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Environmental innovation, trade openness and quality institutions: an integrated investigation about environmental sustainability

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Abstract

Environmental degradation has become an important issue for countries worldwide due to increase in carbon emission in recent years. It is an important concern for countries to achieve environmental sustainability; however, the debate on the role of innovation and institutions in environmental sustainability is still not adequate. There is a lack of understanding as to how countries can achieve higher economic growth as well to protect the quality of environment. Innovation is considered as effective tools as it enhances energy efficiency and cleaner production, which in turn lowers carbon emission. Quality institutions have also been considered as it enhances the quality of environment. Consequently, this study investigates trade openness, innovation and quality institutions in environmental sustainability in 176 countries of the world. By employing OLS regression, fixed effect and generalized method of moments, the results show that trade openness, renewable energy consumption and foreign direct investment are negatively associated with carbon emission, whereas most of institutional quality indicators significantly contribute to environmental sustainability; however, it is still below the desired level to enhance the quality of environment. Innovation positively and innovation square negatively affect carbon emission. Our analysis also confirms the existence of environmental Kuznets curve hypothesis and pollution halo hypothesis. The findings suggest policy makers on further improvement of trade policies, innovations, promotions of political and legal institutions and promotion of renewable energy sources to cope with environmental sustainability.

Keywords Trade openness · Innovation · Institutional quality · Environmental Kuznets curve · Environmental sustainability · Patent application

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1 Introduction

Environmental degradation is an important issue in the field of economics and has got considerable attention from different researchers and economists since decades. Countries are facing major problems of global warming due to continue increase in carbon emission. Several factors have been identified recently that cause environmental degradation where governments are trying to tackle these problems that influence environmental quality by Shahbaz et al. (2013a, b). The impact of trade openness on environment has also explored by enormous researchers in the prevailing studies but got mixed results and conclusions. For instance, Le et al. (2016) illustrate that openness to trade increase carbon emission and degrade environmental quality. On the other hand, Jayanthakumaran and Liu (2012) argue that openness to trade is an important factor that enhances environmental quality through composition, trade and technique effect. Chen et al. (2021) argue that trade openness positively affect carbon emission, and this effect varies on different levels of carbon emission; however, they show that the indirect effect of trade openness on emission is positive while indirect effect is negative. Likewise, the impact of innovation on environmental quality has also been debated by several scholars in the preceding literature. Rennings (2000) argues that "environmental innovation is a modified process, systems or practices which give benefits to the environment". A study by Long et al. (2017) emphasizes that innovation increases sustainable development toward cleaner production. Dauda et al. (2019) illustrate that innovation reduces carbon emission. Likewise, Yuan et al. (2021) studied green innovation and institutional quality on carbon emission. They have found that green innovation reduces carbon emission and that institutional quality has a moderating negative association between carbon emission and innovation. Hodson et al. (2018) noted that energy efficiency is increased by innovation, and then, it in turn reduces carbon emission. While Mensah et al. (2018) studied this association and found inconclusive outcomes for some individual countries in their sample. Additionally, some studies argued that excessive innovation may increase emission; however, if there is strict regulation regarding environmental quality in countries, it will lead to green paradox and will effect economic growth negatively. However, if there is a high potential, it will lower carbon emission though excessive innovation by Huiqing Wang and Wei (2019). Economic growth has also been considered as a key driver of emission over the past several decades. Grossman and Krueger (1995) argue that the relationship of economic growth and carbon emission depicts a U-shaper reversed link. The EKC (environmental Kuznets curve) suggests that there is environmental issue in countries in the early phase of growth by Liang and Yang (2019). On the other hand, some researchers have shown interest in the linkage between financial development and carbon emission such as Shahbaz et al. (2013a, b). Some studies illustrate that an increase in financial development increases carbon emission such as Shahbaz Muhammad et al. (2011); Diallo and Masih (2017), while some argues that financial development is an important factor for economic growth of a country. Likewise, some environmental economists argue that financial development enhances the quality of environment because well-structured financial institutions with sound policies provide support to green technological innovation and renewable energy projects, which are useful to protect environmental quality. However, some authors support the negative impact of financial development on environmental quality such as Lee et al. (2015); Khan et al. (2020a, b); Jiang and Ma (2019). Likewise, the impact of foreign direct investment on carbon emission has also been investigated widely by several researchers. Some researchers show that the inflow of foreign direct investment is harmful for environmental quality such as L. Zhu et al. (2019);

however, some researchers state that the inflow of FDI reduces emission by Hui Wang and Liu (2019), Huang et al. (2019). Institutional quality is another crucial factor that positively contributes to environmental quality. Normally, environmental degradation in developing countries is associated with the poor quality of institutions such as political institutions because poor level of institutions weakens the regulations regarding environment by showing a bias implementation of environmental regulation and policies. The institutions and governance might be required to efficiently explore the trade environment relationship (Bekhet et al., (2020); Torras & Boyce, (1998)) as institutions of a country play an important role to provide policies related to trade, which might be helpful to protect environmental quality. A lot of researchers are in favor of positive impact of institutional quality on environmental quality such as Ali et al. (2019); Ibrahim and Law (2016) and Mavragani et al. (2016) argue that high-quality institutions and good governance enhance the quality of environment. Wu et al. (2021) illustrated that quality institutions above the threshold level do not contribute significantly for environmental deterioration in spite of growing transportation and increasing industrialization.

Based on the ongoing debate on trade environment relationship, the current study explores the association of innovation, quality institutions and trade openness with carbon emission. We investigate trade environment relationship because the increase in globalization stimulated the dispersion of technologies worldwide related to environment with advance environmental canons in trade encountered, which concurrently enhance environmental copiousness at domestic level among firms and the citizens. Trade openness is a key economic determinant; however, it has been argued that it is harmful for environment. Therefore, it has been a challenge for the government and policy makers of a country that how to protect the quality of environment as well to ensure higher economic growth through trade openness. The findings of our study show that trade openness has a negative impact on carbon emission in our sample and models in the presence of innovation and institutional variables. We also explore the role played by institutions in this association to know whether the quality of institutions is important to protect and enhance environmental quality as well to achieve the economic growth in the presence of high level of trade.

Our current study findings show that most of institutional quality indicators significantly contribute to environmental quality in our sample countries; however, it is still below the desired level to enhance the quality of environment. The remaining parts of the paper are structured in the given sequence; part 2 gives a detailed literature review, part 3 represents the methods of the study; results are given in Sect. 4, while part 5 is composed of conclusion.

2 Literature review

2.1 Trade openness and environmental quality

The nexus between trade and environmental quality has been debated by several researchers in the prevailing studies for long time, and it is an important issue in trade policies. Mixed results and conclusion have been achieved by researchers on the impact of trade openness on environmental quality. Existing studies evidence positive impact, negative and ambiguous effect of trade openness on environmental quality. Some studies indicate that openness to trade is harmful for environment, while some researchers argue that openness to trade enhances the quality of environment, while some argue that there is no association between environmental quality and trade openness. Bernard and Mandal (2016) studied trade environment relationship in sixty emerging and developing countries. Their findings show that high volume of trade enhances environmental performance index. They further state that political factors increase the quality of environment, while the impact of income and population are detrimental. Likewise, Le et al. (2016) studied the association between openness to trade and carbon emission. They found long-run association between trade, carbon emission and economic growth. They further evidence that trade openness degrades environmental quality, but this effect varies in different countries. Q. Zhang et al. (2017) studied the linkage between openness to trade and carbon emission in ten economies. They found that trade openness negatively influences carbon emission. Moreover, Ertugrul et al. (2016) have studied the association of trade openness, carbon emission and real income in top ten CO2 emitter's developing countries. They found cointegration relationship among their variables for some individual countries and found that energy consumption and trade openness were the main drivers of carbon emission. A recent evidence given by Njindan Iyke and Ho (2017) who also explores the nexus between carbon emission and trade opens in eastern and central Europe. They found that trade openness lowers the rate of carbon emission in the long run, while it increases emission in the long run. Similarly, different studies have been conducted for different regions and different time periods such as the study of Fang et al. (2018) has explored the impact of trade openness on environment in Chinese cities. By using FMOLS model, they found that economic growth affects water pollution positively which depend on the different level of trade openness. As mentioned above that some researchers argue that this association is unimportant. For example, Omri (2013) has studied carbon emission and trade openness in 14 Middle East and North American countries where his findings indicate that the impact of trade openness on environment is unimportant and inverse. Likewise, Shahbaz et al. (2013a, b) studied the trade environment association where they found that trade improves carbon emission while enhancing the level of foreign direct investment related to research and development. Jayanthakumaran et al. (2012) have studied the association of global trade and carbon emission for a sample of Chinese provinces over the time period of 1997–2007. Their results indicate that increases in international trade reduce greenhouse gas emission and an increase in income enhances consumer expenditure on environment-friendly items. Park et al. (2018) studied the impact of economic growth, trade openness, financial development and internet use on carbon emission. They found that internet use has a long-run association with carbon emission and electricity consumption positively affects carbon mission. They further illustrate that the impact of financial development and economic growth on carbon emission is negative. Likewise, Mahrinasari et al. (2019) studied trade and environmental degradation in Asia. They found that carbon emission and trade have a positive relationship in the sample countries. Some other studies show that trade openness negatively influences carbon emission. Yu et al. (2019) studied trade openness and environmental quality in CIS countries. They found that openness to trade increases carbon emission directly, while it reduces emission indirectly. Similarly, H.-p. Sun et al. (2019a, b) studied the association between carbon emission and openness to trade in belt and road countries. They found that their variables in the long run were stationary and the impact of trade openness on environment was positive and negative, but this impact varies in different samples.

2.2 Innovation and CO2 emission

Innovation has been considered one of a new factor in the growth environment nexus, and it has been argued that it significantly contributes to environmental quality. For instance, a study conducted by Hodson et al. (2018) states that innovation reduces carbon emissions owing to efficient use of energy and cost-effective ways to lower the emissions of carbon dioxide. Similarly, Cagno et al. (2015) have conducted a study where they illustrate that innovation advances the efficiency of energy and thus reduces the use of nonrenewable energy use, which in turn reduce pollution. Álvarez-Herránz et al. (2017) studied the nexus between economic growth, innovation and carbon emission. They state that innovation helps move the economy to the use of sustainable energy sources and production. Likewise, Cai and Zhou (2014) argue that innovation is an important factor which helps mitigate environmental pollution. Countries are trying to enhance innovations to response climate changes Carraro and Siniscalco (1994). However, on the other hand, Dauda et al. (2021) have studied innovation, carbon emission and trade openness in African countries for the period of 1990–2016. They have employed fixed-effect and GMM models where their findings validate an inverted U-shape association between carbon emission and innovation at the panel level in some countries, while renewable energy use reduces emission in the panel. They also found that human capital reduces carbon emission in some individual countries as well in the panel. Their results also confirm pollution haven hypothesis, halo effect and environmental Kuznets curve. Similarly, Mushtaq et al. (2020) have studied the impact of economic growth and income inequality on carbon emission in China through the moderating role of innovation at regional and national levels. They have collected data for the period of 1995–2015 and employed panel econometric techniques. They found that income inequality and economic growth affect carbon emission in China where innovation has a moderating role in this association. Consequently, Töbelmann and Wendler (2020) have studied the impact of innovation on carbon emission in EU-27 countries for the period of 1992–2014. They have employed GMM model and proxies patent application for innovation. They found that innovation has no contribution to reduce carbon emission, while general innovative activities do not influence carbon emission. They further indicate that this effect might be small comparatively to the effects of increased economic activities. They also conclude that the effect of innovation varies across different countries and regions with less developed countries showing higher level of heterogeneity. Likewise, Cansino Muñoz-Repiso et al. (2019a) have studied technological progress and quality institutions on environment. They have found that income and greenhouse gas emission are adjusted to traditional EKC hypothesis. They states that technological progress and quality institutions enhance environmental sustainability, while FDI and international trade have a negative impact on environment.

2.3 Economic growth and carbon emission

The relationship between environmental quality and economic growth is widely studied by large number of researchers by using EKC (environmental Kuznets curve) framework. Based on the EKC framework, real output degrades environmental quality till a certain level of growth and then pollution becomes decreasing when GDP reaches a certain level. Hence, such association is an inverted U-shape Grossman and Krueger (1995). As a result, people of countries demand the government for environmental laws to enhance the quality of environment. Individuals turn to be highly concerned at a higher income level about health issues and hence insist on environmental quality that leads to policy implication to restrain carbon emission and enhance environmental quality. Additionally, if there is a smooth development of the economy composition, which is largely moved from polluted industries to innovative activities and production, as well service-oriented production, the pollution in those countries will have enough minimization. Some other studies have used the absence or presence of EKC using different methods and pollutants. Osobajo et al. (2020) examine the impact of energy consumption and GDP on carbon emission. They employed fixed-effect and OLS models to the data for 1994–2013. They found a bidirectional causal relationship of these variables with carbon emission while unidirectional relationship of energy with carbon emission. The findings of OLS model and fixed-effect model show that GDP and energy consumption increase carbon emission. Yefan Zhou et al. (2018a, b) have studied the impact of energy consumption and economic growth on carbon emission in the world to test the EKC hypothesis. The panel quantile regression was used in their analysis and found heterogeneous effect of independent variables on carbon emission across different quantiles. They further state that energy consumption increases emission in panel, while they have found greater effect of energy consumption on carbon emission in developed countries than developing countries. Abid (2016) has tested environmental Kuznets curve in MENA and European Union counties. They have used GMM model where their findings show a monotonic increasing impact of GDP on carbon emission in both samples. Tamazian and Rao (2010) studied the relationship between economic growth and environmental quality. They have also focused on the impact of financial and institutional quality on environment as well. Their findings support the EKC hypothesis and state that financial development and institutional quality are important for environmental quality development.

2.4 Quality institutions and carbon emission

The role of institutions in carbon emission mitigation has drawn considerable attention recently. The current literature has focused on several factors such financial development, economic growth, trade openness and economic growth, and these factors have been considered as a major channel through which institutions influence carbon emission Azam et al. (2020); Adams and Acheampong (2019); Sinha et al. (2019); H. Sun et al. (2019a, b); Saidi et al. (2020). EKC hypothesis has also been tested by several researchers while exploring the impact of institutions on environmental quality while got mixed conclusions. Some of these studies indicate that EKC exists only in the presence of additional factors such as institutional quality, trade openness or financial development. However these results and effects may vary in different samples of countries and regions. For instance, recently Tang et al. (2021) examined the role of quality institutions and education in enhancing environmental quality in 114 countries. They used GMM model, and their findings confirm the environmental Kuznets curve hypothesis. They also found that human capital and institutional quality facilitate the role of FDI and renewable energy in lowering the rate of emission. In addition, Khan et al. (2021) explore the role of institutional quality on carbon emission in the global panel. They used data from 2002 to 2018. They found that renewable energy consumption reduces emission, while nonrenewable energy degrades environmental quality. They also found that financial development increases, while FDI reduces emission. Their results further indicate that technological progress positively while institutional quality reduce carbon emission. Likewise, Ahmed et al. (2020) have explored institutional quality, financial development, trade openness and environmental degradation in Pakistan for the period of 1996–2018. By using ARDL model, they found the significant long-run association of quality institutions, financial development and environmental degradation. They also found long-run association between trade and environmental degradation. Similarly, Hunjra et al. (2020) studied institutional quality, financial development and environmental quality in South Asian countries. They found the increasing impact of financial development on carbon emission. Their findings show that institutional quality moderates the negative influence of financial development on environmental sustainability. Kousar et al. (2020) find the relationship of renewable energy consumption, water crises and environmental quality in the presence of governance in South Asian countries. They have found that FDI increases carbon emission while renewable energy and water availability reduce carbon emission. They further state that governance weakens the association of environmental degradation and foreign direct investment. Wawrzyniak and Doryń (2020) analyzed the effect of institutions quality on carbon emission in 93 developing and emerging countries. They have employed GMM model where the findings indicate the decreasing influence of institutions on carbon emission when GDP increases. They further show the decreasing influence on carbon emission in the presence of good governance. They also evidence the moderating role of control of corruption in carbon emission and economic growth association. Haldar and Sethi (2020) have studied the moderating role of quality institutions in the relationship between carbon emission and energy consumption along with other variables such as capital formation, financial development, trade and FD in 39 developing countries. They employed system GMM, fully modified ordinary least square; panel grouped mean and panel quantile regression. They found that institutional quality has a moderating role in energy usage and enhances its effectiveness in carbon emission reduction. Their results also evidence the existence of EKC hypothesis in the presence of institutional quality. Ali et al. (2019) explore the role of quality institutions in reducing carbon emission in a sample of 47 developing countries. By employing GMM model, the author found that quality institutions minimize the rate of carbon emission and enhance environmental quality. Likewise, Abdelaziz and Helmi (2019) explore trade openness and quality institutions in developing and developed countries. They found no influence of trade openness on environmental quality in the whole sample, while they found a harmful impact of trade openness on environment in the disaggregated analysis.

2.5 Foreign direct investment, carbon emission and economic growth

The relationship between foreign direct investment, economic growth and carbon emission has also been studied by several researchers in the preceding literature but with mixed results which is composed of positive, negative and insignificant impact of foreign direct investment of carbon emission. Different researchers have dissimilar opinion; Khan et al. (2020a, b) have studied the interrelationship of environmental factors 190 countries. They used dynamic and static models and found that their study variables affect each other significantly. They further found that renewable energy has negative while FDI has positive influence on carbon emission. Likewise, Zafar et al. (2020) investigate the effect of natural resources, renewable energy and FDI on carbon mission in a sample of OECD countries. They state that renewables energy is positive impact on environmental quality. They further illustrate that natural resource abundance and FDI increase carbon emission. Moreover, Manta et al. (2020) examine the association of carbon emission, financial development and energy consumption in European countries. They used FMOLS and VECM estimators where their findings indicate no impact of carbon emission and energy on economic growth in the long run. However, they have found a bidirectional relationship among financial development and growth. They further indicate that financial development does not reduce emission and the use of energy increases financial development, while financial development increases emission in the short run. Similarly, Shaari et al. (2020) explore the impact of energy consumption on carbon emission in OIC countries. They used panel ARDL and dynamic fixed-effect estimators and found that national output contributes to environmental degradation in the long run; however, they found no effect of national output on carbon mission in the short run. They further illustrate that population have a decreasing impact on emission in the short run, but it has no effect on carbon emission in the long run. Mert et al. (2019) examine foreign direct investment, carbon mission and energy consumption in European countries. They evidence the EKC hypothesis in their sample countries. They also state that there is no role of regulations on the validity of PHH hypothesis. They also state that renewable energy consumption lowers the rate of carbon emission.

3 Methodology

3.1 Model specification

This study examines the impact of trade openness, innovation, institutional quality, FDI inflow, financial development, renewable and nonrenewable energy consumption on environmental quality. Equation 1 is the baseline model, whereas in Eq. 2 we add innovation to the model, while in Eq. 3 we take the square of innovation and per capita GDP which can be rewritten as follows:

$$ED = \beta_0 + \beta_1 TO_{it} + \beta_2 RE_{it} + \beta_3 NRE_{it} + \beta_4 GDP_{it} + \beta_5 FDI_{it} + \beta_6 FD_{it} + \beta_7 POP_{it} + \varepsilon_{i,t} \tag{1}$$

$$ED = \beta_0 + \beta_1 TO_{it} + \beta_2 RE_{it} + \beta_3 NRE_{it} + \beta_4 IN_{it} + \beta_5 GDP_{it} + \beta_6 FDI_{it} + \beta_7 FD + \beta_8 POP_{it} + \varepsilon_{i,t} \tag{2}$$

$$ED = \beta_0 + \beta_1 TO_{it} + \beta_2 RE_{it} + \beta_3 NRE_{it} + \beta_4 IN_{it} + \beta_5 (IN)^2_{it} + \beta_6 GDP_{it} + \beta_7 (GDP)^2_{it} + \beta_8 FDI_{it} + \beta_9 FD_{it} + \beta_{10} POP_{it} + \varepsilon_{i,t} \tag{3}$$

In the above equations, ED represents environmental degradation (measured by per capita CO2 emissions), RE is renewable energy use, TO is trade openness (export + import), NRE is nonrenewable energy consumption, IN is innovation, IN^2 is innovation square, GDP represents economic growth, GDP^2 is the square of per capita gross domestic product, FDI is foreign direct investment, FD is financial development, POP is urban population, where *i* signifies country, *t* time. CO2 emission (metric tons per capita) is used to proxy for environmental quality Jiang and Ma (2019); Khan et al. (2021).The environmental quality is lower in countries where per capita carbon emission is high. Renewable energy consumption is suggested by previous studies that it plays a very important role in enhancing environmental quality. Khan et al. (2021); Khan et al. 2020a, b) state that renewable energy consumption reduces carbon emission. Similarly, it has been argued that renewable energy is beneficial for environment as it has the potential to subside diminish carbon emission Belaid and Youssef 2017). Based on the previous studies, we also assume that renewable energy from renewable sources will have a negative influence on carbon emission. Nonrenewable energy consumption which is measured miles of barrel oil equivalent per million is also used in our model. Nonrenewable energy is the energy from fossil fuels, and it upsurges carbon emission in most of the countries Khan et al. 2020a, b). We also expect in our study that fossil fuel energy is not in favor of environmental quality, and it will have an increasing impact on carbon dioxide emission in our sample countries.

We also use innovation in our model measured by patent application Sulaman Muhammad et al. 2020). Several studies have used this variable as an important measure. Some studies state that innovation reduces carbon emission; however, simply using the innovation in our model may not fully capture the effect so we also use innovation square to capture the full effect of innovation on environmental degradation. In Eq. 3, the innovation square shows its quadratic form, which indicates that when a country reaches a certain stage of innovation it may start to lower the carbon emission rate with increasing capabilities in innovative activities. The association between carbon emission and economic growth has also been widely deliberated by following the environmental Kuznets curve. This tells that an increase in population is the cause of an increase in income per capita and this start declines when continually increasing income per capita.

Al-Mulali et al. (2016) state the negative impact of per capita income on pollution at the early stage of development. According to the previous studies, economic growth has been considered as one of the explanatory variables of carbon emission. We find the impact of GDP and also include the square of GDP per capita to testify the existence of EKC hypothesis. In Eq. 3, the sign of β_6 and β_7, the EKC is shown in the quadratic form, indicating that if the income reaches a certain level in an economy, it could bring decrease in carbon emission, which increases the income continuously. Foreign direct investment is proxied by the level of FDI inflow as a percent of GDP (H. Zhu et al., 2016). It has been argued that the inflow of FDI degrades environmental quality in those countries where the policies about environmental protection are poor Forslid et al. (2017). Domestic credit to the private sector as a % of GDP is used as a proxy for financial development Jiang and Ma (2019); Khan et al. (2020a, b). However, some other studies have used some other to proxy financial development.

In Eq. 4, we include institutional quality to the model. The quality of institutions in every county is not the same and it varies in countries. Due to the quality of institutions, the environmental quality can be influenced due to differences in institutional quality. There could be better policies if there is good institutions such as good regulations, better level of governance and control of corruption, which could protect the quality of environment by eliminating the inflow of FDI with investment in polluted industries. Good quality of institutions can help the encouragement of renewable energy usage and also focus to utilize green technology to protect the quality of environment. We use different measures for institutional quality to deeply investigate the role of institutional quality in environmental degradation as suggested by Khan et al. (2021) in their study limitation. They suggested using broad measure and using alternative ways to deeply investigate the role of institutional quality. In model 4, first we use all six institutional quality indicators, which are rule of law, government effectiveness, regulatory quality, voice and accountability, political stability and control of corruption. These indicators are recently used by previous literature such as Halkos and Paizanos (2017); Khan et al. (2021). Secondly, we use the institutional quality index constructed by using principle component analysis in model 4A; thirdly, we use political system indicators in model 4B which are rule of law, regulatory quality and voice and accountability. And lastly, we use the legal system indicators in model 4C to proxy institutional quality, which are control of corruption, government effectiveness and political stability. We use these different ways to proxy institutional quality in different models to deeply examine the role of institutions in environmental sustainability. Several researchers suggested that quality institutions are important for enhancing environmental quality. The empirical model can be expressed as follows:

$$ED = \beta_0 + \beta_1 TO_{it} + \beta_2 RE_{it} + \beta_3 NRE_{it} + \beta_4 IN_{it} + \beta_5 (IN)^2_{it} + \beta_6 GDP_{it} + \beta_7 (GDP)^2_{it} + \beta_8 INST_{it} + \beta_9 FDI_{it} + \beta_{10} FD_{it} + \beta_{11} POP_{it} + \varepsilon_{i,t} \quad (4)$$

where ED represents environmental degradation, TO is trade openness, RE is renewable energy consumption, NRE is nonrenewable energy consumption, IN is innovation, IN^2 is innovation square, GDP is gross domestic product per capita, GDP^2 is the square of per capita GDP, INST is institutional quality, FD is financial development, FDI is foreign direct investment, POP is urban population, where *i* signifies country, *t* time.

3.2 Data source

Table 1 shows variables definitions and data sources. Patent application has been used as a proxy for innovation. Hagedoorn and Cloodt (2003) indicate that patent application could be used to represent innovation. Innovation is a modified new practice, which helps promote the production quality process and leads to decrease the output level, which is undesirable such as waste or carbon emission to improve environmental quality. We also use trade openness as important variables in our study, which is taken as the ratio of export plus import. We also find the role of institutional quality on environment in our study. Data for all variables of our study are collected from the World Bank database (World development and world governance indicators).

Table 5 shows the results of descriptive statistics for all variables. The descriptive statistics is given in Table 5 in appendix 1 where column 1 shows the variables, column 2 presents the number of observations where columns 3, 4, 5 and 6 give the value of mean, std. deviation, minimum and maximum, respectively. CO2 is carbon emission, TO is trade openness, Re is renewable energy consumption, NRE is nonrenewable energy consumption, INV is innovation, GDP is per capital gross domestic product, ROL is rule of law, RQ represents regulatory quality, VOA is voice and accountability, PS is political stability, COC is control of corruption, GOV is government effectiveness, FDI is foreign direct investment, FD is financial development where POP is urban population.

Table 6 in appendix 2 illustrates the results of correlation matrix of the study variables providing the linear relationship of variables where the values near to 1 or -1 show strong correlation between the pairs of variables. The details can be seen in the given tables in appendix.

3.3 Estimation methods

We employ OLS, fixed effect and GMM (generalized method of moments) to the data for analysis. The simple OLS and fixed-effect static models for panel data may lead to several econometric problems and may give unreliable outcomes under panel data as it uses strict exogeneity assumption (Wooldridge012). Therefore, we focus on dynamic GMM model to estimate the data on panel level. GMM model is a robust estimator, which accounts for different issues of endogeneity. GMM estimator gives reliable and consistent results even if there is endogeneity from different sources such as dynamic endogeneity and heterogeneity (Wintoki et al. 2012). In dynamic GMM model, difference GMM utilizes the first differences of regressor and the dependent variables to transform the regression for abstracting the country-specific effects and makes regressor time invariant. Here with the

Table 1 Data source and variables

Variables	Description	Symbols	Source
Carbon emission	Per capita CO2 emissions (metric tons per capita)	CO2/ED	World development indicator
Trade openness	Export + import ratio% GDP	TO	WDI
Renewable energy consumption	Renewable energy consumption (kilotons)	RE	WDI
Nonrenewable energy consumption	Total final energy %	NRE	WDI
Innovation	Patent application	INV/IN	WDI
Per capita gross domestic product	GDP (gross domestic product) per capita	GDP	WDI
Institutional quality	Six bloc of institutional quality, rule of law, voice and accountability, political stability, government effectiveness, regulatory quality, control of corruption,	INST	WDI
Foreign direct investment	Foreign direct investment as a percentage of GDP	IFDI	WDI
Financial development	Domestic credit to private sector as a percentage of GDP	FD	WDI
Urban population	Urban population	POP	WDI

first-differenced lagged dependent variable is instrumented with precedent levels; therefore, autocorrelation problem can be eliminated. However, in some cases the lagged levels of regressor-poor instruments in the first-difference regressor lower the efficiency. For bringing better efficiency in assessment, Sys-GMM estimator deals better for simultaneity bias and country-specific effects. For the better results with efficiency, this study could apply system GMM estimator of Arellano and Bover (1995); Blundell and Bond (1998). System GMM utilized for controlling country-specific effects and endogeneity as well as omitted variable biasness. We are utilizing two-step systems GMM to efficiently analyze our data. The main equation of our study will be stated as follows:

$$ED_{it} = \beta_0 + \beta_1 ED_{2i,t-1} + \beta_2 Y_{i,t} + \beta_3 X_{i,t} + \varepsilon_{i,t} \tag{5}$$

where ED is independent variable proxy for environment, ED_{it-1} the lag of left-hand-side variables utilized in the equation as an explanatory variable to quantify the anterior years effect on current year. Y represents explanatory variables; X represents control variables, while ε is the error term.

4 Results and discussion

4.1 Results

We have analyzed the data by using OLS, fixed effect and generalized method of moments (GMM). The outcomes of difference GMM and system GMM are almost matching the results of fixed-effect and OLS models given in Table 2. However, we mainly focus on the system GMM estimator as this is more robust and efficient estimator. The Sargan and Arellano–Bond tests for GMM models also confirm the validity of the instruments and model fitness. The results show that the lagged dependent variable is highly significant, which indicates that GMM model is suitable and carbon emission in the panel is harmful for environmental quality. In Table 2, the results of three empirical models are given where OLS, fixed effect, difference GMM and system GMM are shown by 1, 2, 3 and 4, respectively, for each model.

The results indicate that trade openness is highly significant and the sign is negative, which indicate that trade openness lowers carbon emission. The negative impact of trade openness on environment is in line with the findings of Jayanthakumaran et al. (2012); Dogan et al. (2017) who also found the same results. However, Bernard and Mandal (2016) found positive impact of trade openness. Our results show that there may not be high volume of trade, which are using fossil fuels for production in the sample countries or it is related to the trade impact on environment through composition and techniques effect. Likewise, the estimated coefficient of renewable energy consumption is also highly significant at 1 percent significance level and the sign is negative which indicates that renewable energy consumption reduces carbon emission in the sample countries. More specifically, the result of system GMM in all three models shows that if there is a unit increase in the usage of renewable energy it will reduce emission by 0.0001 units. The results illustrate that country with higher consumption of renewable energy controls degradation of environment and safeguarded the quality of environment. These findings are in line with Li and Su (2017), Jebli et al. (2019); Bhattacharya et al. (2017); Khan et al. (2021) who also state the negative impact of renewable energy on carbon emission. This negative sign shows

Table 2 Model results

	Model-1				Model-2				Model-3			
	1	2	3	4	1	2	3	4	1	2	3	4
TO	−0.002***	−0.016***	−0.000***	−0.0001***	−0.000*	−0.017***	−0.018***	−0.0001***	0.003**	−0.019***	−0.019***	−0.0001***
	(0.001)	(0.002)	(0.000)	(6.430)	(0.001)	(0.002)	(0.000)	(8.920)	(0.001)	(0.002)	(0.000)	(0.000)
RE	−0.082***	−0.068***	−0.0482***	−0.015***	−0.089***	−0.114***	−0.107***	−0.009***	−0.081***	−0.110***	−0.079***	−0.098***
	(0.003)	(0.009)	(0.000)	(0.000)	(0.004)	(0.009)	(0.002)	(0.000)	(0.004)	(0.008)	(0.002)	(0.002)
NRE	0.001***	0.001***	0.001***	0.000***	0.001***	0.000***	0.000***	0.000***	0.001***	0.000***	0.000***	0.001***
	(3.510)	(7.050)	(4.540)	(3.550)	(3.780)	(6.230)	(1.390)	(4.320)	(3.690)	(5.390)	(1.990)	(2.070)
INV					0.037	0.080*	0.0120***	0.040***	4.100***	3.760***	−1.050	6.640***
					(0.039)	(0.045)	(0.004)	(0.002)	(8.600)	(1.030)	(6.380)	(6.610)
$(INV)^2$									−8.641**	−1.231***	−1.771***	−4.471***
									(0.000)	(0.000)	(0.000)	(0.001)
GDP	0.274***	(7.050)	0.034***	0.062***	−0.006	0.0207**	0.017***	0.0182***	−0.033	0.034***	0.045***	0.015***
	(0.092)	0.033	(0.001)	(0.001)	(0.0252)	(0.008)	(0.000)	(0.000)	(0.028)	(0.009)	(0.001)	(0.002)
$(GDP)^2$									−0.004	−0.003***	−0.002***	−0.007***
									(0.003)	(0.001)	(0.000)	(0.000)
IFDI	−0.173**	(0.037)	0.0575***	−0.026***	0.001	−0.002*	−0.001***	0.000***	0.020	0.018	0.092***	−0.027***
	(0.077)	0.105***	(0.002)	(0.001)	(0.003)	(0.001)	(7.630)	(1.260)	(0.0781)	(0.032)	(0.009)	(0.008)
FD	−0.240**	(0.037)	−0.124***	0.012	−0.002	0.008***	0.008***	−0.002***	−0.268**	0.314***	0.603***	−0.885***
	(0.110)	0.202**	(0.009)	(0.009)	(0.002)	(0.002)	(0.000)	(9.070)	(0.126)	(0.088)	(0.034)	(0.047)
POP	0.586***	(0.095)	0.019***	0.056***	0.293***	−0.041	0.176***	0.0481***	0.173***	−0.006	−0.026***	0.406***
	(0.054)	0.060	(0.003)	(0.002)	(0.066)	(0.061)	(0.006)	(0.004)	(0.063)	(0.055)	(0.008)	(0.015)
Const	3.665***	5.112***		0.625***	3.776***	7.211***		0.270***	4.650***	7.314***		7.358***
	(0.501)	(0.536)		(0.0342)	(0.371)	(0.557)		(0.0282)	(0.532)	(0.454)		(0.188)
Obs	1,037	1,037	771	1,037	966	966	839	966	995	995	844	995
R^2	0.813	0.322			0.742	0.347			0.751	0.371		
No. id		136	128	136		105	102	105		105	100	105
AR2			−1.00(0.316)	−1.70(0.08)			−1.00(0.316)	−1.70(0.08)			−1.31(0.189)	−0.65(0.514)
Sargan test			413.9(0.000)	819.5(0.000)			413.9(0.000)	819.5(0.000)			575.5(0.001)	1108(0.001)

***,**,*indicates significance level at 1, 5 and 10%, respectively. AR2 is Arellano and Bond test 2 that there might be a high level of conversion from fossil fuels to renewable energy, which enhances the quality of environment.

Findings on the impact of nonrenewable energy consumption on carbon emission are highly significant and the sign is positive which strongly evidences that energy from fossil fuels increase carbon emission. The results indicate that nonrenewable energy consumption is harmful for environmental quality. These results are in line with the findings of Khan et al. (2021).

The results in Table 2 for the OLS, fixed effect, difference generalized method of moments (DGMM) and system generalized method of moments (SGMM) mostly in all models except OLS in model 2 and fixed effect in model 3 indicate that innovation upsurges CO2 emissions. The estimated coefficient gives the significant and positive value for innovation, which supports that Innovation increases carbon emission. However, the estimated coefficient of innovation square is highly significant and the sign is negative which shows that it reduces carbon emission in the panel.

Mostly in all models of Table 2, the outcome demonstrates that economic growth increases CO2 emissions, while the square of per capita GDP reduces CO2 emissions. This shows an evidence of environmental Kuznets curve (EKC) in the panel. The results indicate that there is a non-monotonic inverted U-shaped association between output and environment. When there is an increase in GDP per capita square, the rate of carbon emission lowers, implying that there is an inverted U-shaped association verified as claimed by the hypothesis of environmental Kuznets curve. Our findings are reinforced by those of Sulaman Muhammad et al. (2020), Hanif et al. (2019); Sapkota and Bastola (2017). The effect of foreign direct investment on carbon emission for model 1 in OLS regression and system generalized method of moments (GMM) is negative, while positive in difference generalized method of moments (GMM) and insignificant in fixed-effect model. For model 2, the estimated coefficient is negative for fixed effect and difference GMM, while positive significant for system GMM.

Likewise, in model 3, the coefficient is positive in difference GMM, while negative significant in system GMM model. As we have mentioned above that the system GMM is the most efficient estimator so we are considering the system GMM results, which are negative and significant mostly in all models. The findings suggest that an increase in the inflow of FDI reduces carbon emission. These findings are in line with those of Jebli and Youssef (2015); Khan et al. (2021); Mert and Bölük (2016); Yang Zhou et al. (2018a, b). The estimated coefficient of urban population is positive mostly in all models, especially in system GMM which indicates that an increase in urban population increases carbon emission.

4.1.1 Model results of trade openness, innovation and institutional quality on carbon emission

The empirical model 4 results are given in Table 3 where 1, 2, 3, 4 represent the OLS results, fixed-effect estimator results, difference generalized method of moments (DGMM) and system generalized method of moments (SGMM), respectively. The outcomes on the impact of trade openness, NRE, RE, innovation, innovation^2, GDP and GDP square of model 4 are exactly the same as in the above three models in Table 2. We have added institutional quality indicators to the model where the estimated coefficient of the rule of law is negative in fixed effect and difference GMM model, while it is positive in system GMM model indicating the poor level of the rule of law and its effect the quality of environmental negatively.

Similarly, the estimated coefficient of regulatory quality is positive in other estimators, while negative significant in system GMM indicates that it reduces carbon emission in the sample countries as our main focus of this study is system GMM. Similarly, voice and accountability are also negatively and significantly associated with carbon emission showing that it is reducing carbon emission. More specifically, the system GMM results indicate that a unit change in voice and accountability will bring 0.057 unit change in carbon emission in the panel countries. Additionally, the estimated coefficient of the political stability is significant and positive, which shows that there is instability in political system which is harmful for environment and it does not reduce carbon emission in countries.

On the other hand, control of corruption is insignificant which indicates that there is no impact of control of corruption on environment while it's positively significant in difference GMM estimator which means that it increases carbon emission; however, we consider the results of system GMM.

Likewise, the estimated coefficient of government effectiveness is highly significant and negative, which shows that government effectiveness is good in countries and it contributes to environmental quality. For instance, a one-percent increases in government effectiveness increase the quality of environment by 0.170 percent. The estimated coefficient of FDI is negative mostly in all models, which show that FDI reduces carbon emission in the sample countries. Specifically, the result of system GMM shows that if there is a percent increase in the inflow of FDI it will reduce carbon emission by 0.001 percent. Likewise, the estimated coefficient of financial development shows that it positively and significantly increases carbon emission in the sample. For illustration, the results show that if there is a percent increase in financial development it will increase emission by 0.001 percent in the panel countries. In the last, the coefficient of urban population is positively significant in system GMM, which evidences that it increases carbon emission.

4.1.2 Models results of dynamic system generalized method of moments

Table 4 presents the system generalized moment method (GMM) results for all four models of trade openness, renewable energy consumption, nonrenewable energy consumption, innovation and institutional quality. The trade openness coefficients in all models are negative and significant, indicating that trade openness reduces carbon emissions in the panel. The research results show that trade is related to advanced production methods and stimulates the environment. Our research results confirm the existence of the pollution halo effect, in which the knowledge spillover from contact with some industrialized countries enhances the green growth of the host country by eliminating and reducing carbon emissions.

The renewable energy coefficient is also significant and negative in all models, which indicates that the use of renewable energy is beneficial to environmental quality and reduces carbon emissions. The negative effects indicate that there is more conversion from nonrenewable energy to renewable energy consumption. Jebli et al. (2019), Li and Su (2017), Khan et al. (2020a, b) reinforce our findings. Khan et al. (2021) also found the same impact of renewable energy on carbon emissions.

For all empirical models, the estimated coefficient of nonrenewable energy consumption in the system GMM is positive and has statistical significance for environmental quality. The results show that the increase in the use of nonrenewable energy will lead to a decline in the environmental quality of these countries. The current findings are consistent with

Table 3 Model results of trade openness, innovation and institutional quality carbon emission

Model-4				
	(1)	(2)	(3)	(4)
Trade openness	−0.000***	9.130	−0.001***	−0.000***
	(0.000)	(0.000)	(6.080)	(0.000)
RE	−0.030***	−0.026***	−0.019***	−0.030***
	(0.000)	(0.001)	(0.000)	(0.001)
NRE	0.001***	7.960***	8.870***	0.000***
	(5.930)	(7.880)	(4.550)	(2.200)
Innovation	2.570**	7.010***	1.530***	7.280***
	(1.2006)	(1.500)	(1.530)	(1.470)
$(\text{Innovation})^2$	−0.000**	−0.000***	−0.000***	−0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
GDP	−0.001	0.003***	0.004***	0.001***
	(0.003)	(0.001)	(0.001)	(0.000)
$(\text{GDP})^2$	0.000	−0.000***	−0.000***	0.001***
	(0.000)	(0.000)	(2.750)	(6.790)
ROL	−0.032	−0.119***	−0.088***	0.383***
	(0.058)	(0.038)	(0.011)	(0.021)
RQ	0.101**	0.136***	0.198***	−0.080***
	(0.043)	(0.031)	(0.007)	(0.012)
VOA	0.021	0.073**	0.147***	−0.057***
	(0.026)	(0.031)	(0.014)	(0.011)
PS	0.077***	0.003	0.005	0.140***
	(0.020)	(0.016)	(0.007)	(0.007)
COC	0.069	0.028	0.088***	0.000
	(0.045)	(0.029)	(0.008)	(0.011)
GOV	0.003	−0.010	−0.007	−0.170***
	(0.054)	(0.030)	(0.013)	(0.013)
IFDI	−0.001**	7.070	−1.970**	−0.001***
	(0.000)	(0.000)	(8.510)	(4.480)
FD	0.001***	0.001***	0.002***	0.001***
	(0.000)	(0.000)	(0.000)	(7.850)
POP	−0.089***	−0.005	−0.022***	0.091***
	(0.010)	(0.008)	(0.001)	(0.0041)
Constant	1.579***	1.515***		1.686***
	(0.042)	(0.056)		(0.0325)
Observations	1029	1029	901	1029
R-squared	0.906	0.485		
Number of id		105	102	105
AR2			−1.11(0.266)	−1.112(0.265)
Sargan test			648.8(0.000)	3801(0.000)

***, **,*indicates significance level at 1, 5 and 10%, respectively the results of Dogan and Seker (2016) and Liu et al. (2017). However, the results of our research on renewable energy are negative, which shows that more use of renewable energy is beneficial and has no harmful effects on the environment. The study of Bhattacharya et al. (2017) further confirmed these findings.

The estimated innovation coefficients of all models in Table 6 indicate that innovation will increase carbon dioxide emissions, thereby supporting innovation to increase carbon emissions. However, in all estimation techniques, the square of innovation is significantly negative. The results show that innovation has a positive impact on carbon emissions, and when it reaches a certain level, it will reduce carbon emissions.

Likewise, the estimated coefficient of per capita GDP in all models is significant and positive except for models 2 and 4B. The results demonstrate that an increase in economic growth increases carbon emission; however, the square of GDP per capita is significant and negative, indicating that it reduces carbon emission. These results of model 3 and 4A evidence the existence of environmental Kuznets curve in the panel. More specifically, our findings illustrate that the coefficients of GDP are positive mostly in all models, while the square of GDP is significantly high and negative in all models at 1 percent and it confirms the EKC curve. These findings are similar to the findings of Hanif et al. (2019) and Muhammad et al. (2020).

In model 4, we include all six indicators of institutional quality. These variables are voice and accountability, regulatory quality, rule of law, control of corruption, government effectiveness and political stability. These variables represent both legal system and political system of the country. These variables are included in the trade environment relationship to deeply investigate the role of institutions in trade policies while keeping an eye on environmental quality. The results on the impact of institutional quality on environment indicate that two variables of legal system, which are voice and accountability, and regulatory quality, have negative impact on carbon emission. These results indicate that if there is an increase in these two indicators it will enhance environmental quality.

The rule of law increase carbon emission in the panel indicates that the rule of law is weak and it negatively influences environmental quality. Similarly, only government effectiveness indicator in political system negatively affects carbon emission while political stability positive and control of corruption has an insignificant impact on emission. The results are in line with the study of Cansino Muñoz-Repiso et al. (2019b) who have mentioned that most of institutional quality factors reduce pollution. Figure 1 illustrates the impact of institutional quality along other independent variables on carbon emission.

In model 4C, we only use legal system indicators as a robust check where the results are completely the same as in model 4. In model 4B, we only use the political system indicators where these results are also almost the same as model 4 which confirms the robustness of results.

In model 4A, we use all six indicators to construct quality institutional index by using principle components analysis. The result on institutional quality index is highly significant, while the sign is positive which shows that institutional quality index constructed from all six indicators positively affects carbon emission because of poor level of control of corruption, political stability and rule of law in the index indicated by models 4, 4C and 4B. This result concludes that the overall index is positive because some indicators of institutional quality in the index are week and its effect on environmental quality is low.

The estimated coefficient of FDI is negative and significant mostly in all models indicating that FDI inflow reduces carbon emission. Our results show that if there is an increase in the inflow of FDI it will reduce carbon emission in the countries. These results are in line

Table 4 Models results of dynamic system generalized method of moments

	Model-1	Model-2	Model-3	Model-4A	Model-4B	Model-4C	Model-4
Trade openness	−0.000***	−0.000***	−0.002***	−0.001***	−0.000***	−0.000***	−0.000***
	(6.430)	(8.920)	(0.000)	(8.920)	(4.110)	(3.300)	(0.000)
RE	−0.015***	−0.009***	−0.098***	−0.031***	−0.031***	−0.030***	−0.030***
	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.001)
NRE	0.000***	0.000***	0.001***	0.001***	0.0001***	0.000***	0.000***
	(3.550)	(4.320)	(2.070)	(2.190)	(1.120)	(1.450)	(2.200)
Innovation		0.040***	6.640***	1.450*	3.690***	2.500***	7.280***
			(6.610)	(8.220)	(1.360)	(7.470)	(1.470)
$(\text{Innovation})^2$			−4.471***	−0.000*	−0.001***	−0.001***	−0.001***
			(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
GDP	0.062***	0.012***	0.015***	0.009***	0.000***	0.001***	0.001***
	(0.001)	(0.000)	(0.002)	(0.001)	(0.000)	(0.000)	(0.000)
$(\text{GDP})^2$			−0.007***	−0.003***	−0.000***	−0.000***	−0.001***
			(0.000)	(0.000)	(2.800)	(2.080)	(6.790)
Institutional quality				*IQ index*			
				0.083***			
				(0.005)			
ROL						*Legal system*	*Legal system*
						0.252***	0.383***
						(0.008)	(0.021)
RQ						−0.062***	−0.080***
						(0.006)	(0.012)
VOA						−0.041***	−0.057***
						(0.003)	(0.011)
PS					*Political system*		*Political system*
					0.142***		0.140***
					(0.003)		(0.007)

Table 4 (continued)

	Model-1	Model-2	Model-3	Model-4A	Model-4B	Model-4C	Model-4
COC					0.140***		0.000
					(0.004)		(0.011)
GOV					−0.059***		−0.170***
					(0.008)		(0.013)
IFDI	−0.026***	0.000***	−0.027***	0.008***	−0.001***	−0.000***	−0.001***
	(0.001)	(1.260)	(0.008)	(0.001)	(8.230)	(9.950)	(4.480)
FD	0.012	−0.002***	−0.885***	0.176***	0.002***	0.001***	0.001***
	(0.009)	(9.070)	(0.047)	(0.010)	(6.910)	(3.730)	(7.850)
POP	0.056***	0.0481***	0.406***	−0.087***	−0.094***	−0.102***	−0.091***
	(0.002)	(0.004)	(0.015)	(0.005)	(0.001)	(0.001)	(0.0041)
Constant	0.625***	0.270***	7.358***	0.911***	1.628***	1.644***	1.686***
	(0.0342)	(0.0282)	(0.188)	(0.047)	(0.013)	(0.012)	(0.0325)
Observations	1037	966	995	708	966	1029	1029
R-squared		105					
Number of id	136		105	93	105	105	105

***,**,*indicates significance level at 1, 5 and 10%, respectively with the findings of Apergis & Payne, 2010, while contradicting to the study result of Peng et al. (2016); Yang Zhou et al. (2018a, b).

Similarly, the estimated coefficient of financial development is positive and significant mostly in all models except models 2 and 3. The results show that an increase in the level of financial development will increase carbon emission in the panel. Our results are in line with X.-P. Zhang and Cheng (2009) who also found the same result for China where Boutabba (2014) found this result for India. Similarly, Raza and Shah (2018); Diallo and Masih (2017), Jian et al. (2019), Jiang and Ma (2019) have also achieved the same conclusion.

The estimated coefficient of urban population indicates that it increases carbon emission in the panel in first three models of Table 6. People in several countries are moving from agrarian and rural areas to urban areas to search higher standard of living. This movement increases the energy consumption and then it increases carbon emission in cities, which are harmful for environment. In model 4 and submodels, urban population negatively influences carbon emission when including institutional quality indicators.

4.2 Discussions

Several studies in the preceding studies show that trade openness increases carbon emission and degrades the quality of environment, while some researchers argue that trade enhances environmental quality through composition, trade and technique effects. Our findings also indicate that trade openness enhances environmental quality in our sample countries, which shows that there may not be high volume of trade activities using energy from fossil fuels for production and transportation. This result supports pollution halo hypothesis, which shows that trade openness enhances environmental quality through composition, trade and technique effects.

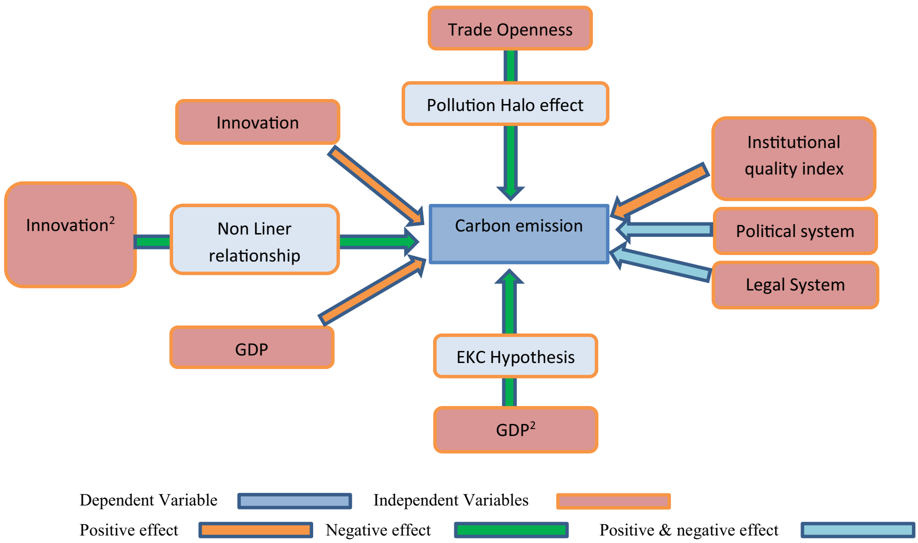

Fig. 1 Determinants of environmental sustainability

Our findings on the impact of nonrenewable energy on environmental quality indicate that there is extensive use of energy to enhance economic growth in a country; however, it badly influences the quality of environment of that country. The pollution in countries is increasing because of the increasing demand of energy for production where energy consumption from nonrenewable sources and it in turn destroys environmental quality. Our findings suggest that fossil fuels energy usage is harmful for environment and its degrading environmental quality and the use of energy from renewable sources are enhancing the quality of environment. Our results are consistent with theories referring that renewable energy is beneficial for environment and its lower carbon emission and nonrenewable energy consumption create pollution and destroy the environment. The use of renewable energy instead of nonrenewable energy gives benefits to the environment in the long run by replacing the energy from dirty and fossil fuels with clean sources of energy and it also helps not to be dependent on oil-exporting countries to import energy. It means that renewable energy can be produced at domestic level, and there will be no need to import energy sources from other countries such as petroleum. On the other hand, renewable energy can be linked to direct sustainable development because accesses to these energy sources are easy and it gives economic benefit, mitigates health and reduces social and environmental problems.

Our research results confirm that the use of renewable energy consumption is beneficial to environmental quality and reduces carbon emissions. The results show that countries that use more of renewable energy are more conducive to controlling environmental degradation and maintaining environmental quality. The negative impact indicates that there is more conversion from nonrenewable energy to renewable energy consumption. The consumption of renewable energy reduces emissions and plays a very important role in improving environmental quality. Therefore, policies related to climate change mitigation in most countries should be broadly focused on converting nonrenewable energy into renewable energy because it is good for the environment. Our results imply that the proportion of renewable energy in various countries/regions is growing, and it has been converted from nonrenewable energy to renewable energy, and people are particularly concerned about this in most countries/regions. We also found that innovation promotes carbon dioxide emissions, but the square of innovation has a significant negative impact on carbon emissions. This means that Innovation can reduce carbon dioxide emissions in the panels.

Our findings indicate that there is a nonlinear relationship between innovation and carbon emissions. The results show that innovation will positively affect carbon emissions, and when carbon reaches a certain level indicated by the innovation square in the model, it will reduce carbon emissions. The results on economic growth and carbon emissions show that an increase in economic growth will increase carbon emissions, but the square of GDP per capita is significant, and a negative sign means it reduces carbon emissions. Our results indicate that there is an EKC curve, indicating that economic growth has increased emissions in the early stages, until it reaches a certain level and then begins to improve environmental quality. If there are policies and regulations on environmental quality, this method can be implemented, and it is possible to achieve it. Over the years, efforts to seek to expand the well-being of the people through development have expanded production, along with large quantities of fossil fuels known for their harmful effects on the environment. National development depends on the progress and sustainability of the country.

The results indicate that there is a non-monotonic inverted U-shaped association between output and environment. When there is an increase in GDP per capita square it lowers the rate of carbon emission, implying that there is an inverted U-shaped association verified as claimed by the hypothesis of environmental Kuznets curve. Our findings confirm that per capita income reduces carbon emission after reaching a certain level of threshold in the long run. Accordingly, the findings suggest that those policies that increase income will also be useful to reduce carbon emission over the time in the panel. It illustrates that economic growth is driven by innovation in energies. Other clean resources for production are also important to enhance green growth and protect environmental quality.

Our findings also indicate that strong level of institutions enhances environmental quality while poor-level institutions are associated with lower quality of environment. The improvement of institutions is needed to enhance environmental quality, which includes the improvement of national laws and regulations as well as establishing the environmental policies. Our findings further suggest that government effectiveness is good enough and protects environmental quality in the panel countries. Better quality of institutions reflects the human life and the rule of law which support freedom to economic and market economies, which in turn enhance the quality of environment. Strong institutions help to implement policies and regulations for energy and encourage the use of renewable energy technologies. Strong institutions also control the level of corruption and strengthen judiciary system. All the institutions together are helpful to bring policy implementation about environmental regulations to protect the quality of environment. Therefore, it is clear that quality institutions have an obvious impact on the policies related to environment and it can help reduce pollution in developing countries and bring improvement in income as well. The quality institutions may also encourage the spillover of technology through the inflow of FDI because quality institutions control other related factors including service quality, civil rights, corruption, politics and accountability and play an important role in enhancing environmental governance to maintain resource utilization. Our findings almost support the theoretical aspects on the role of institutional quality; however, some of institutional factors in our findings are found that these are still weak to protect the harmful impact of factors on environment. The findings regarding FDI and carbon emission suggest that an increase in the inflow of FDI reduces carbon emission. Our findings indicate that the inflow of foreign direct investment transfers green technology, which in turn enhances the quality of environment and the foreign investors' aim is not only profit maximization but focusing to protect environment as well, and it may be subject to several projects of FDI in the countries using renewable energy instead of energy from fossil fuels. The findings illustrate that international investors invest facilitating to invest in clean activities, which are not harmful for environmental quality and help reduce carbon emission.

Our results indicate that such degradation may vary across regions and countries due to the differences in institutions quality. Better governance, stringent regulations and control of corruption are likely to have an improving effect on the quality of environment by eliminating the inflow of FDI in polluting industries and encouraging the development of renewable energy sources as well as the utilization of green technology. Most of our institutional quality variables are negatively significant with carbon emission so that's why FDI also lowers carbon emission as institutions control policies regarding FDI not to invest in polluting industries and utilize green technology. Based on our findings, financial development increases carbon emission. Financial development in some panel countries has been used for capitalization and considered that it is enhancing the growth of small- and medium-level industries. These small and medium enterprises have lower advantages of economies of scale and emission reduction so pollution can be increasing as a result of financial development. It has been suggested that environment-friendly technologies are not the priority for the financial sector for the provision of finance. This can be the reason of increasing pollution. We conclude from our results that financial development dose not lower the rate of pollution while it increases emission.

4.3 Theoretical and practical implications

Our study investigated different factors associated with environmental quality. We found that innovation positively affects carbon emission, while it enhances environmental quality when it reaches a certain level. Innovation is an important factor for environmental quality is it brings new technological innovation and it increases energy efficiency, which is beneficial for environmental quality improvement. Countries should focus to enhance innovation and green technologies, considering that global warming and environmental problems encounter. Our findings indicate that trade openness is negatively associated with carbon emission, which evidences that trade is related to the advance method of production and stimulates environment. Countries should further encourage globalization and trade openness, which can transfer green technology and new knowledge, which are beneficial for environmental quality. Renewable energy consumption reduces carbon emission, while the use of nonrenewable energy degrades environmental quality in our findings. Our results are consistent with theories, referring that renewable energy is beneficial for environment and nonrenewable energy consumption creates pollution and destroys the environment. Therefore, the policies related to climate change alleviation in most countries should widely concentrate to convert nonrenewable energy to renewable energy since it is environmentally favorable. Financial development in panel countries is still weak to provide funding to environment-friendly projects; however, financial development should give special focus to facilitate green projects in countries and provide incentives for the improvement of environmental quality. Financial institutions and banks should engage in those activities and projects, which recognize the importance of environmental problems.

Our results illustrate that financial development is positively associated with carbon emission; however, financial institutions can play an important role in establishing policies regarding environmental quality. The results on the impact of institutional quality on environment indicate that strong institutions boost environmental performance, while weak institutions are associated with environmental harm. The improvement of national laws and regulations are important to enhance environmental quality. The quality institutions may also encourage the spillover of technology through the inflow of FDI because quality institutions control other related factors including service quality, civil rights, corruption, politics and accountability and play an important role in enhancing environmental governance to maintain resource utilization. Our findings almost support the theoretical aspects on the role of institutional quality; however, some of institutional factors in our findings are found that these are still weak to protect the harmful impact of factors on environment. We suggest countries that strengthening institutions are the most important factors that enhance environmental quality because institutions quality is also associated with other factors such as foreign direct investment, energy usage and financial development. The findings suggest the panel countries to focus on institutional quality factors as these factors are important in safeguarding environmental quality. Our findings in this study are important for the countries to concentrate on these factors to achieve higher level of environmental quality as well as to enhance economic growth.

5 Conclusion

This study examines the impact of innovation, trade openness and quality institutions along other explanatory variables on environmental quality. The study uses data for 176 countries for the period of 2000 to 2019. By using OLS regression, fixed-effect estimator and GMM models, we found that openness to trade reduces carbon emission in the sample countries. Our findings indicate that the openness to trade in the countries is associated with advance method of production, which safeguards environmental quality. Our findings confirm the existence of pollution halo effect where the spillover of knowledge from engaging with some industrialized countries strengthen green growth in the host economies by eliminating and reducing carbon emission. We also found that the use of renewable energy reduces carbon emission and it is beneficial for environmental quality. However, we found that nonrenewable energy from fossil fuels increases emission and degrades environmental quality.

The pollution in countries is increasing because of the increasing demand for energy for production where energy consumes from nonrenewable sources and in turn destroy the environmental quality. We conclude that countries are trying to convert from the use of nonrenewable energy consumption to renewable energy consumption, which can protect environmental quality, and it will also minimize the dependency on other countries on importing nonrenewable energy sources. The impact of innovation is positive while the innovation square has negative impact on carbon emission indicating that innovation square lessens CO2 emissions in the panel. The results show that innovation positively affects carbon emission, while it reduces carbon emission when it reaches to a certain level indicated by innovation square in the model. The results of GDP per capita show positive impact on carbon emission; however, the square of GDP per capita is significant and negative, indicating that it reduces carbon emission. Our findings confirm the EKC.

The results of FDI show that it affects carbon emission negatively. Financial development also positively affects carbon emission, which means that countries need to strengthen financial institutions regarding environment to provide funding for green technologies and environment-friendly projects; however, the results indicate that the financial institutions of countries in the panel are still weak to provide such funding to environment-friendly projects where FDI negatively affects carbon emission in the panel. Most of intuitional indicators negatively affect carbon emission; however, there are still some factors, which are positively associated with carbon emission. Our findings give recommendation to the panel countries to focus on the improvement of institutions such as rule of law, control of corruption and political instability to achieve higher level of environmental quality. The study also indicates that improvement in innovation is also important as innovation enhances energy efficiency which is beneficial for the quality of environment. The study also suggests the improvement of renewable energy consumption and lowering the use of energy from fissile fuels to enhance environmental quality.

Our study is limited to the sample countries and methods used. Future studies can be conducted by using different samples and techniques as well new determinants to more efficiently investigate this association. Our study analyzed the environmental Kuznets curve and pollution halo Halo hypothesis; future studies may also focus to test financial Kuznets curve in such kind of association. We use single indicators of institutions quality as well institutions quality index constructed of six indicators and found its role in carbon emission mitigation; however, there may exist interaction term of institutions quality with other factors such as economic growth, foreign direct investment and financial development. Future studies may include the moderating role of institutions quality on carbon emission through these factors. Our sample analysis are conducted for global panel; future studies can be conducted for developing and developed countries to differentiate the impact of these factors on carbon emission as the quality of institutions and other factors may not be the same in different sample of countries.

Appendix 1

See Table 5

Table 5 Descriptive statistics

Variable	Mean	Std. dev	Min	Max
CO2	4.848	6.334	0.017	63.82
TO	89.038	51.410	0.167	437.32
RE	31.729	30.236	0.000	98.27
NRE	2455.00	2831.83	9.548	22,120.4
INV	6603.46	27,493.51	1.000	31,305
GDP	2.419	5.121	−62.37	121.78
ROL	.0016	1.005	−2.60	2.100
RQ	−0.0026	0.992	−2.64	2.260
VOA	−0.026	1.011	−2.31	1.800
PS	−0.036	1.011	−3.314	1.965
COC	−0.008	1.018	−1.868	2.469
GOV	0.008	0.993	−2.44	2.436
FDI	8.200	56.181	−1268.17	1282.63
FD	53.161	45.005	0.186	308.97
POP	2.068	1.964	−6.514	17.762

Appendix 2

See Table 6

Table 6 Correlation matrix

	ED	TO	RE	NRE	INV	GDP	ROL	RQ	VOA	PS	COC	GOV	FDI	FD	POP
ED	1.000														
TO	0.259	1.000													
RE	−0.507	−0.259	1.000												
NRE	0.781	0.237	−0.198	1.000											
INV	0.296	−0.181	−0.143	0.204	1.000										
GDP	−0.187	0.026	0.119	−0.198	0.029	1.000									
ROL	0.566	0.294	−0.271	0.630	0.148	−0.245	1.000								
RQ	0.557	0.331	−0.302	0.579	0.127	−0.228	0.936	1.000							
VOA	0.330	0.109	−0.119	0.413	0.062	−0.230	0.818	0.825	1.000						
PS	0.469	0.394	−0.216	0.537	0.042	−0.145	0.778	0.739	0.692	1.000					
COC	0.552	0.279	−0.236	0.643	0.124	−0.229	0.965	0.909	0.793	0.761	1.000				
GOV	0.574	0.314	−0.321	0.634	0.162	−0.239	0.962	0.938	0.785	0.743	0.953	1.000			
FDI	0.047	0.286	−0.092	0.020	−0.050	−0.038	0.133	0.128	0.111	0.141	0.108	0.117	1.000		
FD	0.403	0.120	−0.257	0.454	0.358	−0.249	0.703	0.649	0.521	0.484	0.679	0.713	0.177	−0.1703	
POP	−0.185	−0.042	0.327	−0.19	−0.009	0.0379	−0.362	−0.417	−0.483	−0.383	−0.332	−0.35	−0.039	1.000	1.000

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Code availability Stata version 15 has been used.

Data availability Data used in this paper is available on world bank world development and world governance indicators. https://databank.worldbank.org/source/world-development-indicators, https://databank.worldbank.org/source/worldwide-governance-indicators.

Declaration

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