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RESEARCH ARTICLE

The role of technological innovations and ICT in reducing Greenhouse gas emission: Evidence from the Belt and Road initiative countries

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Abstract

Climate change is a global problem and its rapid increase with negative and irretrievable consequences in all sectors of the economy is linked to greenhouse gas emissions. Such an increase in greenhouse gas and carbon emissions is associated with ecological, economic and social issues which can be solved with the rising innovations and information and communication technology. In this regard, this study examines the effect of innovations and information and communication technology on environmental degradation in the Belt and Road initiative countries from 1996 to 2018 using dynamic models. The results indicate that innovations proxy by patent applications reduce emissions while mobile cellular subscriptions, human capital and urban population are the drivers of emissions. ICT proxy by internet use reduces total greenhouse gas emissions while it is positively associated with carbon dioxide emission however, an increase in ICT increases greenhouse gas and reduces carbon dioxide emissions. The effect of economic growth on greenhouse gas and carbon dioxide emission varies across models. The findings of this study have considerable policy implications for the sample countries regarding innovation technology and information and communication technology indicators in reducing carbon dioxide and greenhouse gas emissions.

Keywords: Greenhouse gas emission; information and communication technology; technological innovations

1. Introduction

Climate change is a global problem with irreversible negative effects in several sectors and greenhouse gas emissions are responsible for such change (Miśkiewicz, 2021). A large number of researchers and experts are working on climate change issues to identify solutions and establish sustainable policies (Miśkiewicz, 2021). This climate change and high rate of greenhouse gas emission can be minimized with a rise in technological innovations as well sustainable growth can be achieved as innovations increase economic performance and raise environmental quality (Long, Chen, Du, Oh, & Han, 2017). Innovations have been considered as a remedy for carbon dioxide reduction and rising environmental quality however, it varies across countries, while improvement in economic growth per capita leads to the rise of carbon emission (Mensah et al., 2018). (Romer, 1990); (Grossman & Helpman, 1991); and (Aghion & Howitt, 1990) argued endogenous growth theory, proving economic growth is driven by technological change. Technological change and innovation are considered the main driver of economic growth where investment in ICT infrastructure and innovation increase economic growth (Nair, Pradhan, & Arvin, 2020). Innovations consist of those applications which provide better solutions to market needs, new requirements and technologies (Maranville, 1992). A rise in technological innovations also includes inventions and thus gives practical implementations to society and to the market which is beneficial in different ways (Mensah et al., 2018). The European Commission has created incentives to urge coal places and obtain stated objectives. The preceding researchers have used different indicators and factors to test their effect on greenhouse gas emissions. Researchers and experts are working to find the factors that significantly lower greenhouse gases and raise environmental quality with the purpose to find effective solution (Miśkiewicz, 2021). The spread of renewable energy has reduced greenhouse gas emissions. climate and diffusions needs technical innovations which have been found in societies and different sectors of the countries which have different kinds (Ausubel, 1991). If there is improved level of information and communication technologies will upsurge infrastructure and thus will leads to lower carbon and greenhouse gas emission (F. N. Khan, Sana, & Arif, 2020). The global digital economy backbone is information and communication technology and it is the main driver of productivity growth in the global world (Abdollahbeigi & Salehi, 2021). Economic growth increases in a country when there is an increase in innovations and a rise in investment in information and communication technology infrastructure (Nair et al., 2020), where environmental innovation has positively affected environmental and economic performance (Long et al., 2017), however, some other researchers believes that ICT negatively affect economic growth and CO2 emissions (Chimbo, 2020) and (Raheem, Tiwari, & Balsalobre-Lorente, 2020), as increase in information and communication technology leads to rise energy consumption (Chimbo, 2020); (Abdollahbeigi & Salehi, 2021). Production for ICT devices construction needs the use of energy which leads to carbon emission discharge and thus increase in greenhouse gases. Likewise, it will produce large number of other heating pollutants. However, the use of information and communication technology can reduce greenhouse gases when used in other sectors and can be helpful adapt to climate change (Abdollahbeigi & Salehi, 2021). Other factors such as industrialization and a rise in urbanization in the modern era have also given many environmental consequences (Mehmood, 2021).

The belt and road countries are mostly developing and emerging countries and there may also be a high level of industrialization to rise economic growth and also rise innovations and information and communication technology to compete with the world. A change in these activities may lead to environmental consequences such as releasing carbon dioxide and other greenhouse gas emissions. Besides carbon dioxide emission, combined all types of contaminants are included as greenhouse gas emissions while an increase in greenhouse gas emission effect human life by lowering environmental quality. Considering this issue, the current study aims to investigate the effect of ICT and technological innovations on greenhouse gases emission and carbon dioxide in a sample of belt and road countries. Data for the period of 1996 to 2018 were used and dynamic models were employed. Considering carbon dioxide and greenhouse gases, previous studies have not attempted such examination for the sample countries. The effect of innovations proxy by patent application and high technology export have not been considered before while this study uses two closely related factors of technological innovations to explore its effect on emission. We also use two indicators of information and communication technology in the model to find its impact on carbon dioxide and greenhouse gas emissions. We also use innovations and information and communication technology indices to fully capture its effect on both CO2 and total greenhouse gas emission which has not been conducted before in previous studies. The results indicate that patent applications reduce both greenhouse gas and carbon dioxide emission. Internet use reduces greenhouse gas and rise carbon dioxide emissions while mobile cellular subscriptions increase both greenhouse gas and carbon dioxide emission. INV significantly reduce both greenhouse gas and carbon dioxide emission while ICT increases greenhouse gas and reduces carbon dioxide emission. Human capital and urban population are also the drivers of greenhouse gas and carbon dioxide emission. The effect of economic growth on greenhouse gas and carbon dioxide varies across models.

The rest of the paper is structured in the given sequence; section 2 presents the review of literature, part 3 is composed of methodology, part 4 presents results and discussions and part 5 gives conclusions and recommendations.

2. Literature review

Several factors are associated with the increase of greenhouse gas and carbon emission which is associated with ecological, economic and social issues. Rising innovations level can be the remedy to achieve sustainable development as it increases economic performance and raises environmental quality (Long et al., 2017). The role of technological innovations has been considered very vital in carbon dioxide emission reduction however, it varies across countries, while improvement in economic growth per capita leads to the rise of carbon emission (Mensah et al., 2018). A large number of studies have been conducted on the effect of innovation and information technology on carbon dioxide and greenhouse gas discharge for different regions however there have been obtained dissimilar and mixed recommendations. (Miśkiewicz, 2021) arranged study on the effect of information technology and innovations on greenhouse emissions using FMOLS, OLS regression and DOLS models in Vis grad countries. The results indicate that innovations proxy by patents reduces greenhouse gas emission. They also found that research and development expenditures were also statistically significant and reduced greenhouse gas emissions. Likewise, (Díaz-Roldán & Ramos-Herrera, 2021) studied the nexus between ICT, innovation and carbon dioxide emission. This effect was also studied in the context of sustainable development in EU countries. The authors collected panel data and used panel data econometric methods. The authors illustrates that there is a decrease in producer prices with a rise in technology. The authors further argues that economic growth raises in EU countries when there is improvement in ICT and greenhouse gases are lower in presence of higher ICT employment. A similar study is organized in BRICS countries by (Zhang, 2021) from 1990 to 2019. By using the STIRPAT model, the authors examine the nexus between economic growth, carbon dioxide and technological innovations. The results show that carbon emission decrease with a rise in patents while carbon emission increase when there is a rise in economic growth in the sample countries. This study further confirms that the EKC hypothesis was valid in BRICS. Similarly, (W. Ali, Rahman, Zahid, Khan, & Kumail, 2019) conducted a research study from 1985 to 2016 in Malaysia to investigate the nexus between structural change, carbon emission, energy use and technological innovations. The authors used ARDL model for analysis and found that there was an insignificant effect of industry value added on emission however environmental quality was positively affected by increased level of innovations in technology. Bidirectional causal association was existed between the study variables and their findings further shows that EKC was not valid for the sample country. The bidirectional causal association between structural change, energy use, and carbon emissions was exist in the short run.

A similar investigation done by (Usman & Hammar, 2021) examined the effect of technological innovation, renewable energy consumption and economic growth on ecological footprint. The author collected data from 1990 to 2017 on Asian pacific economic cooperation countries and employed the STIRPAT model. The results reveal that renewable energy rise environmental quality however economic growth has a detrimental influence on environmental quality and technology innovations also exert the same effect. (Twum et al., 2021) explore the determinants of an efficient environment from 1990 to 2018 using the truncated regression model. The authors found the existence of U-shape nexus between environmental efficiency and technology. The authors further confirm that human capital raises the efficiency of the environment in all panels whereas FDI affects the main panel and east Asia sample positively. (Dauda, Long, Mensah, & Salman, 2019) studied carbon dioxide, economic growth and technology innovations in a sample of 18 developed and developing countries. Using cross-sectional ADF unit root, DOLS and FMOLS models, the findings shows that a rise in the use of energy rise carbon dioxide in all panel while innovation reduce emission in G6 and increase in BRICS and MENA countries. Their study further validates the EKC hypothesis for BRICS. They further tested the pollution halo and pollution haven hypothesis in the panel and got mixed results. (Shi, Si, Chan, & Zhou, 2021) studied the carbon emission reducing effect of technological innovation in China transportation industry from 2012 to 2018. They found that technological innovation reduces carbon emission in transportation industry both in eastern and north eastern parts of the countries while they did not evidence this effect in other regions. They further found an inverted U-shape relationship between technological innovation in the transportation industry's carbon emission. Likewise, (Mensah et al., 2018) studied the effect of innovations on carbon dioxide emission in OECD countries from 1990 to 2014. The authors used data from 28 countries and applied STRPAT models to investigate the innovation and economic growth EKC hypothesis. They found that innovations reduce emission in most countries in OECD. Economic growth was also found the driver of carbon dioxide emission in this study however, the EKC hypothesis was validated. (Li, Lin, Jiang, Liu, & Lee, 2021) organized a study in 66 countries to explore the effect of technological innovations and advancement on carbon dioxide by including economic growth. Their study confirms the nonlinear relationship between technology and carbon emission which was affected by economic development both negative and positive in the stage of threshold effect exceeds. This study further identified the N and U shape relation in OECD and high-income countries samples. ICT and carbon dioxide nexus were studied by (N. Khan, Baloch, Saud, & Fatima, 2018) for a sample of emerging economies. They further explore the moderating effect of financial development and found that ICT rise carbon dioxide.

Likewise, economic growth increases emissions while the ICT growth interaction significantly reduces pollution. (C.-W. Su et al., 2021) conducted a study on the effect of technological innovation, and ICT to further test for EKC hypothesis. BRICS were taken as the sample countries and the authors found that EKC was valid however the effect of fixed telephone and broadband subscriptions increases carbon dioxide while ICT proxy by mobile cellular subscriptions lowers carbon dioxide emission. The study further identifies that trade, electricity and high-technology export are also the drivers of carbon dioxide. Taking data for 30 Chinese provinces from 2009 to 2018, (Niu, 2021) examined the nexus between carbon dioxide and technology innovations used fixed effect models. The research shows that innovations curb emission while research and applications rise emission in China. (Rafique, Li, Larik, & Monaheng, 2020) also conducted a study on BRICS and investigated the nexus between financial development, foreign direct investment, technology innovations and carbon dioxide. The study time period was 1990 to 2017 and the results shows that trade, energy use and economic growth were positive for carbon dioxide emission. On the other hand, (M. Ali, Raza, & Khamis, 2020) used data from 1996 to 2017 of 33 EU countries to examine the nexus between energy innovations, economic growth and environment. By using cross section test and panel data models, the authors found that economic growth has a U-Shape association with carbon emission and thus the EKC was validated however energy innovations negatively affect carbon emission.(Cheng & Hou, 2021) studied real economic growth sectors, innovations and financial development in 48 countries fo different income levels. The time period of the study was 19971 to 2015 and the results illustrate that innovations and finance growth relationship variables across countries and time. Likewise, (Vural, 2021) used the data of Latin American countries for the period of 1991 to 2014 and investigated the relationship between trade, technology innovation, renewable energy and carbon dioxide. The study results shows that technology innovation rise renewable energy production while carbon dioxide and renewable energy were negatively linked in this study. Another study for the period of 1990 to 2019 in G8 countries were conducted by (Abid, Mehmood, Tariq, & Haq, 2021) who investigated the effect of technology innovations on carbon dioxide by considering other related factors that's includes energy use, foreign direct investment and financial development. The authors used FMOLS model and found that FDI, technology innovations and carbon dioxide were associated negatively in the long run and there was a long run bidirectional causal link between variables.

3. Methodology

This study investigates the effect of technological innovation on greenhouse gas emissions in belt and road countries from 1986 to 2018. Data for the variables have been collected from the world bank database and analyzed with static and dynamic models. These models are OLS, fixed effect, and generalized method of moments. Static models such as OLS and fixed effect models are used for comparison purposes while the main focus is on system GMM, especially the two-step system GMM. Using static models in panel data analysis such as OLS has several econometric problems such as the autocorrelation's problems. Such problems in the analysis produce unreliable results. The fixed effect model also produces econometric problems the same as the OLS and it is considered an inefficient estimator. The fixed effect model IV estimator may produce unreliable outcomes due to the instruments and be biased same as OLS because the fixed effect time invariant correlations with explanatory and dependent variables in the error terms. Considering such problems, the GMM model can be the best to deal with such problems in panel data analysis to get efficient results (Weili, Khan, & Han, 2022). There are two types of GMM model, the system and the difference GMM, where the difference GMM model use the first difference of the dependent and independent variable to overcome the specific country effects of lagged dependent variable is instrumented with its previous levels. In such circumstances, it removes the autocorrelation problems however the lagged levels may be considered as poor instruments using the first difference and thus may reduce the efficiency. To increase the efficiency of the model, the model of (Arellano & Bover, 1995) and (Blundell & Bond, 1998) system GMM is the best estimator as compared to the difference GMM. Two equations are in the system GMM which are the differential equations and another is in the level (KURUL, 2021). The second equations variables construction to its specific first-order difference and measure the variables in the difference in its specific lag level. Based on these discussions, in panel data analysis, the two-step system GMM model is the best and most suitable for panel data analysis (Arellano & Bover, 1995); (Blundell & Bond, 1998). Considering the focused model GMM, the effect of innovations on environmental degradation, the empirical models can be constructed as follows;

$$GHG_{it} = \beta_0 + \beta_1 GHG_{it-1} + \beta_2 Patent_{it} + \beta_3 TEN_{it} + \beta_4 IU_{it} + \beta_5 MCS_{it} + \beta_6 HC_{it} + \beta_7 GDP_{it} + \beta_8 POP_{it} + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

$$CO2_{it} = \beta_0 + \beta_1 CO2_{it-1} + \beta_2 Patent_{it} + \beta_3 TEN_{it} + \beta_4 IU_{it} + \beta_5 MCS_{it} + \beta_6 HC_{it} + \beta_7 GDP_{it} + \beta_8 POP_{it} + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2)$$

This study constructed two models, where the dependent variable in equation 1 is total greenhouse gas emission shown as GHG and taken as total greenhouse gas emission, which is the total of all types of emissions besides carbon dioxide. CO2 is the dependent variable in equation 2 represents carbon dioxide emission measured as metric tons per capita. The first lags of greenhouse gas and carbon dioxide emission are shown by GHG_{it-1} and $CO2_{it-1}$ which are castoff as explanatory variables in the model to quantify the effect of previous years' emissions on current year GHG and CO2 emissions respectively. Patent represent innovations measured as patent application residents, TEN is high technology export, IU is internet use measured as individual using the internet as a percent of the population, MCS is mobile cellular subscription per 100 people, HC is human capital measured as Labor force participation rate, total (% of total population ages 15–64) (modelled ILO estimate), GDP is economic growth while POP is population. It's been argued that technological innovations affect the quality of the environment. Economic sectors are the core environmental problems which need ICT and innovations investments to reduce their effect on the quality of the environment. With a sound environmental policy and regulation, innovations play important role in enhancing environmental quality. (Sharif et al., 2020) argues that technological innovation enhances energy efficiency and introduces efficient energy technology that raises the quality of endowment. (Wang, Yang, Zhang, & Yin, 2012) and (H.-N. Su & Moaniba, 2017) claim that innovations explain emission variations. Consequently, patent applications filed by residents and high-technology export are used to measure innovations and their effect on carbon dioxide and greenhouse gas discharge. Generally, a proxy for innovations is used as patent application residents such as (Albino, Ardito, Dangelico, & Petruzzelli, 2014); (Popp, Hascic, & Medhi, 2011); (Raiser, Naims, & Bruhn, 2017). We use these two proxies in the model separately as well as an index of the two using principal component analysis. High technology export as a proxy is also been used by several researchers such as (H. Khan, Weili, & Khan, 2021c).

Table 1. Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
GHG	407877.5	1423	1300	1.240
PATENT	12544.54	98653.2	1.000	1393
TEN	31.051	378.81	0.0001	7575.371
IU	27.562	26.670	0.0001	89.357
MCS	68.420	53.3758	0.001	207.751
HC	3.410	1.200	218	7.870
GDP	3.837	4.1074	-17.93	17.031
POP	3.280	9.790	1161	8.240

Table 2. Correlation matrix

	GHG	PAR	TEXP	IU	MCS	HC	GDPPC	URB
GHG	1.0000							
PATENT	0.8771	1.000						
TEN	0.009	0.003	1.000					
IU	0.129	0.046	0.107	1.000				
MCS	0.254	0.182	0.064	0.439	1.000			
HC	0.98	0.839	0.008	0.174	0.318	1.000		
GDP	0.244	0.181	0.014	0.079	0.126	0.268	1.000	
POP	0.991	0.879	0.011	0.166	0.296	0.992	0.251	1.000

4. Results and discussions

Table 3 presents the results of difference and system GMM models on the effect of innovations on greenhouse gas emissions. INV which is the index of innovations exert a negative effect on greenhouse gas emission shown by its coefficients in the two-step system GMM model and thus indicates that improved level of innovations in the belt and road countries leads to lower greenhouse gas discharge. Specifically, if there is a percent rise in technological innovation will reduce innovations by 0.05 percent shown by the value of the coefficient in the two-step GMM model. The findings reveal that the belt and road countries' innovations improvement is important which can help mitigate and minimize greenhouse gas emissions and enhance the quality of the environment. The findings show that the belt and road countries' innovations are improving and thus greenhouse emissions can be minimized and controlled through innovations thus innovations are the best remedy in the belt and road countries to safeguard environmental quality. By raising the level of innovation, several sectors which produce emissions will be minimized such as energy sector efficiency can be increased and production can become more efficient with innovations. Our findings are similar to the results of (Miśkiewicz, 2021) who also found that innovations reduce greenhouse gas emissions.

Table 3. The effect of innovation on greenhouse gas emission

DEP.VAR. GHG	DGMM	SGM	DGMM	SGMM
INV			-0.008	-0.0525***
			(0.008)	(0.0102)
ICT			0.068***	0.0001***
			(0.0003)	(0.0001)
PATENT	-7.720***	-8.960***		
	(2.420)	(5.031)		
TEN	0.0002***	0.012***		
	(1.540)	(1.220)		
IU	-0.000***	-0.039***		
	(4.410)	(2.260)		
MCS	0.001***	0.001***		
	(0.0001)	(0.0001)		
HC	0.936***	0.001***	0.889***	0.740***
	(0.008)	(0.000)	(0.009)	(5.200)
GDP	0.002***	0.052***	0.002***	-0.003***
	(6.260)	(1.840)	(2.740)	(2.790)
POP	5.840***	2.890***	-1.861***	-6.320***
	(0.002)	(0.001)	(0.001)	(0.001)
GHG_{it}	2.980***	-1.900***	7.870***	5.290***
	(6.011)	(4.261)	(4.211)	(6.071)
Constant		0.0001***		0.0002***
		(0.000)		(0.0001)
Observations	302	350	302	350
Number of id	35	37	35	37
AR1	-3.23 (0.010)	-1.50 (0.134)	-2.23 (0.010)	-1.40 (0.134)
AR2	-3.33 (0.011)	-1.23(0.217)	-2.13 (0.121)	-1.33(0.217)
Sargan test	704.66 (0.011)	738.17 (0.212)	704.66 (0.011)	737.17 (0.012)

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

The estimated coefficient of ICT is positive and significant both in system GMM and different system models. The results indicate that ICT increase greenhouse gas emission in the sample countries. More specially, if there is a percent increase in ICT increase greenhouse gas emission by 0.6 and 0.001 percent respectively shown by the difference and system GMM models. Likewise, the estimated coefficient of patent application (innovation) is significant and negative in difference and system GMM models. The results indicate that patent applications reduce greenhouse gas emissions in the sample countries. More specially, if there is a percent increase in patents reduce greenhouse gas emissions by 7.7 and 8.9 percent respectively shown by the difference and system GMM models. (Miśkiewicz, 2021) also proxies innovations by patent application and found similar results. This individual indicator result is similar to the innovation index result where innovation negatively affects greenhouse gases and thus the conclusions for innovations are the same improved innovations in the belt and road countries lead to lower greenhouse gases emission. Similarly, the estimated coefficient of technology is significant and positive in difference and system GMM models. The results indicate that technology export increases greenhouse gas emissions in the sample countries. More specially, if there is a per cent increase in technology increase greenhouse gas emission by 0.0002 and0.012 percent respectively shown by the difference and system GMM models.

The estimated coefficient of IU is negative significant both in difference and system GMM models which indicates that IU significantly reduce greenhouse gas emission in the sample countries. The results of both difference and system GMM illustrate that if there is a per cent increase in internet use will reduce greenhouse gas emissions by 0.000 and 0.03 percent respectively. The estimated coefficient of IU is negative significant both in difference and system GMM models which indicates that IU significantly reduce greenhouse gas emission in the sample countries. The results of both difference and system GMM illustrate that if there is a percent increase in internet use will reduce greenhouse gas emissions by 0.000 and 0.03 percent respectively. The estimated coefficient of MCS is positive significant both in difference and system GMM models which indicates that MCS significantly increase greenhouse gas emission in the sample countries. The results illustrate that if there is a percent increase MCS will increase greenhouse gas emissions by 0.001 percent.

Similarly, the effect of human capital on greenhouse gas emissions shows that the coefficient value is positive and significant and thus a rise in human capital increase greenhouse gas emission in the belt and road countries. The effect of economic growth is also positive and statistically significant in all models but it's not true for system GMM. The findings confirm the increasing effect of economic growth on greenhouse gas discharge. The findings show that economic activities for high economic growth increase greenhouse gases and lower the quality of the environment. Similarly, a rise in urban population also leads to an increase in greenhouse gas emissions while it is negative in the innovation index model.

In table 4, the results of the two-step difference and system GMM models are given, where the dependent variable is carbon dioxide emission. The effect of technology innovation and ICT results are presented where the index of innovation coefficients gives a negative coefficient in the system GMM model which shows that an increase in innovation reduces carbon dioxide emission. The two-step system GMM findings illustrate that a one percent rise in technology innovation reduces the emission of carbon dioxide by 0.03 percent in the belt and road countries however, these results contradict the study of (Çakar, Gedikli, Erdoğan, & Yıldırım, 2021) in which the authors found opposite results to the current study findings. Similarly, the effect of ICT on carbon dioxide is also analyzed where its coefficient is also significant and the sign is negative shown in the system GMM model however this effect is shown positive in the difference GMM. Considering the system GMM model outcomes, ICT improve the quality of the environment because it reduces carbon dioxide emission. Specifically, the results of two-step GMM show that carbon dioxide decrease by 0.02 percent if there is an increase of one percent in information and communication technology. Similar findings to this study were obtained by the previous researcher (Raheem et al., 2020) concludes similar suggestions while another researcher Francis Atsu et al. (2021) used fixed telephone subscriptions for ICT and got opposing results which contradict the findings of this study.

Similarly, the individual indicators of innovation are employed to extract its effect on carbon dioxide where the first indicator is the patent application and the coefficient of this indicator is negative and significant in both models which shows that increase in patents reduces carbon dioxide emission. The belt and road countries' emission of carbon dioxide will be decreased by 2.2 and 4.8 percent respectively shown by GMM and two-step system GMM if there is an increase by one percent in patents residents. Contradictory findings were obtained by (Chuzhi & Xianjin, 2008) and (H. Khan, Weili, & Khan, 2021a) who shows that innovations increase the carbon emission. On the other hand, another proxy for innovation used in the analysis is high technology export and its coefficient in the system GMM is significant and positive which shows that high technology export leads to high carbon emission in the belt and road countries. The findings show that there will be 0.0001 percent increase in the level of carbon dioxide emission if the high technology export raise by one percent in the belt and road countries. (Çakar et al., 2021) got similar conclusions and illustrate that a rise in innovations leads to the high discharge of carbon dioxide. (H. Khan et al., 2021c) also used this proxy for innovations and found the same results that high technology export upsurge carbon dioxide emission.

Table 4. The effect of innovation on CO2 emission

DEP.VAR. CO2	DGMM	SGMM	DGMM	SGMM
INV			-0.046	-0.032***
			(0.028)	(0.005)
ICT			0.139***	-0.024***
			(0.002)	(0.004)
PATENT	-2.200***	-4.870***		
	(7.190)	(1.530)		
TEN	-0.005***	0.0001***		
	(5.500)	(1.710)		
IU	0.015***	0.000***		
	(9.360)	(2.750)		
MCS	0.0001***	0.0001***		
	(0.0001)	(0.0001)		
HC	-4.477***	0.006***	0.040*	0.007***
	(0.121)	(0.0001)	(0.023)	(0.0003)
GDP	0.019***	-0.012***	0.006***	-0.012***
	(5.331)	(5.540)	(6.26)	(0.0001)
POP	2.360***	1.100***	4.440***	5.411***
	(6.231)	(0.002)	(0.000)	(0.000)
$CO2_{it}$	0.0001***	0.957***	0.399***	0.970***
	(0.0001)	(0.0002)	(0.000)	(0.001)
Constant		0.0001***		0.0001***
		(0.0001)		(0.0001)
Observations	302	350	302	350
Number of id	35	37	35	37
AR1	-1.82 (0.065)	-1.92 (0.055)	-1.79(0.074)	-1.89(0.059)
AR2	-1.65(0.168)	-1.35(0.178)	-1.24(0.216)	-1.21(0.226)
Sargan test	340.53(0.008)	273.72 (0.901)	338.44(0.012)	274.86(0.906)

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

Individual proxy of ICT is presented by IU where its coefficient in both estimators is significant and the sign is positive which shows that increase in internet use increases carbon dioxide and leads to environmental degradation. A percent change in internet use will increase the rate of carbon dioxide by 0.001 percent which is confirmed by the coefficient of IU in two step system GMM model. (Raheem et al., 2020) reinforce the findings of this study in which the authors also found that ICT increases carbon dioxide and lowers environmental quality. (Faisal, Tursoy, & Pervaiz, 2020) also found the same results while (Park, Meng, & Baloch, 2018) found opposite

results to our findings.(Atsu, Adams, & Adjei, 2021) also indicates that ICT reduce carbon dioxide emission. The second indicator is MCS which gives positive and significant coefficients in both estimators. The results shows that increased MCS leads to high carbon emission in the belt and road countries. Specifically, a one percent increase in mobile cellular subscription leads to 0.001 percent carbon emission in the sample countries.
Likewise, the estimated coefficient of human capital is also positive and significant which indicates that a rise in human capital in the sample countries will increase carbon dioxide emissions. The effect of economic growth is positively significant in different GMM models while negative significant in system GMM models which exert both positive and negative effects on carbon dioxide emission across models. These findings of (Al-Mulali, Ozturk, & Lean, 2015); Danish et al. (2018), and (H. Khan, Weili, & Khan, 2021b); (Chien et al., 2021); (Zoundi, 2017) and (Zoundi, 2017) indicates that economic growth degrade environmental quality, however, (Park et al., 2018) argues differently that the EU countries emission is reduced by economic growth. Population in our findings also exert a positive effect on carbon dioxide and thus leads to environmental degradation.

5. Conclusion

The current study explores information and communication technology and innovations in greenhouse gases and carbon dioxide for the sample of Belt and Road countries. Data for the period of 1996 to 2018 were collected from the world development indicator and static and dynamic models were employed for analysis. The results indicate that patent applications reduce both greenhouse gas and carbon dioxide emission while technology export increases them. ICT proxy by internet use reduces greenhouse gas and rise carbon dioxide emissions while ICT proxy by mobile cellular subscriptions increases both greenhouse gas and carbon dioxide emission. INV significantly reduce both greenhouse gas and carbon dioxide emission while ICT increases greenhouse gas and reduces carbon dioxide emission. Human capital and urban population are also the drivers of greenhouse gas and carbon dioxide emission. The effect of economic growth on greenhouse gas and carbon dioxide varies across models.
The results indicate that rising innovations are important to decarbonize the economy for sustainable development. However, the technology variable seems to increase carbon dioxide and greenhouse gas emissions. The belt and road countries can get benefit from rising innovations to help enhance energy efficiency and introduce modern and advanced technology which are less polluted. Likewise, innovations and information technology can be linked with each other's and thus with sustainable development. As indicated by our results, the ICT index is positively related to greenhouse gas emissions while it has still at the desired level to reduce CO_2 emissions. Information and communication technology proxy by internet use indicates that it reduces greenhouse gas emission, however, the mobile cellular subscription rise both greenhouse gas and carbon dioxide emission which need attention. The countries of belt and road should enhance information technology infrastructure to reduce pollution. It can also be done by rising innovations level that can improve the information technology and thus lower the emission level. rising innovations are considered important for sustainable development as innovations are related to higher economic growth as well as rising environmental quality. The belt and road countries can get benefit to focus on rising innovation levels to achieve this objective and not only to focus on rising economic growth through other factors such as trade, production and industrialization. The innovation level in the sample countries is at the desired level however this need further attention that can be helpful in production and industrialization to rise economic growth and safeguard environmental quality. By doing so, innovations can make the production process efficient by introducing advanced machinery, skills and techniques that can rise the production level with low carbon emissions as well can attain higher economic growth. The sample countries also need advancement in information technology through innovations to open boundaries and communicate globally to increase trade activities which can be beneficial to increase economic growth with a lower environmental cost.

ICT can also introduce smart applications and energy-efficient ICT devices as well innovations related to internet use which can be linked to sustainable development in the belt and road countries. ICT can help in green energy projects which can be a substitute for fossil fuels energy and thus rise the quality of the environment. By doing so, information and communication technology can facilitate trade activities, and foreign direct investment and can be used in other related activities which are related to a rise in economic growth. Our findings regarding innovations and information technology illustrate that rising innovations and information technology in the belt and road countries are important to rise environmental quality as well sustainable development. Our study is limited to the sample countries of the belt and road initiative and the study variables. Future studies can include other related factors and can use other proxies for innovations and information technology to draw useful recommendations and can be conducted on a different sample of countries.

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Appendices

Appendix 1

Table 5. The effect of innovation on greenhouse gas emission

DEP.VAR. GHG	OLS	FE	OLS	FE
INV			0.025	-0.005
			(0.026)	(0.004)
ICT			0.373***	0.076***
			(0.055)	(0.016)
PATENT	-4.620	-7.940***		
	(3.820)	(2.490)		
TEN	3.100	-1.240		
	(6.180)	(1.030)		
IU	0.010***	-0.001***		
	(0.001)	(0.0004)		

Table 5 continued . . .

MCS	0.350***	0.158***		
	(0.118)	(0.037)		
HC	1.015***	0.715***	0.971***	0.765***
	(0.021)	(0.107)	(0.020)	(0.096)
GDP	-0.005	0.002**	-0.009	0.002***
	(0.006)	(0.001)	(0.006)	(0.001)
POP	8.421	5.850***	7.171**	1.280***
	(5.261)	(1.510)	(2.821)	(3.201)
Constant	-6.734***	-0.744	-4.177***	-0.730
	(0.586)	(1.659)	(0.327)	(1.520)
Observations	350	350	350	350
R-squared	0.934	0.366	0.922	0.341
Number of id		37		37

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

Appendix 2

Table 6. the effect of innovation on CO2 emission

DEP.VAR. CO2	OLS	FE	OLS	FE
INV			0.318**	-0.058**
			(0.160)	(0.027)
ICT			2.566***	0.206*
			(0.331)	(0.107)
PATENT	-2.540	-3.840**		
	(2.260)	(1.580)		
TEN	0.000	-0.000**		
	(0.0003)	(6.500)		
IU	0.071***	-0.012***		
	(0.008)	(0.002)		
MCS	2.301***	0.767***		
	(0.694)	(0.235)		
HC	0.242*	0.232	-0.055	0.022
	(0.126)	(0.675)	(0.123)	(0.625)
GDP	-0.001	0.017**	-0.029	0.019***
	(0.0370)	(0.006)	(0.040)	(0.007)
urb	5.460*	3.100***	5.320***	8.730***
	(3.100)	(9.530)	(1.690)	(2.070)
Constant	-13.24***	-2.708	3.706*	4.301
	(3.456)	(10.49)	(1.959)	(9.823)
Observations	350	350	350	350
R-squared	0.323	0.182	0.175	0.112
Number of id		37		37

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

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