiency, typically with a greater degree of freedom. This study employs static and dynamic models for panel data to determine the relationship between research variables in nations along the "Belt and Road" by analyzing research data. Apply an alternative model to the data, such as a static simple ordinary least squares estimator. In addition to basic least squares estimators, other estimators for panel data, such as fixed-effects models and dynamic models, were employed in this study. Generalized method of moment (GMM), wherein GMM includes two types of estimators, difference GMM and System GMM, designed by Holtz-Eakin and Rosen (1990); Blundell and Bond (1998) provides correct and consistent estimates in panel data analysis. In addition, the dynamic panel model includes a component of the Sargan test for over-identification constraints, the Arellano-Bond test for second-order serial correlation, and the unit root test for panel data to determine data stationarity. Other models, such as OLS and fixed effects other than GMM estimators, were used in the current study for comparison purposes only. The primary focus was on GMM models, particularly the two-system GMM, to examine the relationships between the study variables, as simple methods such as ordinary least squares estimation raise different econometric issues. When there are dependent variables left out of regression, these concerns can immediately become relationship concerns. In terminological error, the presence of fixed effects of temporal factors may also be related to descriptive variables, and there may be endogeneity difficulties between independent and descriptive variables. These descriptors can also be associated with the term error. As discussed previously, endogeneity can be a concern, so research must use instrumental variables, such as IV estimators, to eliminate this issue. Nonetheless, when employing weak instruments such as IV, fixed effects can be just as biased and inconsistent as those of conventional minimum square estimators. To avoid these issues connected with OLS and fixed effects estimators, the current investigation will employ the dynamic estimator difference GMM of Arellano and Bond (1991) instead of the simple estimators discussed previously. The time-invariant indicator is then ranked using a differenced GMM estimator, which transforms the regression using the initial difference of the dependent variable and the independent variable to help eliminate country-specific effects. In the difference GMM, the lagged dependent variable is compared to its previous level, hence eliminating autocorrelation issues. Yet, the metric lag level may account for inadequate instruments in the first difference regressor, which appears to diminish efficiency.

Thus, this study employs the dynamic models created by Blundell and Bond (2000) which contain difference and system GMM models, in order to boost the level of efficiency. The system GMM model yields a system of two equations and one difference equation, the second of which is still at the level of Kurul and Yalta (2017). Then, the second equation variable is derived from its specific variable, and the first difference is identified by the related unique lag level. GMM estimations are also separated into one step difference GMM and one step system GMM. This study employed two-step difference GMM and two-step system GMM because the two-step GMM beat the one-step GMM in automated communication and treatment of homosexuality. In addition, the two-stage estimator employs the optimal weight matrix.

The following model is presented as the regression model of the present study;

$$y_{i,t} = \alpha + \beta Y_{i,t-1} + \Upsilon X_{i,t-1} + \eta_i + \epsilon_{i,t}$$

In the regression model above, the dependent variable is represented by “y”, where X represents the vector of the explanatory variable, η in the study represents the country fixed-effect time invariant, while ϵ is the error term. In addition, the subscripts “I" and “t" are the country and time, respectively. The dependent variable in the equation above is lagged, and here we have country-specific fixed effects. Omission country-specific fixed effects related to panel data estimators leads to inconsistent and biased Ordinary Least Squares (OLS) estimators on the levels, and explanatory variables on different right-hand sides may be endogenous. For the purpose of the simultaneity problem, explanatory variables for the endogeneity problem in the regression model have to be controlled. To solve such a concurrency problem, the initial values should be taken as the instrument of explanatory variables Levine and Zervos (1998). All models of the study explain in detail as following.

4 Results and discussions

This section presents the results and discussions. Section 4.2 presents the panel unit root tests results while section 4.3 presents the results on the effect of income inequality, and institutional quality on carbon emissions.

4.1 Results of the panel unit root tests

Prior to carrying out an official analysis, it is essential to check and see whether or not the values of the previous variables have remained the same. Because of this, second-generation unit root tests have been used in order to investigate whether or not the variables are stationary. This is a direct result of the previous point. The second generation of tests is based on the presumption that each series in the sample has been arbitrarily sectioned off into cross sections. This presumption is what allows the tests to function. The average cross-sectional intervals and the first difference of a single series are utilized in the second generation of tests, which results in an improvement in ADF. This is done in order to filter out the cross-sectional correlation that is caused by a single common component, as was indicated by the previous sentence Pesaran (2007). When defining the unit root in the panel for each region or country, the uniformity of a null hypothesis is the method that is utilized. This is done in order to compare the null hypothesis to contradictory alternatives that allow for differences between geographical areas or countries. The CIPS and CADF tests of the second generation are used whenever an examination of data stationarity is carried out. The evidence that all of the research variables are stable at the level of the first difference is provided by the panel unit root test.

The panel unit root test is superior to other unit root tests used for individual time series are superior because it combines evidence from cross-sectional data with information from the series that are being tested. This gives it greater power and ability than other unit root tests. This provides an advantage for the test in comparison to other unit root tests. The results of the tests that were run on all of the study variables that were used in all of the nation-specific models are presented in the following table. At the first level of significance, each of the researched aspects was tested, and the findings revealed that each of the variables was significant. Similar to the way that second-generation tests do, first-generation tests determine whether or not the variables being studied are stationary at levels or first-order differences. First-generation tests, on the other hand, concentrate on the level of the variable. This investigation’s findings from all of the panel unit root tests unmistakably revealed that the data series were stationary, and as a result, the null hypothesis of the *p*-value given the unit root test was rejected as a result. Table 2 contains the findings of the panel unit root test for each variable, as well as a sample of the countries that were used for the research.

4.2 Model results on the effect of technological innovation on carbon emissions

In the following section, the study investigate the impact that technological innovations, economic growth and urbanization has had on the amount of carbon emissions produced in each of the

TABLE 2 Panel Unit Root test results.

Variables	CIPS		CADF	
	I(0)	I(1)	I(0)	I(1)
CO2	−1.657	−3.565 ***	−0.284	−3.821***
PAR	−2.345*	−2.887***	−2.326**	−3.476**
RD	−3.766***	−5.053***	−2.441***	−5.274***
FTS	−3.463***	−2.893***	−3.231**	−3.725***
UBN	−1.629	−2.402***	−2.547***	−2.110**
EDU	−1.820	−4.212***	−1.575	−2.622***
GDP	−3.631***	−5.147 ***	−3.044***	−4.279***
FDI	−2.878***	−6.065***	−2.381***	−5.244***
GVR	−2.453***	−3.863***	−2.210**	−2.725***
LBF	−1.801	−4.212***	−1.645	−2.532***
SVN	−1.442	−3.502***	−1.354	−2.228***

Note: **, *** shows significance level at 5 percent and 1 percent respectively.

TABLE 3 Descriptive statistics.

Variable	Mean	Std. Dev	Min	Max
CO2	4.472	3.421	0.002	15.047
PAR	17.34	12.2	1.001	1400.0
RD	0.78	0.819	0.035	4.92
FTS	17.369	13.376	0.472	51.49
UBN	54.233	15.857	17.19	92.401
EDU	74.905	27.133	0.541	99.582
GDP	3.584	3.828	−13.75	17.13
FDI	4.318	6.386	−41.081	60.46
GVR	0.034	.644	−1.33	1.321
LBF	3.420	1.23	225.00	8.90
SVN	22.715	8.016	−8.290	47.42

countries that are part of the Belt and Road. In the beginning, the analysis of the data that had been obtained began with the application of descriptive statistics. The purpose of descriptive statistics is to make the process of data interpretation less complicated by delivering an easily consumable summary of the data via graphical or numerical methods. This can be accomplished by the use of descriptive statistics. The purpose of statistical methods was to define the data by locating the value that was most representative of the whole set of data. Not only were there measurements taken to determine the central tendency, but there were also measurements taken to determine the spread of the data. These included the standard deviation, the highest and lowest possible values, as well as the range of values. The metrics of spread reveal how dispersed the data are as well as how similar or different the data are from one another. In addition to discussions and various other types of data presentation, tabulations were utilized in order to summarize the descriptive data that was collected. In spite of this, the only reason for using descriptive statistics is to provide a description of the data. They remove any possibility of deducing anything from the facts or making any assumptions based on those facts. This suggests that descriptive statistics require being supplemented by other methods of data analysis in order to be fully adequate.

The descriptive statistics for the variables that were utilized in the analysis can be found in Table 3, whereas the correlation matrix for the variables can be found in Table 4.

Table 4 presents the direct effect that urbanization has on carbon dioxide emissions, Table 6 presents the nonlinear relationship that exists between urbanization and carbon dioxide emissions, and Table 7 presents the findings regarding the transformative effect that governance has on the relationship that exists between urbanization and carbon dioxide emissions. The names of the variables are listed in column 1 of each of the tables that follow; the results of the OLS model, the fixed effect model, the difference GMM model, and the system GMM model are listed in columns 2, 3, 4, and 5, respectively. As was mentioned in the section devoted to techniques, the GMM, and more particularly the two-step system GMM model, is the primary focus of our attention because it is the estimator that is the most accurate. In order to determine whether or not the instrument is valid, both the Hansen and Sargan tests as well as the autocorrelation test were carried out. Both the Arellano and Bond test of serial correlation and the Sargan test of over-identification restriction are applied in this process. The Hansen test takes the place of the Sargan test after it has been completed. The findings of the majority of these applied tests were in agreement with the hypotheses that were proposed in this study. The Hansen test value is an indicator of whether or not the instruments can be trusted and are valid. With the use of serial correlation tests, one can ascertain whether or not the hypotheses regarding the serial correlation of residuals of the second order are supported. These tests are carried out on the model data that is given in the paragraphs that immediately follow each table.

The direct influence that urbanization has had on carbon emissions, when joined with other variables that explain the phenomenon, is presented in Table 5 Although OLS, FE, difference GMM, and system GMM models are used for analysis, system GMM is the primary focus of this work, as is discussed in the methods chapter. Other models, such as difference GMM, are also applied. In every model, the generated urbanization coefficient is positive and statistically significant, suggesting that urbanization raises the amount of carbon dioxide emissions and lowers the quality of the environment in the countries that are a part of the belt and road. To be more specific, the parameters in the two-step system GMM model imply that carbon dioxide emissions will increase by 0.003% for every percentage point increase in urbanization in the countries along the belt and road. The findings indicate that urbanization in the countries that were studied resulted in higher levels of carbon dioxide emissions and contributes to the deterioration of the environment. Our findings, which are consistent with those of Al-Mulali et al. (2015) indicate that urbanization leads to an increase in the emission of carbon dioxide in the nations of Europe. In yet another investigation, Aye and Edoja (2017) came to the conclusion that population has both a positive and a negative impact on the amount of

TABLE 4 Correlation matrix.

	CO2	UBN	EDU	PAR	RD	FTS	GDP	FDI	GVR	SVN	LBF
CO2	1.000										
UBN	0.431	1.000									
EDU	0.431	0.163	1.000								
PAR	0.056	−0.029	−0.06	1.000							
RD	0.531	0.615	0.142	0.074	1.000						
FTS	0.361	0.428	0.361	−0.028	0.591	1.000					
GDP	−0.120	−0.153	−0.057	0.132	−0.230	−0.072	1.000				
FDI	0.063	0.038	0.157	−0.033	−0.034	0.104	0.192	1.000			
GVR	0.526	0.551	0.255	−0.053	0.624	0.342	−0.104	−0.057	1.000		
SVN	0.351	0.068	−0.135	0.442	0.175	−0.044	−0.011	−0.161	0.152	1.000	
LBF	−0.021	−0.134	−0.239	0.853	0.002	−0.234	0.136	−0.047	−0.131	0.474	1.000

carbon dioxide that is released into the atmosphere. According to the findings of yet another investigation Anwar et al. (2020) urbanization has a significant bearing on the production of carbon dioxide.

In the vast majority of models, the estimated education has a negative value and a significant impact, demonstrating that increasing levels of education in belt and road countries leads to lower levels of carbon dioxide emissions and better overall environmental quality. To be more specific, the two-step system GMM model predicts that an increase in the percentage of the population in belt and road countries who have completed secondary education will result in a 0.001% reduction in carbon dioxide emissions. As the data have shown, a high level of educational attainment is absolutely necessary in the sample countries if there is to be any improvement in the standard of the environment.

The findings indicate that the estimated coefficient of innovation proxy by patent application is positive and statistically significant across all models. This suggests that patent applications increase carbon dioxide emissions and reduce environmental quality in the countries that are part of the belt and road. The coefficients of the two-step system GMM model suggest, in particular, that an increase of one percent in innovation in the countries along the belt and road will result in a 2.5 percent rise in carbon dioxide emissions. In the event that there are distinguishing improvements that lead to invention and, consequently, patenting. According to Ausubel (1991), climatic change and diffusion cannot occur without significant developments in several technical achievements. Environmental innovations, as stated by He, Pan et al. (2017), help to lessen the impact of environmental problems. Zhou et al. (2016) Laws that require inventors and investors to gain patent awards via patent application in order to protect invented inventions. Patent applications are submitted in order to safeguard invented inventions. Getting patents for energy goods is an example of energy technology innovation performance activities that also promotes energy technology. This suggests that increased innovation can help reduce carbon emissions by improving energy efficiency and gaining access to renewable energy sources such as solar technology. Despite this, our findings regarding the influence of patent applications on carbon emissions point in a positive direction. Countries along the Belt and Road should work to strengthen their patent systems, as this will make it easier to enhance environmental quality. This innovation proxy was also used by Chuzhi and Xianjin (2008) and Khan, (2021a), and they discovered similar results. According to the findings of numerous studies, patents also have a beneficial effect on carbon emissions. However, the outcome of our study goes against the findings of Chien, (2021a) who used quantile regression and patent application as proxies for innovation and came to the conclusion that it brings about a reduction in carbon emissions in Pakistan.

In the model with a fixed effect, the estimated coefficient of research and development is significantly negative, while in the model with an ordinary least squares regression, it is notably positive, and in the models with a difference and a system GMM, it is insignificant. This research focuses on the results of system GMM models, and as a consequence, our findings reveal that expenditures on research and development have a minor impact on carbon emissions. In a similar vein, the infrastructure coefficient is shown to be positive but rather insignificant across all estimators. This suggests that infrastructure in the belt and road countries does not have a significant impact on the amount of carbon dioxide emissions.

The majority of models forecast positive and statistically significant economic growth, which increases carbon dioxide emissions and lowers environmental quality in belt and road countries. The two-step system GMM model coefficients show that a percent increase in economic growth in belt and road countries will increase carbon dioxide emissions by 0.03 percent. Economic growth in the sample countries increases carbon dioxide and environmental impact. This result matches Khan, (2022a). Usman et al. (2020) say economic growth increases ecological footprint. Our findings contradict Khoshnevis Yazdi and Shakouri, (2017). According to Raza and Shah (2018) economic expansion reduces G7 countries' CO2 emissions. Their analysis also shows that economic growth in G7 nations boosts carbon emissions and environmental degradation. However, Aye and Edoja (2017)

TABLE 5 Model Results of technological innovations, R&D, urbanization and CO2.

Variables list	OLS	Fixed effect	DGMM	SGMM
Patent application	2.130	0.001***	0.0001***	2.450**
	(3.220)	(4.310)	(0.0001)	(2.570)
Research & Development	0.743***	−1.233***	1.523	0.029
	(0.20)	(0.23)	(3.125)	(0.036)
Urbanization	0.047***	0.142***	0.232***	0.001***
	(0.015)	(0.023)	(0.219)	(0.001)
Education	0.014**	−0.015***	−0.036***	−0.0001***
	(0.012)	(0.022)	(0.0674)	(0.001)
Fixed telephone subscription	0.000**	0.013	0.013	0.001**
	(0.022)	(0.012)	(0.105)	(0.0001)
Economic growth	−0.032	0.010***	0.041**	0.032***
	(0.033)	(0.007)	(0.013)	(0.002)
FDI	0.027	0.008*	0.002**	0.001**
	(0.028)	(0.005)	(0.012)	(0.001)
Governance	0.290	0.390**	−1.233*	0.015*
	(0.397)	(0.196)	(1.445)	(0.025)
Labor force	−8.860	−1.120	−3.830*	5.661
	(1.280)	(1.780)	(3.120)	(1.060)
Saving	0.123***	−0.028**	−0.032*	−0.001*
	(0.036)	(0.011)	(0.065)	(0.003)
$CO2_{i,t-1}$			0.318***	0.950***
			(0.304)	(0.0111)
Constant	−3.436**	−1.548		−0.090
	(1.561)	(1.674)		(0.126)
Observations	163	163	160	160
R-squared	0.468	0.434		
Number of id		29	15	29
AR1			0.03 (0.968)	−2.11(0.045)
AR2			−0.22(0.833)	−0.49 (0.554)
Sargan test			108.72(0.327)	127.87(0.850)

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

found that economic growth increased carbon dioxide emissions. Economic expansion may reduce carbon emissions because Belt and Road countries are developing and emerging economies focused on production, industrialization, trade, foreign direct investment, and other economic activity. Yet, production and industrialization increase energy demand, causing a carbon emissions dilemma.

Foreign direct investment raises carbon dioxide emissions and decreases environmental quality in belt and road countries. The two-step system GMM model coefficients show that a one percent increase in foreign direct investment in belt and road countries will increase carbon dioxide emissions by 0.03 percent. Foreign direct investment increases carbon dioxide emissions and environmental damage in the sample nations. Foreign direct investment increases carbon emissions, although innovation moderates this relationship Bakhsh et al. (2021). Abid et al. (2022) found comparable results to ours that FDI negatively affects carbon emissions and supports the pollution halo hypothesis.

In other scenarios, government efficacy affects carbon emissions positively and adversely. In fixed effect and system GMM, government effectiveness increases carbon dioxide emissions, but in difference GMM, it decreases carbon dioxin

TABLE 6 Results of the nonlinear model.

Variables	OLS	FE	DGMM	SGMM
Patent application	2.170	0.001***	0.002*	2.090**
	(3.260)	(5.700)	(0.001)	(1.370)
Research & Development	1.722***	−1.138***	−0.974**	−0.096*
	(0.318)	(0.239)	(1.658)	(0.152)
UBN	0.283***	0.106**	13.89**	0.018**
	(0.181)	(0.105)	(5.558)	(0.028)
UBN^2	−0.022***	−0.001**	−0.099**	−0.001***
	(0.0037)	(0.001)	(0.041)	(0.000)
Education	0.023**	−0.012**	−0.558**	−0.003**
	(0.019)	(0.013)	(0.239)	(0.005)
Infrastructure	−0.023	0.014	0.192*	0.001*
	(0.032)	(0.016)	(0.099)	(0.005)
GDP	−0.037	0.012**	0.0494*	0.046***
	(0.052)	(0.002)	(0.027)	(0.012)
FDI	0.022	0.004	0.062*	0.011*
	(0.067)	(0.006)	(0.066)	(0.014)
GVR	−0.073**	0.387*	9.564*	0.104*
	(0.206)	(0.192)	(4.578)	(0.107)
SVN	0.133***	−0.024**	−0.017	0.0007
	(0.016)	(0.017)	(0.088)	(0.001)
LBF	−1.520	−2.050	1.730	−5.592
	(1.370)	(1.800)	(1.340)	(1.455)
$CO2_{i,t-1}$			0.521**	0.947***
			(0.343)	(0.021)
Constant	−9.155***	−0.713**		0.494***
	(2.465)	(2.947)		(0.835)
Observations	163	163	112	160
R-squared	0.497	0.435		
Number of id		29	15	29
AR1			−0.86(0.391)	−2.07(0.039)
AR2			−0.69(0.488)	−0.69(0.488)
Sargan test			109.88(0.235)	136.02(0.732)

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

emissions. The OLS model coefficient is positive and insignificant, showing that government policies have no impact on carbon emissions.

Savings reduce carbon dioxide emissions and increase environmental quality in belt and road countries in most models, except OLS. The two-step system GMM model shows that a one percent savings increase in belt and road countries will reduce carbon dioxide emissions by 0.001%. Data show that sample countries must save to enhance the environment. In most models, labor force has little impact on carbon emissions.

4.2.1 Results of the nonlinear model

The findings of a nonlinear connection between components regarding the influence of urbanization on carbon emissions are displayed in Table 6. This connection investigated how urbanization influences the amount of carbon emissions produced. The urbanization coefficient that is generated is positive and statistically significant in every single model, which suggests that urbanization raises the amount of carbon dioxide emissions and lowers the quality of the environment in the countries that are a part of the belt and road. To be more specific, the coefficients in the two-step system GMM model show that an increase of one percent in urbanization in the countries along the belt and road will result in an increase of 0.018% in carbon dioxide emissions. This information was derived from the relationship between urbanization and carbon dioxide emissions. According to the findings, urbanization in the countries that were investigated led to increased levels of carbon dioxide emissions, which contributes to the deterioration of the environment.

However, the coefficient of urbanization square reveals that once the level of carbon emissions reaches a certain threshold, urbanization begins to have a negative impact on carbon emissions. This is the situation when the predetermined limit has been attained.

In the vast majority of models, the estimated education has a negative value and a significant impact, demonstrating that increasing levels of education in belt and road countries leads to lower levels of carbon dioxide emissions and better overall environmental quality. To be more specific, the two-step system GMM model predicts that an increase in the percentage of the population in belt and road countries who have completed secondary education will result in a 0.001% reduction in carbon dioxide emissions. As the data have shown, a high level of educational attainment is absolutely necessary in the sample countries if there is to be any improvement in the standard of the environment.

The derived coefficient of innovation proxy by patent application is positive and statistically significant in the majority of models. This finding indicates that patent applications increase carbon dioxide emissions and worsen environmental quality in belt and road countries.

The estimated coefficient of research and development is consistently and significantly negative across the vast majority of models. This finding is also supported by statistical evidence. According to the findings, increasing the amount of money spent on research and development in nations along the belt and road lowers carbon dioxide emissions and raises the level of environmental quality in the sample countries. Anser et al. (2021) state that countries in Europe were able to reduce their carbon emissions as a result of increased research and development. It is possible for operations in the industrial sector to be improved as a result of government spending on research and development in this area. This might include the enhancement of processes as well as the investigation of energy combinations that are both more efficient and better for the environment. More spending on research and development will allow for improvements to be made to industrial operations, products, and processes, as well as the achievement of the ideal energy mix that improves environmental quality. According to Jiao et al. (2018), research and development are essential tools for reducing emissions of greenhouse gases; therefore, businesses should raise the amount of effort they put into research and development in order to cut their levels of carbon dioxide emission. Nonetheless, our findings suggest that emissions are increased as a result of research and development.

In a manner parallel to this, the infrastructure coefficient is significant and positive, indicating that the growth of infrastructure in the countries along the belt and road significantly contributes to an increase in the amount of carbon dioxide emissions. The two-step system GMM model predicts that a one percent increase in infrastructure in the sample countries will result in a 0.002% rise in emissions. This information was derived from the GMM. The GMM model served as the source for the aforementioned information.

The vast majority of models have speculated that the coefficient of economic growth will be positive and significantly correlated with the rate of growth of the economy. This suggests that economic growth will result in increased emissions of carbon dioxide and will reduce the overall quality of the environment in the countries that are part of the Belt and Road Initiative. To be more specific, the coefficients in the two-step system GMM model show that an increase of one percent in economic growth in the countries along the belt and road will result in a change of 0.04 percent in the amount of carbon dioxide emissions. This information can be found in the table below. According to the findings, an increase in economic growth in the countries that were investigated leads to an increase in the amount of carbon dioxide produced as well as damage to the environment. This is the case in all of the countries.

The findings demonstrate that the computed coefficient of foreign direct investment is positive and statistically significant, which indicates that foreign direct investment increases carbon dioxide emissions and degrades environmental quality in countries that are part of the belt and road. The research indicates that increasing levels of foreign direct investment inflows are to blame for increasing levels of environmental degradation and emissions of carbon dioxide in the countries that served as samples. Our findings are comparable to those of (Zafar et al., 2020), who contend that FDI increases carbon emissions. However, our findings contradict the findings of Bakhsh et al. (2021) who also discovered that foreign direct investment increases carbon emissions. To put it another way, the similarities between our findings are significant. On the other hand, the calculated coefficient of trade openness is found to be positive and significant in a variety of GMM models, which suggests that trade openness leads to an increase in CO2 emissions. This conclusion can be drawn from the fact that the coefficient is found to be positive and significant. In contrast to this finding, the OLS fixed effect models find that it is significant and negative, indicating that increased trade openness leads to lower levels of carbon emissions. The findings run counter to the conclusions of both of these studies Khan et al. (2020). In a manner analogous to this, the coefficient of government efficiency is found to be positive across the board with the exception of the OLS model. This suggests that the effectiveness of governments has a positive effect on the emission of carbon dioxide in a variety of models, such as the estimated coefficient in system GMM, which is positive and statistically significant. In addition, the coefficient of government efficiency is found to have a positive value in all models (with the exception of OLS), which suggests that governments are generally effective.

TABLE 7 Results on the interaction effect of governance on CO2 emission.

Variables	OLS	FE	DGMM	SGMM
Patent application	3.200	0.0001***	0.0003*	−3.170
	(3.320)	(5.70)	(0.000)	(2.390)
RD	2.281***	−1.335***	−1.661	0.222***
	(0.268)	(0.240)	(5.604)	(0.072)
UBN	0.148**	0.079**	−3.956	0.001**
	(0.189)	(0.116)	(7.921)	(0.004)
UBN^2	−0.002*	0.0023	0.042	−1.250*
	(0.001)	(0.003)	(0.066)	(4.900)
Education	0.023**	−0.017**	−0.210**	−0.021**
	(0.000)	(0.012)	(0.253)	(0.001)
Infrastructure	−0.031	0.016	−0.033*	−0.042**
	(0.053)	(0.013)	(0.197)	(0.011)
GDP	−0.023	0.007**	0.048***	0.059***
	(0.051)	(0.017)	(0.016)	(0.003)
FDI	0.031	0.008	0.016*	0.013*
	(0.017)	(0.005)	(0.017)	(0.041)
GVR	4.108**	−0.272	−10.13	0.232***
	(1.623)	(1.177)	(10.54)	(0.129)
Interaction	−0.073**	0.011	0.182	−0.081***
	(0.018)	(0.020)	(0.188)	(0.013)
SVR	0.124***	−0.029**	−0.074	0.005
	(0.026)	(0.012)	(0.074)	(0.001)
LBN	−1.220	−8.660	−8.880	2.721
	(1.260)	(1.830)	(6.410)	(9.311)
$CO2_{i,t-1}$			0.324***	0.950***
			(0.298)	(0.010)
Constant	−6.091**	−0.591**		0.001***
	(2.694)	(2.963)		(0.001)
Observations	163	163	112	160
R-squared	0.518	0.436		
Number of id		29	15	29
AR1			−0.01(0.566)	−2.12(0.035)
AR2			0.54(0.320)	−0.73(0.532)
Sargan test			102.13(0.332)	213.40(0.247)

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

The estimated coefficient of saving is shown to be both negative and positive across all of the models, whereas the estimated coefficient of labor force is shown to be insignificant. The data support these conclusions. When a country has a larger work force and greater gross savings, it has a stronger capacity to manufacture things, which leads to an increase in the amount of carbon emissions produced. This in turn leads to an increase in the global temperature.

4.2.2 Results of the interaction effect of governance on CO2 emission

Governance in belt and road countries is shown to have a transformative effect on carbon emissions in Table 7. In the countries that make up the belt and road, urbanization is responsible for increased emissions of carbon dioxide and a decline in the quality of the surrounding environment. According to the coefficients of the two-step system GMM model, an increase of one percent in urbanization in countries along the belt and road will result in an increase of 0.001% in carbon dioxide emissions. The sample nations' urbanization rates are higher, which in turn results in higher CO2 emissions and worsening environmental conditions.

Since the urbanization square demonstrates that the calculated coefficient is in the negative, we can deduce that urbanization leads to a lower overall level of carbon dioxide emissions.

In the countries along the belt and road, increased levels of education lead to lower levels of carbon dioxide emissions and higher overall environmental quality. According to the GMM model with a two-step system, a reduction in carbon dioxide emissions of 0.001% can be achieved in belt and road countries with an increase in schooling of one percent. According to the findings, education is absolutely necessary in the sample countries in order to improve the environment.

According to the findings, the filing of patents leads to an increase in carbon dioxide emissions and a decline in the quality of the environment in countries along the belt and road.

The coefficients for research and development can be either positive or negative, depending on the model. Although both the fixed effect and OLS coefficients are negative, the system GMM coefficient is large and positive, indicating a positive impact on carbon emissions. On the other hand, the OLS and fixed effect coefficients are negative. According to Sheng and Guo, (2019) research, innovation helps reduce carbon emissions in the Khan, (2021a) used a comparable innovation metric and arrived at comparable findings. Additionally, it seems that patents contribute to an increase in carbon emissions. The claim made by Chien, (2021b) that the application of patents reduces Pakistan's emissions is not supported by our evidence.

In GMM models, the infrastructure coefficient is negative, whereas in OLS and fixed effect models, there is no such coefficient.

The vast majority of models project positive and statistically significant economic growth, which will lead to an increase in carbon dioxide emissions and a decrease in the quality of the environment in countries along the belt and road. According to the coefficients of the two-step system GMM model, an increase of one percent in economic growth in countries along the belt and road will result in an increase of 0.02 percent in carbon dioxide emissions. The amount of carbon dioxide produced and the impact on the environment increased as the sample countries' economies grew. In line with the findings of Sharif et al. (2019) economic growth is the primary factor in the production of carbon emissions and the deterioration of the environment Okere et al. (2021). It is possible that the countries along the Belt and Road will be able to lower their carbon emissions as a result of their rising economic growth, which is intended to improve living standards, put an end to poverty, and balance out income disparities. However, industrialization, which leads to a greater demand for energy, may be the cause of both economic expansion and environmental deterioration.

Carbon dioxide emissions are increased, and the quality of the environment is degraded, in belt and road countries that receive foreign direct investment. In the sample countries, increases in both carbon dioxide emissions and environmental damage are caused by increased levels of foreign direct investment. Our findings are consistent with those of Mert and Bölük (2016). Additionally, decreases in carbon emissions resulted from increases in foreign direct investment, lending support to the pollution halo theory. According to the findings of Zhu et al. (2016), Asian foreign direct investment helps reduce the rate of environmental degradation. There is a possibility that developing and least developed countries will be included in the sample countries. These countries are still attempting to stimulate economic growth by luring significant amounts of foreign direct investment, even if it comes at the expense of the environment. Countries that are the recipients of foreign direct investment may become more polluted if they produce a high volume of carbon dioxide. Increasing levels of pollution and carbon emissions in host countries as a result of increased levels of foreign investment are consistent with the pollution haven theory. According to Zafar et al. (2020), increased levels of carbon dioxide emissions are a consequence of increased levels of foreign direct investment. Our findings run counter to those that were found by Bakhsh et al. (2021).

In OLS and two system GMM models, the coefficient of the interaction term between governance and urbanization is negatively significant, indicating that governance plays a transformational role in the link between urbanization and carbon emissions.

Similarly, the coefficient of saving is positive, negative, or insignificant across all models, whereas the labor force is insignificant across all models.

5 Conclusion

This investigation focuses on three primary goals: the direct effect that urbanization, along with other explanatory and control variables on emissions; the nonlinear relationship that urbanization has with emissions; and the interaction effect of governance plays in the relationship between urbanization and carbon emissions. OLS, fixed effect, two-step difference GMM, and two-step system GMM models were used in this study to conduct the analysis of panel data collected from 39 belt and road countries between the years 2002 and 2022. In this study, unit root tests of the second generation are used. These tests assume that all variables are stationary at level or at the first difference. In a similar vein, the results of the models regarding the direct effect of urbanization on carbon emissions reveal that urbanization has a positive and significant influence on carbon emissions, and that an increase in urbanization in the belt and road countries contributes to the deterioration of the environment. Carbon emissions is related to patent applications, economic growth, foreign direct investment, and the efficiency of the government, despite the fact that research and development and cost savings have a negative influence on carbon emissions.

The findings of a model that investigated the nonlinear influence of urbanization on carbon dioxide emissions suggest that urbanization significantly raises carbon dioxide emissions, while the square term of urbanization yields negative and significant coefficients. These findings were derived from an examination of the relationship between urbanization and carbon dioxide emissions. The findings indicate that an increase in urbanization initially causes a high carbon emissions discharge and a decline in the quality of the surrounding environment, but that carbon emissions levels begin to decline once they reach a predetermined threshold. As a consequence, the findings show that an increase in urbanization has the potential to reduce global warming. In a similar vein, patent applications, infrastructure, economic growth, direct foreign investment, and governance all have a positive impact on carbon emissions, whereas spending on education and research and development have a considerable reduction in carbon dioxide emissions.

The findings of the model that investigated the moderating effect of government efficacy on the association between urbanization and carbon emissions indicate that urbanization has a positive correlation with carbon emissions; however, the square term produces negative coefficients. This suggests that government efficacy has a moderating effect on the association between urbanization and carbon emissions. Similarly, patents, economic growth, foreign direct investment, and governance are all connected with higher levels of carbon emissions, but education and infrastructure are associated with lower levels of carbon emissions. The fact that the interaction term coefficient between urbanization and government effectiveness had a negative significance suggests that governance has a transformative influence on the effect that urbanization has on the reduction of carbon emissions in countries that are taking part in the belt and road project.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

Formal analysis were by HK, and formal writing were done by IK. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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