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Moderation of competitiveness in determining environmental sustainability: economic growth and transport sector carbon emissions in global perspective

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Abstract
The rising GHG emissions and climate change have resulted in number of catastrophes such as floods, droughts and heat waves. Accordingly, researchers are interested in exploring the nexus between GHG emissions and economic growth. This research study is motivated to explore the moderation of transportation competitiveness for economic growth and carbon emissions of transport sector in global perspective. The annual time series data for study variables are used for time period from 2008 to 2018 for 121 countries. The panel quantile regression (PQR) estimation technique is used for analysis of results. The study results validated inverted U-shaped environmental Kuznets curve (EKC) for quantile group-1 and 2, while U-shaped EKC was validated for quantile group-3 and 4. The moderation of transport competitiveness significantly tends to achieve environmental sustainability for economic growth and carbon emissions of transport sector for quantile group-1 and 2. However, the moderation of transport competitiveness increases carbon emissions of transport sector in quantile group-4. The study results implicated that process of economic growth resulted in expansion of transport sector in quantile group-3 and 4 beyond sustainable level. The various policy recommendations are advocated to improve the quality of transport sector to mitigate carbon emissions.

Keywords Panel Quantile Regression · Environmental Kuznets Curve (EKC) · Climate Change · Global Warming · Institutional Quality

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1 Introduction

The global warming is increasingly discussed subject for last two decades as its adverse impacts on environment are very significant (Cakar et al., 2021; Yang et al., 2021; Fang et al., 2022). The different studies of Intergovernmental Panel on Climate Change (IPCC) indicates that GHG emissions are responsible for global warming (Liu et al., 2021; Alataş 2021; Zhao et al., 2022). Among these GHG emissions, the share of carbon emissions is largest which significantly contributes in global warming (Chatti, 2021; Wen & Wang, 2022; Yang et al., 2021). The transport sector provides logistic services for mobility of goods which facilitates the process of international trade and economic growth (Fang et al., 2022; Huang et al., 2021; Sohail et al., 2021b). The transport sector mostly uses fossil fuels which creates carbon emissions, and the share of transport sector in total carbon emissions is above twenty percent (Sohail et al., 2021b; Wang & Wang, 2021; Zhao et al., 2022). The rising usage of fossil fuels by transport sector and continuously increasing carbon emissions of this sector is creating sustainability issues (Robaina & Neves, 2021; Cakar et al., 2021; Sohail et al., 2022a; Liu et al., 2022a). The global motivation and collective efforts of world community are prerequisites for managing the carbon emissions of transport sector (Liu et al., 2022a; Paris et al., 2021; Sohail et al., 2022a; Zhao et al., 2022).

The mitigation management of carbon emissions requires multiple strategies, and the macroeconomic policy direction is very important to promote the use of renewable energy consumption in different sectors of economy including transport sector. The stabilized monetary/fiscal policy and political stability promotes usage of clean energy consumption which mitigates carbon emissions (Sohail et al., 2021c; Jian et al., 2021; Sohail et al., 2021d). The literature also indicates that rising poverty is linked with environmental pollution as inclusive growth can combat poverty and promotes better environmental sustainability (Jiang et al., 2021; Zhang et al., 2022). Studies also registered that financial expansion and its inclusion in formal economic system along with increasing literacy rate are helpful in using renewable energy in transport sector to mitigate carbon emissions (Liu et al., 2022b; Shahbaz et al., 2022; Sohail et al., 2021a). It is also found that the positive economic stimulate also reduces carbon emissions (Lan et al., 2022; Sohail et al., 2022b). The research studies also highlighted the concept of embodied carbon emissions as repercussion of international trade (Kongkuah et al., 2022; Sun et al., 2022; Xu & Yao, 2022). The climate adaptive policies are highly important for agricultural, industrial and transport sector sustainability (Cai et al., 2022; Sohail et al., 2022b). The energy shocks are observed to impact carbon emissions as negative energy shock reduces energy-based carbon emissions (Ansari et al., 2022; Hafeez et al., 2022).

The share of energy used in total transport sector was around 23 percent of total energy consumption in 1973 and it has increased to 29 percent in 2017. Furthermore, the share of oil in total energy used in transport sector is around 93 percent (Mahfooz et al., 2019; Sohail et al., 2021a; Wen & Wang, 2022). The extensive usage of fossil fuels in transport sector increases carbon emissions and further aggravates challenges of climate change (Chen et al., 2022; Mahfooz et al., 2019; Sohail et al., 2021a). The role of transport sector is also observed in shadow economy as shadow economy is observed in raising environmental pollution (Amin et al., 2022; Ma et al., 2022; Sohail et al., 2021b). The noneconomic factors such as global socialization, literacy and implementation of environmental laws are also critical factors in determining the environmental pollution as proper implementation of policies can mitigate transport sector carbon emissions (Jian et al., 2021; Lan et al., 2022; Sohail et al., 2021a). In this regard, the role of using renewable/clean energy in transport sector is highly important to mitigate carbon emissions (Liu et al., 2022a; Sohail et al., 2021b, 2022a).

The global economic growth increases the expansion of allied sectors and promotes tourism (Irshad & Ghafoor, 2022; Yang et al., 2021). The expansion of all sectors of economy requires logistic services for mobility as rail, road, marine and aviation transportation services facilitate the delivery of goods and mobility of people on long-distance routes (Du et al., 2022; Liu et al., 2021). Furthermore, over the time, expansion of international trade led by globalization have necessitated the usage of different modes of transportation services (Chatti, 2021; Law et al., 2022). The population expansion and rapid urbanization have also increased the role of transport sector (Cakar et al., 2021; Huang et al., 2021; Yang & Khan, 2022). Consequently, the expansion of economic activity resulted in increased usage of fossil fuels in transport sector which further increased the volume of carbon emissions (Jiang et al., 2022; Robaina & Neves, 2021). Keeping in view the importance of transportation sector, it is highly important that carbon emissions of transportation sector must remain within the sustainable limits (Fang et al., 2022; Habib et al., 2022; Paris et al., 2021).

Different countries during the Conference of Parties, 26 (Cop, 26) held in Glasgow, UK, in 2021 reiterated the commitments for production of electric vehicles, promotion of green technologies and usage of renewable fuel for transport sector ((Liu et al., 2021; Zhao et al., 2022). The rapidly increasing share of carbon emissions of transportation sector which is presently above 20 percent of the total emissions is creating serious environmental concerns (Chatti, 2021; Zhao et al., 2022). It is highly important to manage the transportation sector on sustainable basis for mitigating carbon emissions of transport sector (Cakar et al., 2021; Chong et al., 2022). The motivation and implementation of holistic approach/policies toward environmental protection can be fruitful in mitigating carbon emissions of transportation sector (Robaina & Neves, 2021; Li & Luo, 2022). Different types of index related to transport sector and logistic services are recorded by various agencies to assess the performance/sustainability of transportation sector. The WEF records the transport competitiveness data on annual basis since 2008 by executing the perception survey for member countries. The transport competitiveness index is based on different indicators which measures the expansion and quality of various sources of transportation such as road, rail, port and air. The expansion/extensiveness of transportation sector is based on availability and increase in number of different modes of transportation. However, the quality of transport sector represents efficiency of different modes of transportation (GCI, 2022). The aim of this research study is to engage transportation competitiveness for determining the carbon emissions of transportation sector.

The Sustainable Development Goals (SDGs) emphasize for clean energy consumption and environmental protection (Adebayo et al., 2022; Khurshid et al., 2022; Udemba et al., 2022). To cope with SDGs environment-specific goals, the role of innovations is very important to mitigate carbon emissions (Amin et al., 2022; Dong et al., 2022; Wang et al., 2022). The increasing volume of carbon emissions have resulted in global warming and climate change (Khan et al., 2022; Sarfraz et al., 2022; Wang & Dong, 2022). The global warming has increased the occurrence of severe heat waves, floods and droughts (Dong et al., 2022; Khurshid et al., 2022; Udemba et al., 2022). Accordingly, the goal of this research study is to analyze the carbon emissions of transport sector for sustainability purpose. As discussed earlier, transport sector uses major portion of fossil fuel and emits almost quarter of total carbon emissions. Therefore, the goal of the research study is to assess the role of transport competitiveness, economic growth, population expansion and institutional quality in determining the carbon emissions of transport sector. The goals of the research study are in line with previous researches (Arshed et al., 2022; Sardar and Rehman, 2022).

This research work contributes to existing stock of knowledge in multiple ways. The sustainability of transport sector carbon emissions is analyzed in global perspective by collecting data for more than 120 countries. The research study analyzed the role of transport competitiveness to determine carbon emissions of transport sector during process of economic growth. The study has used four dynamic panels on the basis of carbon emissions of transport sector to analyze the study results. The extended STIRPAT model is used for theoretical foundations of the research study. The robust approach of panel quantile regression (PQR) is used for estimation of results. The PQR is appropriate estimation technique for non-normal data series as it uses median as measure of central tendency. In each of the quantile groups, the environmental Kuznets curve (EKC) is validated for sustainability analysis. Furthermore, moderation analysis is performed to ascertain changes in direction of the slope of EKC. The policy implications are advocated on the basis of the analyzed results.

Keeping in view the research gap and possible contribution of the research study, three distinct objectives are narrated for this research study.

1. To assess the role of transport competitiveness in determining the carbon emissions of transportation sector.
2. To validate EKC hypothesis based on economic growth and carbon emissions of transportation sector.
3. To assess the moderation of transport competitiveness for change in direction of the slope of EKC curve and its relative flattening/steepening.

The sequence of the rest of the research paper is as follows: The literature review is discussed in second section, while the theoretical foundations of the research study are presented in third section of the research paper. The methodology of the research study is highlighted in fourth section, while the results and discussion are presented in fifth section of the research paper. The conclusions and policy implications based on analyzed results are discussed in last section of the research paper.

2 Literature review

Effective literature review is highly important to identify the research gap and contribution of the research study (Sohail et al., 2022a; Sardar & Rehman, 2022). In this regard, the literature review section includes relevant studies regarding EKC and STIRPAT variables. Furthermore, the relevant studies of different moderators used for carbon emissions are included in the literature review (Arshed et al., 2022; Sohail et al., 2022b; Sardar and Rehman 2022). The theory of EKC was initially advocated to explain the relationship between economic growth and income inequality (Kuznets, 1955). Subsequently, EKC was used in field of environment to explain the behavior of economic growth and environmental pollution (Grossman and Krueger 1991; Selden & Song, 1994; Stern et al., 1996). Theory of EKC is frequently used for analyzing the nexus between environmental sustainability and economic growth (Zhang, 2019; Jin & Kim, 2020; Cheikh et al., 2021; Sohail et al., 2021a; Sohail et al., 2022a; Sardar and Rehman, 2022). The U-shaped EKC relationship indicates that initially the progress of economic growth increases environmental pollution, while in the later stage the expansion of economic growth mitigates environmental pollution due to usage of renewable energy and technological development (Arshed et al., 2022; Aydoğan & Vardar, 2020; Cheikh et al., 2021; Sohail et al., 2022a). The inverted U-shaped EKC is tested by large number of researchers by using time series and panel data (Xie et al., 2019; Isik et al., 2019; Aydoğan & Vardar, 2020; Cheikh et al., 2021; Liu & Lai, 2021; Sardar and Rehman 2022). The U-shaped EKC was also validated by several researchers for different groups of countries (Zhang, 2019; Jin & Kim, 2020; Dogan & Inglesi-Lotz, 2020; Wang et al., 2021; Sardar and Rehman 2022).

The STIRPAT model is used by researchers to investigate the impact of different variables on environmental pollution (Sohail et al., 2021a; Sohail et al., 2022a; Sardar and Rehman, 2022). The carbon emissions are frequently used as dependent variable to measure the environmental pollution (Sohail et al., 2021a; Sardar and Rehman, 2022). In the literature, number of researchers have used carbon emissions to assess the environmental degradation (Azizalrahman, 2019; Amin et al., 2020: Cheikh et al., 2021; Sohail et al., 2021a; Sardar and Rehman, 2022). In STIRPAT model, population is considered as the most important variable as all economic activities are meant for improving the living standards of people (Sohail et al., 2021a; Sardar and Rehman, 2022). In the literature, it has been observed that rising population has adverse impact on environment as it requires more housing, educational, health and transportation facilities (Xie et al., 2019; Isik et al., 2019; Dogan & Inglesi-Lotz, 2020; Wu et al., 2021; Sardar and Rehman, 2022). However, planned expansion of population results in sustainability as it mitigates carbon emissions (Rauf et al., 2018; Katircioglu et al., 2018; Dogan et al., 2020; Sardar and Rehman 2022). The economic growth is used by large number of researchers in STIRPAT model (Dogan & Inglesi-Lotz, 2020; Huangfu et al., 2020; Isik et al., 2019; Sohail et al., 2021a; Wu et al., 2021). The implementation of effective policy regarding environmental protection is highly important (Arshed et al., 2022; Sohail et al., 2021c, 2022a). In this regard, the quality of institutions is highly important and the literature indicates that better institutional quality tends to mitigate carbon emissions (Zakaria & Bibi, 2019; Shah et al., 2020; Shah et al. 2020; Khan et al., 2021; Sardar and Rehman, 2022). Furthermore, weak institutional quality having poor governance confines proper implementation of environmental policies and this increases environmental pollution (Andersson, 2018; Acheampong et al., 2019; Sheraz et al., 2021a; Habiba et al., 2021; Sardar and Rehman, 2022).

In the literature, a number of studies are found which indicate that the expansion of transportation sector increases usage of fossil fuels which emits carbon emissions and creates environmental pollution (Xu & Lin, 2018; Solaymani, 2019; Amin et al., 2020; Godil et al., 2021b; Sohail et al., 2021a; Sardar and Rehman, 2022). In this regard, the role of transportation competitiveness is highly important to envisage its moderation impact in determining the carbon emissions. The literature also indicates that moderation of different variables is engaged by researchers to determine the changes in carbon emissions (Sharma et al., 2021; Arshed et al., 2022; Sardar and Rehman, 2022). The moderator is considered as third variable, which explain the changes in slope of independent and dependent variable (Kirikkaleli & Kalmaz, 2020; Rjoub et al., 2021; Liobikienė & Butkus, 2021; Sardar and Rehman, 2022). In this regard, researchers have used energy consumption, R&D and renewable energy as moderator to explain the changes in carbon emissions (Ehigiamusoe et al., 2020; Katircioğlu & Taşpinar, 2017; Naz et al., 2019; Qi et al., 2019; Sharma et al., 2021; Sheraz et al., 2022). Furthermore, the role of financial development and urbanization was also used as moderator in the literature to identify changes in environmental pollution (Feng & Wu, 2022; Gill et al., 2019; Kirikkaleli & Kalmaz, 2020; Rjoub et al., 2021; Uddin, 2020). In the literature, researchers have also used moderation of natural resource dependence, globalization and technological development as moderator to envisage variations in carbon emissions (Badeeb et al., 2020; Liobikienė & Butkus, 2021; Sheraz et al., 2021b, 2022).

The literature indicates that different variables are used to explain variations in environmental pollution. Furthermore, the literature also envisaged that EKC hypothesis is validated for different data sets used for different panels of countries. The moderation is very important aspect to explain changes in the behavior of independent and dependent variables. The synthesis of the literature review indicates that the research gap and contribution of the research study are evident as the role of transportation competitiveness is not engaged as moderator to explain the carbon emissions of transportation sector with GDP. Consequently, the first objective of the research study is to envisage the role of transportation competitiveness in determining the carbon emissions using EKC and STIRPAT framework. Secondly, the research study engages the linear and nonlinear terms of economic growth for carbon emissions of transportation sector to validate EKC hypothesis. Thirdly, the moderation role of transportation competitiveness is engaged to assess the changes in turning point and slope of the EKC for sensitivity analysis. Thus, the contribution of this research study is multi prong as it engages the nonlinearity of economic growth and interaction terms of transportation competitiveness and economic growth to assess the changes in behavior of EKC. Furthermore, this research study also contributes in research methodology as it uses two types of moderation to ascertain the impact of transportation competitiveness on carbon emissions of transportation sector.

3 Theoretical framework

To achieve the objectives of the research study, theoretical foundations of research study are very important. Accordingly, in this research study the famous environmental theories of EKC and STIRPAT are used. The EKC theory was first advocated by Simon Kuznets in 1955 to explain variations in income inequality and economic growth (Kuznets, 1955). Later, Grossman and Krueger (1991) used this theory to identify the relationship between economic growth and environmental pollution. Subsequently, many researchers have used this theory to validate EKC hypothesis for different data series of different countries. Generally, two main shapes of this theory are found in the literature, i.e., U-shaped EKC and inverted U-shaped EKC (Zhang, 2019; Jin & Kim, 2020; Dogan & Inglesi-Lotz, 2020; Wang et al., 2021; Sardar and Rehman, 2022).

The inverted U-shaped EKC have two stages and in first stage the positive relationship exists between economic growth and carbon emissions of transportation sector. This positive relationship indicates environmental pollution increases with economic growth. This represents that whole attention is devoted toward production side, while due care is not given to protect the environment from carbon emissions of transport sector. This creates sustainability issues and subsequently, in second stage the negative relationship between economic growth and environmental pollution indicates that increase in economic growth mitigates environmental pollution. The second stage indicates that the process of economic growth which includes the industrial and agricultural production has improved and the efficient use of transport sector have mitigated carbon emissions. Furthermore, the inventions and innovations are providing environment friendly solutions to the production and transportation services which were previously based on environmental degradation practices.

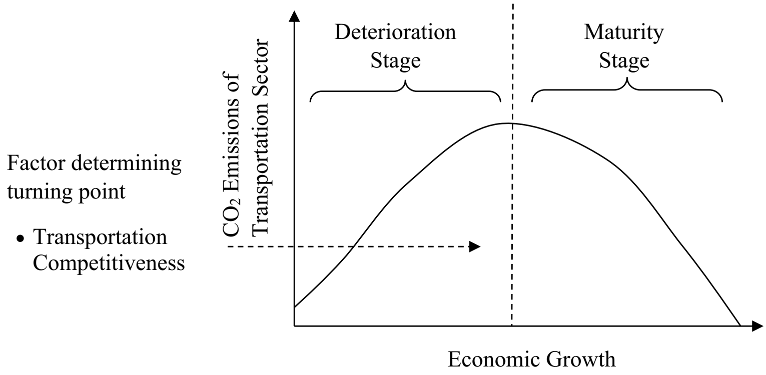

Fig. 1 Theoretical foundations of environmental theory (Inverted U Shape EKC)

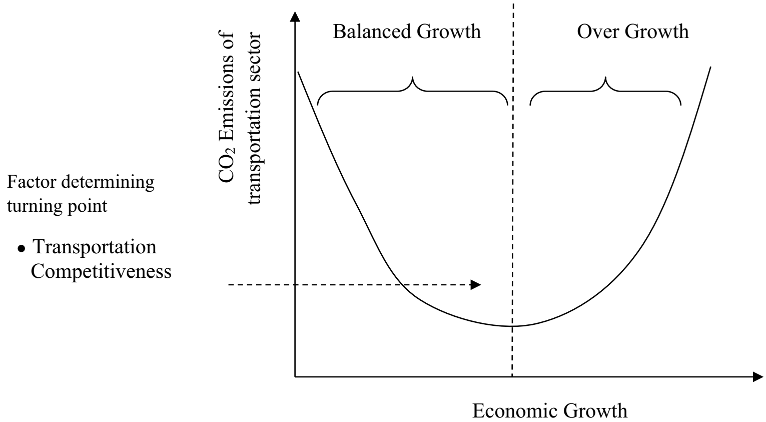

Fig. 2 Theoretical foundations of environmental theory (U Shape EKC)

The second possibility of EKC is U shape for economic growth and environmental pollution caused by transportation sector. In this possibility, the first stage represents the negative relationship between economic growth and carbon emissions of transportation sector. This indicates the balanced growth stage as the progress of economic growth has the tendency to mitigate carbon emissions. This also refers the possibilities of using environment friendly practices in production and transportation sector. However, the second stage indicates the direct relationship between economic growth and environmental pollution caused by transportation sector. This indicates that the process of economic growth is creating environmental pollution. This stage of economic growth and environmental pollution ushers the need of such policies that could retain the sustainability of environment. In this regard, the usage of innovation and inventions for transportation sector is necessitated. The above two possibilities of theoretical framework are highlighted in Fig. 1 and 2.

Accordingly, in this research study, these above narrated possibilities are competing for validation. Furthermore, the role of transportation competitiveness is also engaged for sensitivity analysis. The moderation of transportation competitiveness is engaged to envisage the behavior/slope of EKC changes. In this regard, two types of moderation are included in research model by multiplying linear and nonlinear terms of economic growth with transportation competitiveness. Accordingly, the first type of moderation of transportation competitiveness for EKC indicates that how turning point of EKC changes, while the second type of moderation indicates the sensitivity of EKC measured by flattening or steepening of EKC. These environmental theories are in line with theoretical foundations of previous research conducted by different researchers (Arshed et al., 2019; Arshed et al., 2021a, Arshed et al., 2021b; Wang et al., 2021; Sardar and Rehman, 2022).

4 Research methodology

The proper research methodology is highly necessary to analyze the study results. In this regard, a panel data of 121 countries is considered for time period from 2008 to 2018. The data period is confined for eleven years as the data of transportation competitiveness are recorded by World Economic Forum (WEF) since 2008. The WEF records the transport competitiveness data on annual basis since 2008 by executing the perception survey for member countries. The transport competitiveness index is based on different indicators which measures the expansion and quality of various sources of transportation such as road, rail, port and air. The expansion/extensiveness of transportation sector is based on availability and increase in number of different modes of transportation. However, the quality of transport sector represents efficiency of different modes of transportation (GCI, 2022). Furthermore, four quantile groups are created while considering the carbon emissions of transportation sector. These groups are regarded as low-CO_2, low–medium-CO_2, high–medium-CO_2 and high-CO_2 group. These groups are based on actual value of each year hence countries are expected to jump groups if they show considerable improvement over time. The study variables are given in Table 1.

On the basis of the above variables, the study model is derived. The basic foundation of the study model is based on IPAT identity which is used to derive the extended STIRPAT model.

$$I_i = a P_i^b A_i^c T_i^d e_i \tag{1}$$

In this IPAT model, "I_i" shows the environment impact, "P_i" represents population size, "A_i" denotes affluence and "T_i" denotes the technology. By using natural log, the STIRPAT model's standard form is derived as under:

Table 1 Study variables

Short form of variables	Variables description	Source of data
CO_2	Log of transportation sector CO_2 emissions (Mt/Capita)	EDGAR (2022)
GDPPC	Log of GDP per capita	WDI (2022)
$GDPPC^2$	Log of the square of GDP per capita	WDI (2022)
PDEN	Log of population density	WDI (2022)
TC	Transportation competitiveness index	GCI (2022)
INST	Institutional quality index	ICRG (2022)

$$\ln I_{it} = a + b\left(\ln P_{it}\right) + c\left(\ln A_{it}\right) + d\left(\ln T_{it}\right) + \ln e_i \tag{2}$$

On the basis of the general STIRPAT model, additional variables can be added to develop extended STIRPAT model (Lv et al., 2019; Xu et al., 2020; Arshed et al., 2021a; Wu et al., 2021; Sohail et al., 2021a; Sardar and Rehman, 2022). Keeping in view of the above, following extended STIRPAT model is used for this research study:

$$\begin{aligned} CO_{2it} = {} & \beta_1 + \beta_2 GDPPC_{it} + \beta_3 GDPPC_{it}^2 + \beta_4 GDPPC_{it} * TC_{it} \\ & + \beta_5 GDPPC_{it}^2 * TC_{it} + \beta_6 TC_{it} + \beta_7 PDEN_{it} + \beta_7 INST_{it} + \mu_{it} \end{aligned} \tag{3}$$

To empirically validate EKC for economic growth and carbon emissions of transportation sector, the nonlinear terms of GDP are used (Wang et al., 2021; Sohail et al., 2021a; Sardar & Rehman, 2022). In this research, paper moderation of transport competitiveness is included to assess changes in behavior of economic growth and carbon emissions of transport sector. In moderation analysis, a turning point shift occurs, when the moderator, i.e., transport competitiveness effects the latent mechanisms in such a way that the turning point of the observed relationship changes location though the shape of the curve may not change (Lind & Mehlum, 2010; Haans et al., 2016; Badeeb et al., 2020; Arshed et al., 2022; Sardar and Rehman, 2022). For derivation of moderation term regarding changes in turning point of EKC, we suppose that.

$CO_{2it} = Y$.

$GDPPC_{it} = X$.

$GDPPC_{it}^2 = X.^2$

$TC_{it} = Z$.

$PDEN_{it} = W$.

$INST_{it} = V$.

By putting the values in Eq. 3 (Haans et al., 2016),

$$Y = \beta_1 + \beta_2 X + \beta_3 X^2 + \beta_4 XZ + \beta_5 X^2 Z + \beta_6 Z + \beta_7 W + \beta_8 V + \mu_{it} \tag{4}$$

The first-order condition by using partial derivative with respect to X is

$$\delta Y / \delta X = \beta_2 + 2\beta_3 X + \beta_4 Z + 2\beta_5 XZ = 0 \tag{5}$$

Now solving for X

$$X *= (-\beta_2 - \beta_4 Z) / (2\beta_3 + 2\beta_5 Z) \tag{6}$$

Now taking derivative of Eq. 4 with respect to Z yields that how turning point changes as Z changes

$$\delta X^* / \delta Z = (\beta_2\beta_5 - \beta_3\beta_4) / (\beta_3 + \beta_5 Z)^2 \tag{7}$$

Equation-8 indicates that denominator is exactly greater than zero; thus, the direction of shift depends on sign of numerator term. This indicates that if the numerator term is positive the turning point will move toward right side as moderator (Transport Competitiveness) increases. Furthermore, negative sign of numerator term will indicate the shifting of turning point toward left side as moderator (transport competitiveness) increases. It is imperative to note that direction of shift depends not only on β_4, but also on β_2, β_3 and β_5 (Badeeb et al., 2020; Arshed et al., 2021b; Arshed et al., 2022; Sardar and Rehman, 2022). To validate moderation of transportation competitiveness for changes in turning point of EKC, the Dawson methodology is engaged to draw graphs. In this regard, regression coefficients of economic growth, square of services of economic growth and interaction terms are used (Dawson, 2014; Arshed et al., 2021b; Sardar and Rehman, 2022). The graph shows the moment of economic growth at low and high levels of transport competitiveness and indicates the changes in curvilinear behavior of economic growth for different levels of moderator (Arshed et al., 2021b; Arshed et al., 2022; Sardar and Rehman, 2022).

A flattening or steepening occurs when the moderator affects the latent mechanisms in such a way that the shape of the observed relationship changes, though the turning point of the relationship need not change (Haans et al., 2016). Furthermore, flattening/steepening of EKC represents the sensitivity of behavior between economic growth and carbon emissions of transport sector (Sardar and Rehman, 2022; Arshed et al., 2022). The flattening of EKC further implicates that the increase in economic growth creates lesser carbon emissions and ensures environmental sustainability (Sardar and Rehman, 2022). The testing for flattening/steepening is based on equations 3 and 5, and in such models, having nonlinear moderation variable for flattening/steepening depends on β_5 (Haans et al., 2016; Sardar and Rehman, 2022). Thus, testing of flattening/steepening in such models is equivalent to testing the significance of β_5 (Haans et al., 2016; Badeeb et al., 2020; Arshed et al., 2022; Sardar and Rehman, 2022). In case of inverted U-shaped EKC, flattening of EKC is validated if β_5 is positive and significant. Furthermore, in case of inverted U-shaped relationship, steepening of EKC is validated if β_5 is negative and significant. However, in case of U-shaped EKC, when β_5 is positive and significant then steepening is validated (Haans et al., 2016). Furthermore, in case of U-shaped relationship, if β_5 is negative and significant then flattening is validated (Haans et al., 2016; Sardar and Rehman, 2022).

The conventional regression analysis may lead to over or under estimation of study coefficients for non-normal data distributions (Binder & Coad, 2011; Powell, 2020; Chowdhury et al., 2021; Sardar and Rehman, 2022). However, the panel quantile regression (PQR) model is suitable estimation technique for analysis of non-normal data series and produces robust results (Powell, 2014; Machado & Silva, 2019; Khan et al., 2020; Sardar and Rehman, 2022). The PQR was first presented by Koenker and Bassett (1978) in their seminal paper, and later on, several researchers have used this estimation technique (Machado & Silva, 2019; Zheng et al., 2019; Powell, 2020; Godil et al., 2021a; Sardar and Rehman, 2022). Furthermore, PQR uses median as measure of average which is not affected by extreme values and serves as appropriate measure of central tendency for non-normal data series (Baker, 2016; Mensi et al., 2019; Bilgili et al., 2021; Sardar and Rehman, 2022). Thus, PQR approach is superior in the sense that it provides more elaborative analysis among the quantiles to envisage the causals of transportation infrastructure and environmental degradations (Powell, 2015; Powell, 2020; Godil et al., 2021a; Sardar and Rehman, 2022; Akram et al. 2021). Keeping in view the suitability of PQR model, a large number of researchers have used this estimation technique while analyzing different causals of environmental pollution for different data sets (Bilgili et al., 2021; Usman & Jahanger, 2021; Gyamfi et al., 2022; Wei & Ullah, 2022; Sardar and Rehman, 2022; Akram et al. 2021; Xie et al., 2022).

5 Results and discussions

The descriptive statistics of the variables considered for the model are computed to ascertain the basic information of the data. In this regard, different parameters regarding measures of central tendency and dispersion are calculated. These includes mean, median,

Table 2 Descriptive statistics

Stats	CO_2	GDPPC	TC	INST	PDEN
N	1331	1331	1282	1282	1331
Mean	2.0040	9.5118	4.2214	4.1299	4.3050
Median (P_{50})	1.8780	9.6437	4.2217	3.9227	4.4557
SD	1.8978	1.1662	1.2030	0.8904	1.4328
IQR	2.4183	1.8659	1.8283	1.3881	1.7611
Range	10.2119	5.0050	5.2558	3.7275	8.4541
P_{25}	0.7798	8.6237	3.2911	3.4180	3.4813
P_{75}	3.1982	10.4896	5.1194	4.8062	5.2425
Skewness	0.1539	−0.4487	0.0868	0.5314	−0.1784
Kurtosis	2.8588	2.2346	2.1617	2.2769	3.5289

Table 3 Variance inflation matrix

	CO_2	GDPPC	TC	INST	PDEN
CO_2	–		–	–	–
GDPPC	1.3356	–	–	–	–
TC	1.1366	2.2825	–	–	–
INST	1.0625	1.8351	3.2059	–	–
PDEN	1.0008	1.0020	1.0303	1.0099	–

percentiles, standard deviation, range, skewness and kurtosis. The results of variables for different measures of average and dispersion are depicted in Table 2.

It is highly necessary to detect and address the problem of multicollinearity among the study variables as its presence generates spurious coefficients/results. In this regard, the coefficient of correlation was calculated and variance inflation matrix was generated. The study results indicated that multicollinearity is not detected among the variables as the value of variance inflation factor for every pair of variables is less than 10 (Wang et al., 2021; Sohail et al., 2021a; Arshed et al., 2022; Sardar and Rehman, 2022). The results of variance inflation matrix are presented in Table 3.

The normality test of variables is highly important to determine the appropriate estimation model for research study. In this regard, the skewness/kurtosis test of normality was calculated and the study results are presented in Table 4. The estimated results indicated that probability values for each variable are significant which represents non-normality of the study variables. This indicates that an appropriate technique for estimation of results be used that could cater the problem of non-normality of data (Wang et al., 2021; Sohail et al., 2021a; Sardar and Rehman, 2022).

The panel quantile regression (PQR) estimation technique is used and study results are presented in Table 5. Furthermore, the transportation competitiveness is included in study model to envisage its impact on carbon emissions of transport sector. The linear and non-linear per capita GDP is included in research model to ascertain the existence of EKC. The study results indicated that inverted U-shaped EKC was validated across quantile group-1 and 2 for economic growth and carbon emissions of transport sector (Isik et al., 2019; Aydoğan & Vardar, 2020; Cheikh et al., 2021; Liu & Lai, 2021; Sardar and Rehman, 2022). However, U-shaped EKC was validated in quantile group-3 and 4 for economic growth and carbon emissions of transport sector (Dogan & Inglesi-Lotz, 2020; Wang et al.,

Table 4 Skewness/kurtosis tests for normality

Variables	Observations	Pr (skewness)	Pr (kurtosis)	Adj. Chi^2 (2)	Prob > Chi^2
CO_2	1331	0.0219	0.2983	6.31	0.0426
GDPPC	1331	0.0000	0.0000	–	0.0000
TC	1282	0.2025	0.0000	–	0.0000
INST	1282	0.0000	0.0000	–	0.0000
PDEN	1331	0.0080	0.0011	16.12	0.0003

Table 5 Estimation of PQR results for four quantile groups (dependent variable: CO_2)

Variables	Quantile group-1 (low CO_2)		Quantile group-2 (low–medium CO_2)	
	Coefficient	*P* values	Coefficient	*P* values
GDPPC	12.7809	0.0000*	1.4880	0.0020*
$GDPPC^2$	– 0.7261	0.0000*	– 0.0885	0.0010*
GDPPC*TC	– 2.2948	0.0000*	– 0.2080	0.0250**
$GDPPC^2$*TC	0.1332	0.0000*	0.0152	0.0030*
TC	10.1316	0.0000*	0.6387	0.1330
INST	– 0.7643	0.0000*	– 0.1729	0.0000*
PDEN	0.0409	0.0000*	01.1042	0.0000*
Variables	Quantile group-3 (high-medium CO_2)		Quantile group-4 (high CO_2)	
	Coefficient	*P* values	Coefficient	*P* values
GDPPC	– 6.1694	0.0000*	– 0.7404	0.0150**
GDPPC ^{2}	0.2979	0.0000*	0.0841	0.0000*
GDPPC *TC	2.4411	0.0000*	– 1.1161	0.0000*
GDPPC ^{2}*TC	– 0.1175	0.0000*	0.0500	0.0000*
TC	– 12.6242	0.0000*	6.3119	0.0000*
INST	– 0.0466	0.0000*	0.0378	0.0000*
PDEN	– 0.0538	0.0000*	0.0100	0.0000*

* and ** show level of significance at 1% and 5%

2021; Zhang, 2019). The inverted U-shaped relationship in quantile group-1 and 2 indicates sustainable economic growth which helps mitigating carbon emissions of transport sector (Aydoğan & Vardar, 2020; Cheikh et al., 2021; Sardar and Rehman, 2022). However, U-shaped EKC across quantile group-3 and 4 indicates the reverse situation as the process of economic growth further increases carbon emissions of transport sector (Dogan & Inglesi-Lotz, 2020; Wang et al., 2021; Sardar and Rehman, 2022).

In quantile group-1, study results revealed that transport competitiveness tends to significantly create carbon emissions of transport sector and remains insignificant. This indicates that expansion of transport sector is significantly creating carbon emissions in quantile group-1. Furthermore, on the basis of linear and nonlinear economic growth, inverted U-shaped EKC relationship was validated for economic growth and carbon emissions of transport sector across quantile group-1 and 2 (Aydoğan & Vardar, 2020; Cheikh et al., 2021; Sardar and Rehman, 2022). The moderation of transport competitiveness resulted in shifting the turning point of EKC toward right side (Haans et al., 2016; Sardar & Rehman, 2022). The shifting of the turning point of inverted U-shaped EKC toward right side indicates that sustainability phase is prolonged across these quantile groups. Moreover, the nonlinear moderation of transport competitiveness resulted in flattening of inverted U-shaped EKC. The flattening of EKC indicates that the sensitivity of EKC has decreased and may tend to emit lesser carbon emissions of transport sector (Haans et al., 2016; Sardar and Rehman, 2022). The moderation analysis across quantile group-1 and 2 provides insight that transport competitiveness facilitates sustainability as economic growth further reduces carbon emissions of transport sector. (Sardar and Rehman, 2022). The result further implicates that improvement of transportation quality tends to mitigate carbon emissions. The same behavior is also validated in Fig. 3 for quantile group-1 and 2, i.e., low-CO_2 and low–medium-CO_2 groups (Sardar and Rehman, 2022; Arshed et al., 2022).

In quantile group-3, U-shaped EKC was validated for economic growth and carbon emissions of transport sector. The U-shaped relationship indicates that process of economic growth in first phase mitigates carbon emissions of transport sector, while in the second phase the process of economic growth increases carbon emissions of transport sector (Dogan & Inglesi-Lotz, 2020; Wang et al., 2021; Zhang, 2019). The transport competitiveness significantly tends to mitigate carbon emissions of transport sector. The transport

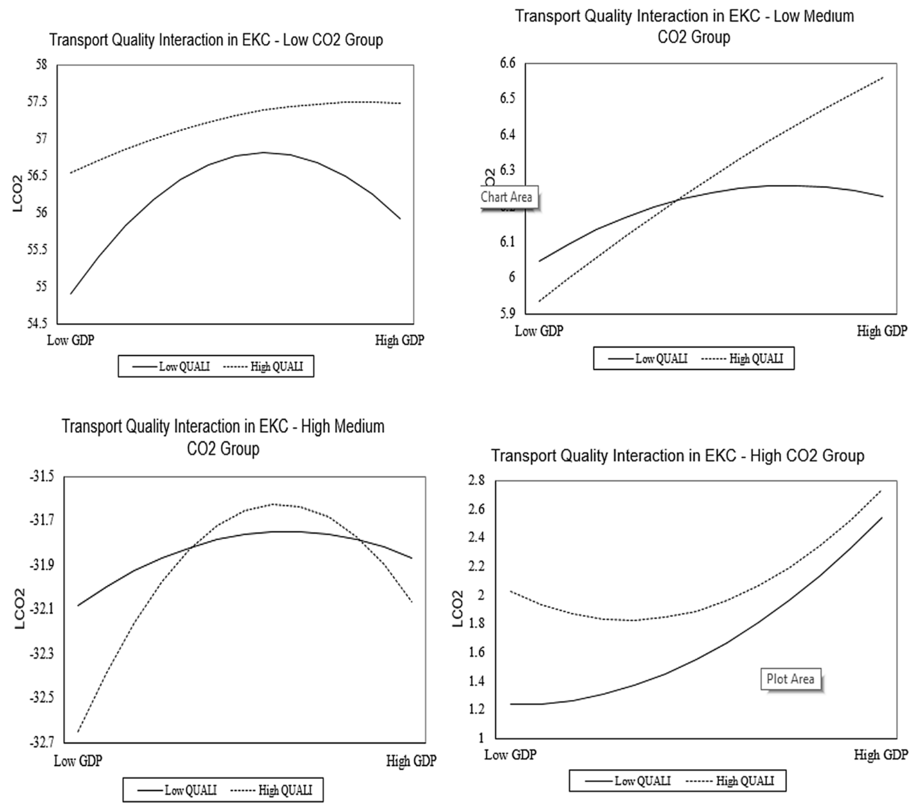

Fig. 3 Moderation of transportation competitiveness

competitiveness also includes the quality of transport sector and this may indicate that improvement of transport quality across quantile group-3 tends to mitigate carbon emissions of transport sector (Haans et al., 2016; Sardar and Rehman, 2022). However, the moderation analysis indicated that transport competitiveness resulted in shifting of turning point of U-shaped EKC toward left side in quantile group-3. This may indicate that moderation of transport competitiveness resulted in early completion of sustainability phase of economic growth. The nonlinear moderation of transport competitiveness indicated the flattening of EKC which reduces its sensitivity toward carbon emissions of transport sector (Haans et al., 2016; Sardar and Rehman, 2022). This analysis further implicates that initially the process of economic growth in quantile group-3 expands transport sector which increases carbon emissions but subsequently the moderation of transport competitiveness tends to mitigate carbon emissions (Arshed et al., 2022; Sardar and Rehman, 2022).

In quantile group-4, U-shaped EKC relationship was validated for economic growth and carbon emissions of transport sector (Dogan & Inglesi-Lotz, 2020; Wang et al., 2021; Zhang, 2019). The transport competitiveness is significantly creating carbon emissions, indicating that quantile group-4 countries are extensively using transport sector which tends to increase carbon emissions. Furthermore, moderation of transport competitiveness changes the turning point of EKC toward left side which indicates that transport competitiveness is increasing carbon emissions of transport sector. The nonlinear moderation of transport competitiveness steepens the EKC curve which increases the sensitivity of economic growth for emitting carbon emissions of transport sector. Thus, it is imperative to notice that moderation of transport competitiveness increases carbon emissions in quantile group-4 countries, and in this quantile group, high-carbon-emission countries are included (Haans et al., 2016; Sardar and Rehman, 2022). The same behavior of moderation analysis across quantile group-4 is also validated in Fig. 3 (Sardar and Rehman, 2022).

Among other variables of research model, the institutional quality across first three quantile groups is observed to be negatively associated with carbon emissions of transportation sector, indicating that institutional quality is significantly mitigating carbon emissions of transportation sector (Zakaria & Bibi, 2019; Shah et al., 2020; Shan et al., 2021; Khan et al., 2021; Sardar & Rehman, 2022). However, in quantile group-4, the institutional quality is not observed to be as good to mitigate carbon emissions of transport sector and institutional quality is significantly increasing carbon emissions of transport sector in this quantile group (Acheampong et al., 2019; Sheraz et al., 2021a; Habiba et al., 2021; Sardar and Rehman, 2022). The rising population density across quantile group-1, 2 and 4 significantly increases carbon emissions of transportation sector as rising population requires more transportation services for availing health, school and other facilities (Isik et al., 2019; Dogan & Inglesi-Lotz, 2020; Wu et al., 2021; Sardar and Rehman, 2022). However, in quantile group-3, planned expansion of population density which includes proper urban planning for housing, schooling, health and employment activities are observed in mitigating carbon emissions of transportation sector (Rauf et al., 2018; Katircioglu et al., 2018; Dogan et al., 2020; Arshed et al., 2021a, 2021b; Sardar and Rehman, 2022) (Table 6).

6 Conclusions and policy discussions

The climate change is the outcome of global warming caused by rising GHG emissions. The transport sector alone is creating more than quarter of the total carbon emissions. Keeping in view the rising share of carbon emissions of transport sector, it is highly

Table 6 Moderation of transportation competitiveness for changes in EKC

Quantile groups	Category	Type of EKC	Changes in turning point	Flattening/steepening
Group-1	Low CO_2	Inverted U shape	Right	Flattening
Group-2	Low–medium CO_2	Inverted U shape	Right	Flattening
Group-3	High–medium CO_2	U shape	Left	Flattening
Group-4	High CO_2	U shape	Left	Steepening

important to assess the role of transportation competitiveness in determining the carbon emissions of transport sector. Furthermore, variable of economic growth is included in this research study to validate EKC hypothesis for transport sector carbon emissions. The moderation of transportation sector carbon emissions is also engaged to envisage the changes in the turning point of EKC. The sensitivity of EKC is also assessed by moderation of transportation competitiveness for its relative flattening/steepening. The panel quantile regression (PQR) is used for estimation of study results as PQR is not sensitive to non-normal data series and generate robust results. The population density and institutional quality are included in research model as control variables.

The study results revealed that inverted U-shaped EKC for economic growth and carbon emissions of transport sector is validated across quantile group-1 and 2. The transport competitiveness is significantly creating carbon emissions in quantile group-1, while remaining insignificant for quantile group-2. The moderation analysis envisaged that transport competitiveness changes the turning point of EKC toward right side indicating facilitation of sustainable economic growth in terms of carbon emissions of transport sector. Furthermore, nonlinear moderation revealed that transport competitiveness flattens inverted U-shaped EKC and tends to reduce sensitivity of emitting transport sector carbon emissions. The results across quantile group-1 and 2 provides important policy implication to improve the quality of transport sector to mitigate carbon emissions by adopting green technologies and renewable energy.

In quantile group-3, U-shaped EKC was validated for economic growth and carbon emissions of transport sector. The transport competitiveness tends to significantly reduce carbon emissions of transport sector in quantile group-3. The moderation of transport competitiveness revealed shifting of turning point of EKC toward left side in quantile group-3, indicating early movement toward unsustainable phase of economic growth. However, the nonlinear moderation of transport competitiveness in quantile group-3 resulted in supporting sustainable economic growth. It may be appropriate from policy perspective to enhance the quality of transport sector by promoting green technologies to achieve sustainability by mitigating carbon emissions of transport sector.

In quantile group-4, U-shaped EKC was validated, while transport competitiveness is significantly increasing carbon emissions of transport sector. The moderation of transport competitiveness changes turning point of U-shaped EKC toward left side and results in promoting unsustainable economic growth. The nonlinear moderation of transport competitiveness steepens EKC curve and increases sensitivity of economic growth for emitting carbon emissions of transport sector. It is imperative to state that high-carbon-emissions countries must improve the quality of transport sector by engaging renewable energy/green technologies to mitigate carbon emissions of transport sector.

Regarding other study variables, institutional quality is significantly mitigating carbon emissions of transport sector in quantile group-1, 2 and 3. This may indicate that institutions are strengthened enough to formulate and implement environmental protection policies. However, institutional quality in quantile group-4 is further increasing carbon emissions of transport sector. This may be the fact the institutions have given more priority to expansion of economic growth rather to protect the environment. The expansion of population density is increasing carbon emissions of transport sector across all quantile groups except for quantile group-3 where planned population expansion tends to mitigate carbon emissions of transport sector. The measures to improve the institutional quality to implement and regulate transport sector may tend to mitigate carbon emissions of transport sector.

To summarize the objectives of the research study, the first objective was regarding the role of transportation competitiveness in determining the carbon emissions of transportation sector. It was observed that the expansion of transportation services across quantile group-1, 2 and 4 increases carbon emissions, while in quantile group-3, the transport competitiveness tends to mitigate carbon emissions. The second objective was regarding the validation of EKC across four quantile groups. The study results revealed that inverted U-shaped EKC was validated in first two quantile groups, while U-shaped EKC relationship was validated in quantile group-3 and 4. The third objective was regarding the moderation impact of transportation competitiveness in changing the turning point of EKC and its relative flattening/steepening. The analyzed results indicated that in first two quantile groups, the moderation of transportation competitiveness is very helpful in changing the turning point and flattening of EKC as it reduces sensitivity of EKC. This indicates that moderation of transportation competitiveness across first two quantile groups facilitates the process of early achievement of sustainability phase as compared to the quantile groups of high carbon emissions.

On the basis of the results discussed above, it has been observed that quality aspect of the transportation competitiveness is highly important for quantile group of countries having high level of carbon emissions. The moderation of transportation competitiveness is efficiently working for countries of quantile groups having low carbon emissions. This implicates that the group of countries having high level of carbon emissions must pursue such policies that must increase the efficiency of transport sector by using green technology and renewable energy. This will help in reducing carbon emissions of transport sector and will help in achieving the sustainability of carbon emissions. Furthermore, the role of institutional quality must be enhanced to properly implement the environmental protection policies to mitigate carbon emissions. The planned expansion of population across majority of quantile groups may also be helpful in reducing the carbon emissions of transport sector.

Assessing the role of transport competitiveness is an important phenomenon. However, the limitation of the research study is availability of data for transport competitiveness for limited time period and limited number of countries. In future, for more in-depth analysis, more research studies may be conducted to envisage the moderation of transport competitiveness for determining the carbon emissions of transport sector with sectoral growth sectors such as industrial, manufacturing or services sector. Furthermore, the moderation role of road, rail, port and air competitiveness may be engaged for determining the sustainability of carbon emissions of transport sector. Additionally, different moderators may also be engaged to explore the dynamics of carbon emissions of transport sector.

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Declarations

Competing interests The authors have not disclosed any conflict of interest.

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