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Environmental Sustainability Analysis Using Moderation of Transport Competitiveness for Industrial-Induced EKC

^a Muhammad Shahzad Sardar, ^b Nabila Asghar, ^c Hafeez ur Rehman

^a PhD Scholar, Department of Economics and Statistics, HSM School, University of Management and Technology, Lahore Pakistan

^b Department of Economics, Division of Management and Administrative Science, University of Education, Lahore Pakistan

^c Professor, Department of Economics and Statistics, HSM School, University of Management and Technology, Lahore Pakistan

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ABSTRACT

Combating adversities of climate change and promoting clean energy are two important goals of the Sustainable Development Goals (SDGs). The nations of the World have developed various commitments to reduce global warming. The transportation sector share is above twenty percent in total global Greenhouse Gas emissions which is continuously rising over time. The Intergovernmental Panel on Climate Change (IPCC) in its recent report conducted a scenario analysis and suggested reducing net emissions by 2050. The transport competitiveness index indicates the quality and expansion of transport services. Accordingly, this research study uses the data of 121 countries for which transport competitiveness is documented by the World Economic Forum (WEF). The period of the study is confined to 2008-2018. The sample countries are segregated into four groups on the basis of transport sector emissions. The study uses Panel Quantile Regression (PQR) framework to estimate results and to validate the industrial Environmental Kuznets Curve (EKC). The findings indicate that transport competitiveness mitigates transport sector emissions in the majority of groups/categories. Inverted U shape industrial EKC has been authenticated in group-1 and U shape industrial EKC for the other three groups. The moderation of transportation competitiveness specified the flattening of industrial EKC across all quantile groups. The empirical findings indicate that moderation results in the sustainability of industrial EKC at higher levels of industrial growth. Among other variables, the governing ability of institutions and planned population expansion are observed in mitigating emissions. The policy options are discussed depending on the results of the groups.

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Corresponding author's email address: hafeez.rehman@umt.edu.pk

1. Introduction

The different means of transportation are instrumental in transporting goods as it facilitates international trade and promotes globalization (Chen and Li, 2021; Sardar et al., 2022). The investment in transportation infrastructure by different emerging economies of the World has proved to be very helpful in achieving economic growth targets (Sobieralski, 2023). The developed economies like the US, Japan, UK, European Union, China etc., have achieved high economic growth trajectories through investments in different modes of transportation (Pradhan et al., 2021). Furthermore, the development of the transportation/logistics sector has backward and forward linkages in promoting tourism and its allied sectors (Kanwal et al., 2020). Despite the financial/economic and social gains/benefits of transportation sector development, the externalities in the form of environmental pollution by emitting carbon emissions pose serious environmental challenges (IEA, 2019; Sardar et al., 2023).

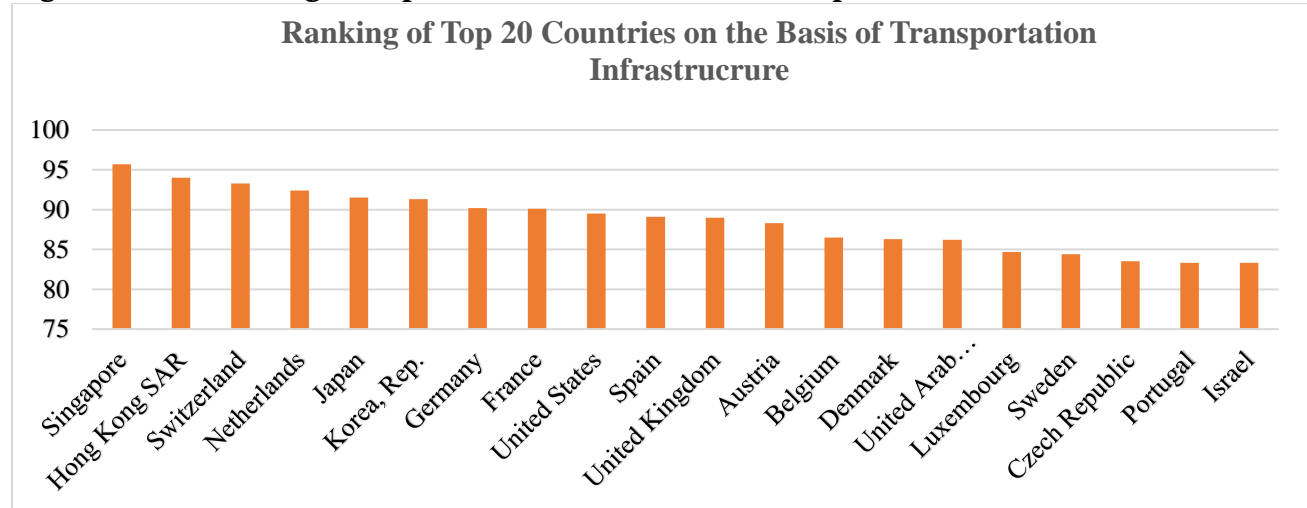
The SDGs are the critical development agenda for nations of the World as it embarks on achieving universal health, education, and a living environment for all human beings. Among all important SDG goals, the clean environment is addressed in target 13, which directly links the provision of clean energy/power to all, as committed in target 7 of SDGs. Clean energy/power is essentially required to kick-start economic activity. However, diesel/petrol is most commonly used to produce electricity/energy and is regarded as the direct cause of air pollution. For the logistics sector, electric vehicles having sufficient charging facilities can reduce the usage of petrol/diesel. The increased fuel efficiency in transport vehicles can reduce emissions. Furthermore, the acceptability/usage of green fuels in the transport sector is also a workable option to dent the growing emissions. Pursuing the policies such as carbon taxing and rebates for freight transportation to adopt green/cleaner energy/fuel can ease emissions toward a downward trajectory (Sobieralski, 2023).

One-fourth of GHG emissions are attributed to the transport/logistics sector, as diesel/petrol is frequently used as the primary fuel source in this sector (IEA, 2019). However, among these emissions, carbon dioxide emissions account for a major share (IEA, 2019; Aslan et al., 2021). The upward economies have started progress on manufacturing electrified vehicles to achieve net zero emission targets. Almost twenty countries have set future targets for electrified vehicles in this regard. The importance of the industrial sector cannot be negated as this sector is creating many employment opportunities, and its expansion is instrumental in promoting economic growth and international trade (Burlina and Maria, 2020). During the production stages of different allied industries, the industrial sector emits carbon emissions, accounting for more than twenty percent of total emissions (IPCC, AR5, 2014; IEA, 2019). Industrial production creates environmental pollution by emitting carbon emissions at different levels of raw material extraction, production, inventory storage, delivery, and recycling stages (Sobieralski, 2023).

The World Economic Forum (WEF) records the competitiveness index of more than 150 countries annually. The term competitiveness refers to the collective role of institutions, policies, and productivity enhancement to achieve higher levels of inclusive economic growth. The WEF executes a perception survey to register the response for transportation competitiveness to assess the extensiveness, quality, and efficiency of different modes of transportation. Based on this survey information, the transportation competitiveness index is prepared. The Global Competitiveness Index (GCI) report of 2018 issued by the WEF indicates that Singapore has the best quality of transportation infrastructure, followed by Hong Kong and Switzerland. In this regard, the ranking of

the top twenty countries with the best transportation/logistics infrastructure is presented in Figure-1. Several studies conducted by researchers have indicated that the transportation setup/infrastructure has a pivotal role in promoting economic prosperity (Kanwal et al., 2020). However, the moderation of competitiveness (transport sector) also significantly increases productivity and promotes social welfare (Sobieralski, 2023).

Figure-1: Ranking of Top 20 Countries based on Transportation Infrastructure Index Score



Source: Global Competitiveness Index Report, 2018

The IPCC climate assessment study indicated that human influence is responsible for climate change and environmental pollution (IPCC AR6 Report, 2021). In this regard, the different scenario analysis were highlighted in this report to curtail emissions. The more important one is managing transportation-related emissions for environmental protection. This research paper makes an effort to fill the research gap in multiple ways as it uses transportation competitiveness documented by World Economic Forum (WEF) for sustainability analysis, which is not mostly used. The moderation of transport competitiveness will be ascertained regarding industrial EKC.

After ascertaining the study/research gap, the research objectives are envisaged. Transport competitiveness is assessed by explaining the transport/logistics sector emissions. The EKC hypothesis/framework is validated for industrial growth and transport sector emissions. The moderation of transport competitiveness is used for ascertaining changes in Industrial EKC for sustainability analysis. The remaining sequence of the research paper is as follows: The literature and theoretical reasoning are portrayed in the second and third sections. Section four highlights the analytical methods, data, and variables. The fifth section consists of the analyzed results and discussion. Conclusions and relevant policy options are made part of the final section of the study.

2. Literature Review

This section covers three central portions. The first portion/part presents the relevant literature regarding the empirical validation of EKC. In contrast, in the second part, the pertinent studies of the STIRPAT framework are discussed, and finally, the latest literature on the transportation sector is highlighted.

2.1 Literature Based on Environmental Kuznets Curve (EKC)

Simon Kuznets first presented the theory/hypothesis of EKC to ascertain the association between economic development and income disparity (Kuznets, 1955). The EKC framework was

engaged/used in environment/economic analysis by subsequent researchers (Grossman & Kruger, 1991; Selden & Song, 1994; Stern et al., 1996). This theory in the field of environment is validated in its different forms, such as inverted U, U, and N shapes. An attempt is made to include recent literature on EKC in this section. In 2018, it was observed that an inverted U shape EKC was authenticated for data sets of growth and pollution (Fujii et al., 2018). Subsequently, in 2019, researchers identified evidence of inverted U-shape EKC (Zhang and Zhao, 2019; He and Lin, 2019).

In 2020, several researchers validated inverted U-shape EKC for various data sets of China, Europe, and emerging economies of the World (Pandey et al., 2020). Subsequently, EKC was validated for MENA, African countries, and OECD countries (Isik et al., 2021; Usman and Jahanger, 2021). The U shape EKC was validated for capital cities of China, Central Asia, BRICS countries, and West African countries for different periods and data sets (Jin and Kim, 2020). In the years 2022 and 2023, extensive work was done by researchers regarding the confirmation of EKC for various countries, states and provinces (Sardar et al., 2023).

2.2 Literature Based on STIRPAT Model

The STIRPAT framework assesses the influence of various variables on ecological pollution (Dietz and Rosa, 1994; York et al., 2004). The IPAT is a mathematical identity and shows that total ecological/environmental pollution is the cross-product of population activities, affluence/economic growth, and technology/R&D (Ehrlich & Holdren, 1971). However, the STIPAT framework/model is a relatively upgraded estimation technique as it is beneficial for assessing the impact of determinants of ecological/environmental pollution (Liu and Xiao, 2018; Xu et al., 2020). In addition to the baseline STIRPAT model, several economists/researchers have engaged the STIRPAT framework/model to determine pollution by incorporating additional variables in the model (Yang et al., 2018).

In the STIRPAT framework, emissions are most commonly engaged/used to explain the environmental phenomenon because carbon emissions are the central portion of total GHG emissions. In literature, several studies have used carbon emissions as a proxy for environmental/ecological pollution (Xie et al., 2019; He and Lin, 2019; Jiang et al., 2021; Mahmood et al., 2023). Among the STIRPAT framework variables, the population is the most critical variable to explain the changes in ecology (Xu et al., 2020). The increase in population directly impacts environmental pollution as the rising population increases the demand for houses, transportation, food, and non-food goods. Together, these factors increase carbon emissions with a rise in population (Zhang, 2019; Wu et al., 2021). In literature, some research studies also show that an increase in population led by planned urbanization helps mitigate environmental pollution (Dogan et al., 2020; Nguyen et al., 2020).

The growth/affluence gauged by economic development is also one of the essential aspects of the STIRPAT framework/model, as economic expansion is a critically important variable in determining environmental pollution (Xu et al., 2020; Wu et al., 2021). In literature, the research studies indicate that economic activity requires more utilization of fossil fuel during the production and transportation process, which subsequently increases the total carbon emissions (Usman & Jahanger, 2021). In literature, the inclusion of nonlinear economic growth is used to assess the changes in the pattern of environmental pollution, indicating how environmental pollution behaves as economic growth/development increases (Isik et al., 2021).

High levels of institutional/governance quality promote economic prosperity. The quality of Institution/governance refers to corruption control, enhanced capacity of bureaucracy, and implementation of laws/rules to alleviate environmental/ecological pollution (Khan et al., 2021). The previous research studies show that high institutional/governance quality supports implementing environmental protection policies that help in managing ecological pollution. Through their legal tools, institutions' capacity and quality facilitate the extenuation of emissions in the production and transportation sector (Ali et al., 2019). However, some studies have witnessed that poor governance, fragile bureaucracy, weak implementation of environmental regulations and rising corruption increase emissions (Habiba et al., 2021; Pahle, 2023).

2.3 Literature Based on Transportation Sector Creating Carbon Emissions

Researchers have conducted different studies to engage the role of transportation sector in creating emissions. In this regard, Wang et al. (2018a) identified the role of transportation activities in China's emissions. The study results indicated transportation activities, population size, and economic growth create emissions. Xu and Lin (2018) used the panel data of 30 states/provinces of China from 2000 to 2015. The impact of economic growth, energy usage, urban development, freight turnover, and passenger turnover on transport emissions differs across the five quintiles of regression analysis. Solaymani (2019) highlighted the importance of implementing environmental rules to shield the environment/ecology against emissions in the transportation sector for 07 top carbon-emitting countries. The study results indicated that all sample countries except Japan have increased carbon emissions. Amin et al. (2020) conducted research for European Union countries by taking data from 1980 to 2014 to analyze transportation sector emissions. The urban sector expansion and economic prosperity were found increasing emissions of the logistic sector.

Godil et al. (2021) tested economic growth/development, renewable/reusable energy, and technological development in the transportation sector emissions of China from 1990 to 2018. The study results envisaged that economic growth increases emissions, while innovations and renewable energy mitigate emissions. Pahle (2023) highlighted the importance of carbon pricing to curtail emissions of the road sector and asserted the need to diversify revenue towards the social well-being of people by promoting green investments in the European Union. Such practices may discourage the production of high-emission vehicles and will encourage the production/usage of hybrid cars.

Tsai et al. (2023) elaborated on the path for attaining net zero emissions in the road sector for Taiwan. The promotion of electric vehicles shifts the burden of emissions from combustion engines to power generation. Thus, the dynamic policy is asserted to achieve net zero emissions, which is possible by promoting electric/hybrid vehicles and cleaner power generation. Kinsella et al. (2023) asserted the need to electrify the private vehicles used as taxis in Dublin to promote cleaner energy in road sector transportation. It was further opined to engage hybrid vehicles to discourage the use of diesel/petrol to reduce emissions. This policy may reduce road emissions by 70 percent and helps in achieving net zero emissions. Ma et al. (2023) used spatial data by using high-resolution traffic cameras to envisage the traffic speed/timing to analyze road transport emissions. The finding suggested that the slow speed of vehicles increases fuel consumption and eventually increases urban transport emissions. Fuel efficiency can be increased by better traffic planning, increasing mileage, and reducing emissions. Xu and Qin (2023) asserted that Hainan State/Province of China declared to stop the production/sale of combustion vehicles by 2023 to limit road transportation emissions. It was further asserted that adopting policies to promote electric vehicles is not reducing emissions as the power used to charge electric vehicles is generated using coal power plants. The vehicle emission

policies in China indicate that it reduces urban pollution by promoting electric vehicles but has a limited role in reducing overall carbon emissions.

Sobieralski (2023) asserted that air transportation has two percent share in overall GHG emissions as its annual growth hovers around 3.6 percent. The study highlighted that this growth rate of air emissions is continuously increasing and is expected to double as the demand for air transportation grows exponentially. The study suggested that different measures to manage air transportation sustainably to reduce emissions. In this regard efficient flight management system can reduce fuel consumption and helps reduce GHG emissions. Zeng and He (2023) highlighted that China may attain the highest level of GHG emissions by 2030. The study suggested that the major emission-producing sectors, including air and road transport in China, must be managed by promoting R&D to mitigate emissions.

Gössling and Dolnicar (2023) advocated that the air industry has a significant role in creating emissions/climate change. The authors asserted that the demand/supply of the aviation industry, government policies, and human behaviour are driving forces of aviation emissions. The innovations and sustainable fuels can ease the pressure of aviation emissions. The carbon taxing policy by the regulators can escalate the cost of the aviation industry, which may discourage its demand and eventually reduce aviation emissions. Furthermore, changing human behaviour for avoiding unnecessary air travel can also reduce emissions. In this regard, promoting alternative sources of travel/business activities, such as online meetings/discussions may be helpful in curtailing emissions. Wang et al. (2023) researched the relevant data of China for industrial production and trade. The research aims to find industrial production and trade linkages with GHG emissions. The findings deduced that industrial structure and international trade are directly linked with emissions of China. The trade also requires logistics/transportation services which ultimately increases emissions.

Yang et al. (2023) researched the impact of high-speed trains on economic openness, regional disparities, and pollution. The study highlighted that investment in high-speed trains is essential for providing connectivity in a shorter time which eventually facilitates economic expansion/growth. The study concluded that high-speed trains have contributed to minimizing the regional disparities across China but at the same time high-speed trains create emissions. Gössling and Humpe (2023) asserted that the aviation sector needs to revamp using renewable fuels by promoting biomass fuels to ease environmental impacts. This study highlighted that every increment of a gigaton of emissions released into the atmosphere results in climate change. The growth of the aviation industry is a threat to net zero emission targets. Aakko-Saksa et al. (2023) asserted that the ports/shipping facilitate eighty percent of global trade, which is seventy percent of the total value of international trade. The emissions of shipping/port transportation account for more than one gigaton, which accounts for almost three percent of total GHG emissions. It was also highlighted that different sizes and types of vessel ships have diesel fuel engines, and the combustion process emits carbon emissions. The research study discussed different fuel options for existing diesel/LNG engines of ships to minimize emissions.

Su-ungkavatin et al. (2023) analyzed marine/shipping transportation and discussed different types of sustainable fuels including biofuels, electric, and battery-based electric fuels. The technical and economic efficiencies of these fuels were highlighted to achieve net zero global commitments. Fan et al. (2023) asserted the importance of reliable calculation methods for the carbon footprints of

the inland shipping industry in China. It was highlighted that using renewable fuels and efficient route management is a prerequisite for reducing freight and passenger shipping emissions.

The review of literature brings up the need for mitigating emissions of transport sector as it consists of twenty percent of overall emissions. Not many studies are available in literature that have used transport competitiveness to analyze the transport sector emissions and have authenticated EKC for industrial value addition and transport sector emissions for sustainability analysis. More importantly, the moderation of transport competitiveness in changing the dynamics of industrial-induced EKC for sustainability analysis is not much discussed in literature. Therefore, to fill this research/literature gap, three distinct/precise objectives are considered.

3. Theoretical Framework

The theoretical/analytical framework of the study is based on EKC and STIRPAT frameworks. The first possibility of the theoretical framework is empirical validation of inverted U shape industrial EKC for transportation carbon emissions, as indicated in Figure 2. The industrial EKC (inverted U) shows that industrial growth/development increases the transport sector emissions. This phase is termed the deterioration stage, as full attention is devoted to industrial development for achieving different macroeconomic goals. In this first phase, the association between industrial value addition and ecological/environmental pollution in the transport sector is positive. The most prevalent reason for increasing emissions is the high usage of the transport sector for the transportation of raw materials and finished goods. However, in the second phase, industrial EKC (inverted U), the increase in industrial growth mitigates the transport sector emissions. This mechanism also represents industrial production's sustainability or maturity stage, as it has an inverse relationship with emissions. The moderation of transport competitiveness determines the turning point of the industrial EKC.

The U shape EKC is also considered for validation/confirmation for industrial growth and transport sector emissions, as shown in Figure 3. In U shape EKC, the first phase represents the balanced industrial growth path as the increase in industrial growth mitigates the emissions. The opposite connection between industrial development and environmental/ecological pollution of the transport sector exists in the primary phase of U shape industrial EKC. However, the second phase of the industrial EKC, in its U shape format, represents the overgrowth of the industrial sector, represent that the growth has exceeded the sustainable threshold levels. In this phase, the arrangements to increase industrial growth result in higher transport sector emissions. A direct association between industrial development/growth and ecological/environmental pollution prevails. The theoretical grounds of this research study are similar to previous researchers (Haans et al., 2016; Pahle, 2023; Sobieralski, 2023). The possibilities of both competing theories will be tested using global empirical data.

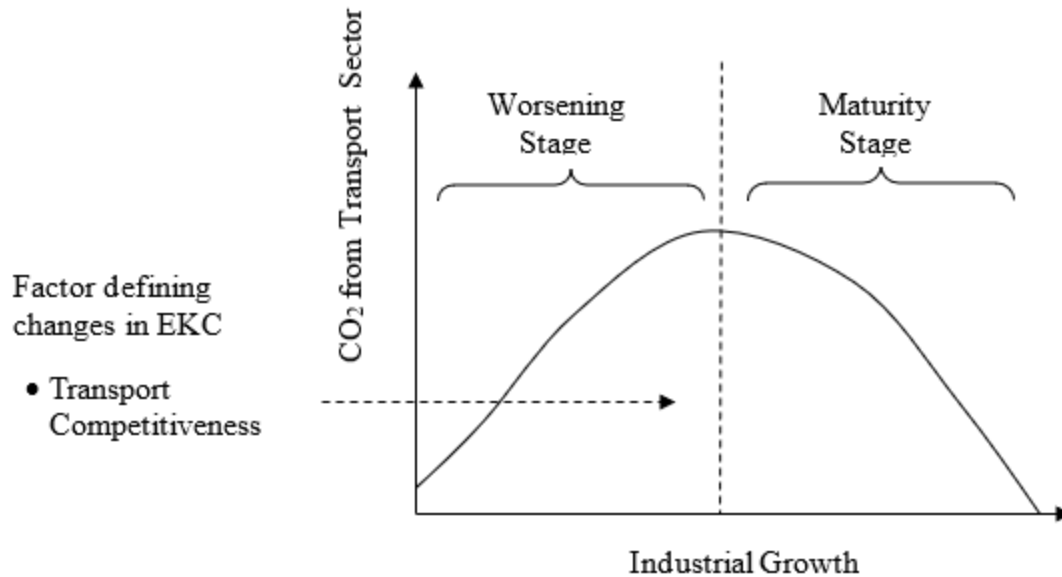


Figure 2: Theoretical/Analytical Framework (Inverted U Shape EKC)

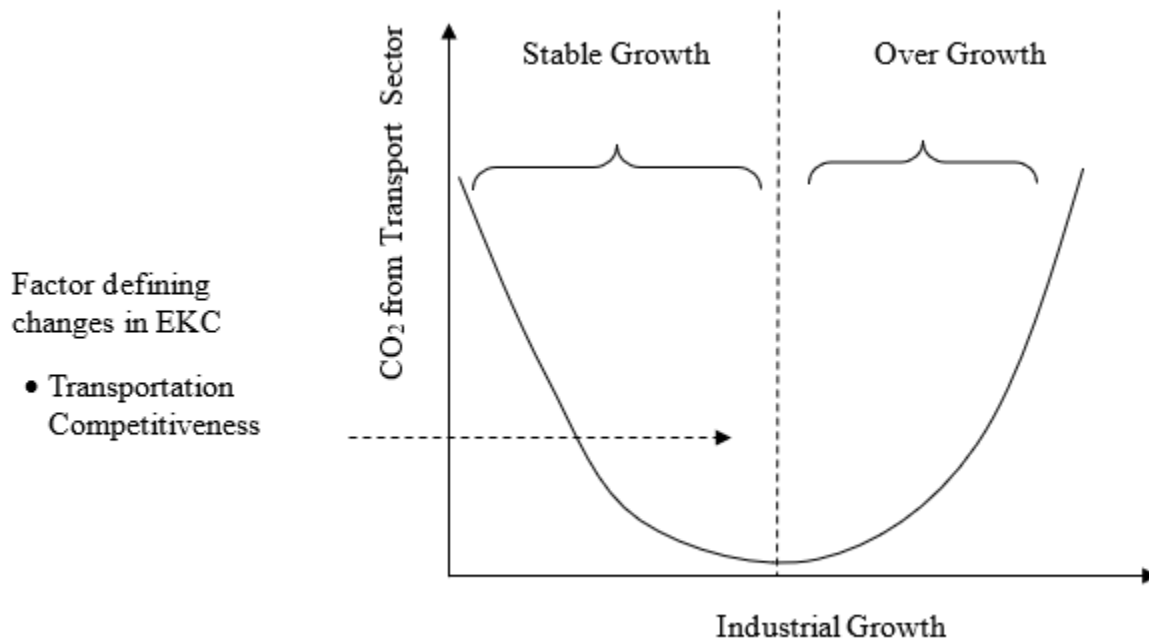


Figure 3: Theoretical/Analytical Framework (U Shape EKC)

4. Research Methodology

4.1 Data, Sample, and Variables

For analysis purpose, the data of 121 countries for the period 20018-2018 has been taken from different sources mentiones in Table 1. Four groups are created based on the transport sector emissions. Groups are created on the real/actual observations of CO₂ for every corresponding year. The sample countries may cross/jump groups/quantiles if they significantly improve with time. The description of the variables is summarised in Table 1.

Table 1: Description of Variables Used in the Econometric Model

Variables	Description of Variables	Sources
CO ₂	Log of Transport Sector Emissions (Mt/Capita)	EDGAR (2023)
IND	Log of Industrial Growth	WDI (2023)
IND ²	Log of Square of Industrial Growth	WDI (2023)
PDE	Log of Population Density	WDI (2023)
TC	TransportCompetitiveness Index	WEF (2023)
INS	Institutional Quality Index	ICRG (2023)

After summarizing the variables, a comprehensive model with its foundation linked with EKC and STIRPAT model is used to achieve the study's objectives. In this regard, the general specifications of the STIRPAT model/framework are derived based on IPAT identity.

$$I_i = a P_i^b A_i^c T_i^d e_i \dots \dots \dots \text{Eq.1}$$

This general form is based on IPAT identity, where "I_i" symbolizes the environmental/ecological impact, "P_i" means population volume/size, "A_i" demonstrates affluence, and "T_i" is the technology/knowledge. The natural logarithm is applied, and the following equation is derived:

$$\ln I_{it} = a + b \ln P_{it} + c \ln A_{it} + d \ln T_{it} + \ln e_i \dots \dots \dots \text{Eq. 2}$$

After deriving the general/standard STIRPAT model/framework, more indicators/variables can be plugged in. Based on these justifications, the extended STIRPAT model/framework is as under:

$$CO_{2it} = \beta_1 + \beta_2 IND_{it} + \beta_3 IND_{it}^2 + \beta_4 IND_{it} * TC_{it} + \beta_5 IND_{it}^2 * TC_{it} + \beta_6 TC_{it} + \beta_7 PDE_{it} + \beta_7 INS_{it} + \mu_{it} \dots \dots \dots \text{Eq. 3}$$

The nonlinear industrial growth is considered to confirm the EKC hypothesis empirically. To validate industrial EKC, β₂ must be positive and significant, while β₃ must be negative and significant. The cross-product of transport competitiveness and industrial growth is included in the model to envisage the moderation of transport competitiveness in explaining the transport sector emissions. This moderation depends on the term (β₂β₅ - β₃β₄) / 2(β₃ + β₅TC)². This approximation means that if the numerator is positive then the turning point will move towards the right side and vice versa.

The multiplication of the squared term of industrial growth with transport competitiveness indicates the flattening and steepening of the EKC. If β₅ is greater than zero and significant, then the flattening of the EKC curve will occur for inverted U shape EKC, and steepening will occur for U shape EKC (Haans et al., 2016). Depending on the normality test, the Panel Quantile Regression (PQR) based on fixed effects is used for estimation purpose. The recent literature indicates that PQR mainly engages in panel data analysis with large cross sections, assuming various quantiles for determining environmental/ecological pollution (Chowdhury et al., 2021).

4. Results and Discussions

The statistics like mean/average and dispersion are calculated to envisage the primary information about study variables included in the analysis. The measures related to average include percentiles, median and mean. The results of these measures for different variables are summarised in Table-2. The Variance Inflation Factor (VIF) is engaged to detect the problem of multicollinearity. The results presented in Table 3, indicate that none of the VIF value does not exceed 10 which reveals the absence of multicollinearity.

Table 2: Basic Statistics

Stats	CO ₂	IND	TC	INS	PDE
Number	1331	1289	1282	1282	1331
Average	2.005	3.2343	4.222	4.129	4.306
Median (50 th Percentile)	1.879	3.2342	4.222	3.923	4.456
Standard Deviation	1.898	0.3966	1.204	0.891	1.433
Inter Quartile Range	2.419	0.4256	1.829	1.389	1.762
Range	10.212	2.7985	5.256	3.728	8.455
25 th Percentile	0.779	3.0065	3.292	3.419	3.482
75 th Percentile	3.199	3.4351	5.119	4.807	5.243
Skewness	0.154	-0.1053	0.087	0.532	-0.179
Kurtosis	2.859	4.3244	2.162	2.277	3.529

Table 3: Variance Inflation Matrix

	CO ₂	IND	TC	INS	PDE
CO ₂	-	-	-	-	-
IND	1.079	-	-	-	-
TC	1.137	1.006	-	-	-
INS	1.063	1.005	3.206	-	-
PDE	1.00	1.035	1.031	1.008	-

The test for normality is also engaged to ascertain the normal distribution of the study variables. The skewness/kurtosis test outcome presented in Table 4 indicates that all study variables are non-normal. The plot of industrial value addition of emissions (transportation sector) is presented in Figure 4, and the fitted line passes through the dotted values of low and high transport quality. In the second portion of Figure 4, the moderation (transport competitiveness) can be seen as it moderates the carbon emissions by flattening the curve.

Table 4: Normality Test

Var.	Obs.	Pr(Skewness)	Pr(Kurtosis)	Adj. Chi ² (2)	Prob>Chi ²
CO ₂	1331	0.0219	0.2983	6.31	0.0426
IND	1289	0.1215	0.0000	34.67	0.0000
TC	1282	0.2025	0.0000	-	0.0000
INS	1282	0.0000	0.0000	-	0.0000
PDE	1331	0.0080	0.0011	16.12	0.0003

The results of the PQR estimation technique are presented in Table 5. The results indicate that industrial growth significantly creates carbon emissions in countries of the first group, indicating that an increased level of industrialization increases emissions. However, in the remaining country groups, industrial growth is inversely associated with emissions (Wang et al., 2021). The quantile group-4 has the strongest impact of industrial value addition in managing carbon emissions. Furthermore, the inverted U shape EKC has been confirmed for quantile group 1 countries, indicating that industrial value addition increases emissions in the first phase of development and subsequently reduces emissions in the second phase (Cheikh et al., 2021). The U shape EKC is authenticated in the second, third and fourth groups, indicating that industrial growth mitigates the transport sector emissions in the first phase. However, in the second phase, the further growth of the industrial sector is unsustainable as it tends to increase emissions (Pahle, 2023; Vukić & Krämer, 2023).

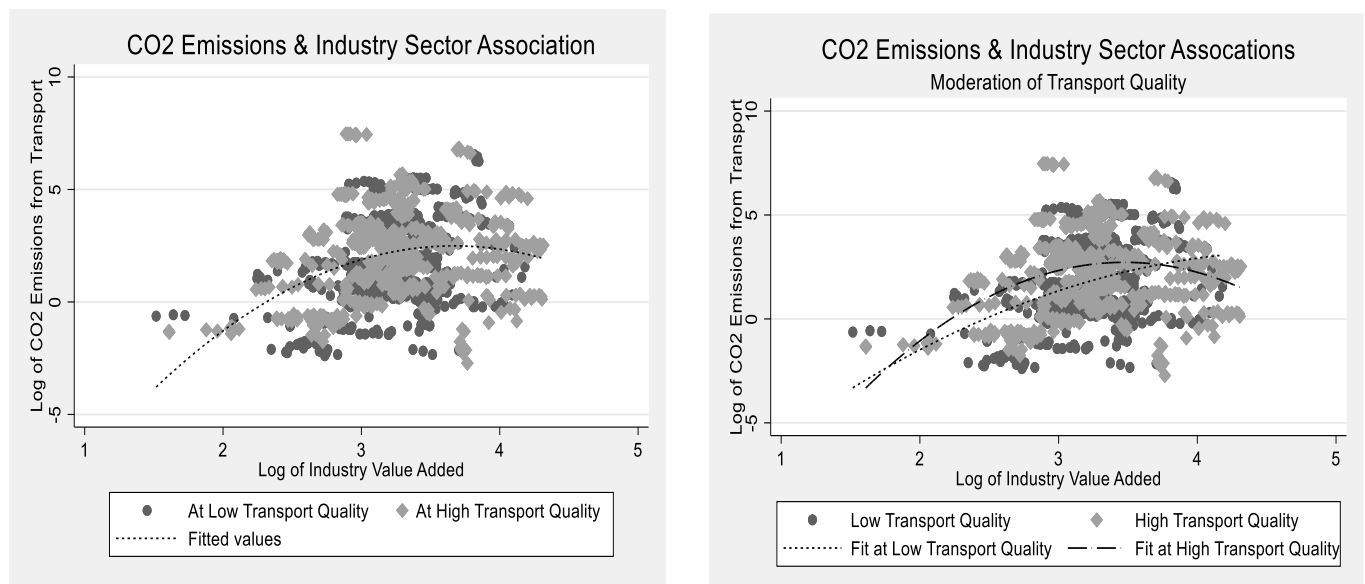


Figure 4: Plot of CO₂ Emissions, Industrial Value Addition and Moderation of Transport Competitiveness

The estimated results indicate that the quality of institutions is reported to significantly impact emissions in all country groups. In group-1 and 3, the institutional quality is effectively implementing the environmental policies and its role is observed significant in reducing emissions (Shan et al., 2021). However, in group-2 and 4, the governance quality is directly related to environmental pollution (Sheraz et al., 2021). The results also reveal that population density is playing its role in mitigating emissions in groups- 1, 3 and 4. However, in group-2, the population density registers a direct association with emissions (Dogan et al., 2020; Pahle, 2023).

Table 5: PQR Estimated Results (Dependent Variable CO_{2t})

Variables	Group-1		Group-2		Group-3		Group-4	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
IND	10.5797	0.0010*	-4.7167	0.0030*	-17.1918	0.0000*	-52.3967	0.0000*
IND ²	-1.6294	0.0000*	0.9517	0.0000*	2.5252	0.0000*	8.1666	0.0000*
IND*TC	-1.9694	0.0370**	1.5932	0.0000*	3.6147	0.0000*	10.3067	0.0000*
IND ² *TC	0.3088	0.0260**	-0.2989	0.0000*	-0.5331	0.0000*	-1.6050	0.0000*
TC	3.2470	0.0370**	-2.0954	0.0000*	-5.9479	0.0000*	-16.2260	0.0000*
INS	- 0.2700	0.0000*	0.1016	0.0000*	-0.1056	0.0000*	0.1326	0.0000*
PDE	-0.0851	0.0010*	0.2115	0.0000*	-0.0943	0.0000*	-0.1170	0.0000*

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

The transport competitiveness index indicates the extensiveness and quality of the transportation services available in any country. The PQR analysis reveals that transport competitiveness increases emissions in group-1. This process indicates that the extensiveness of transportation is playing its role in creating real sector productivity. When more transportation services are increased with the increase in industrial production, it generates more carbon emissions. However, transport competitiveness is observed in mitigating emissions in groups- 2, 3 and 4. This analysis further indicates that the quality perspective of the transport sector has enhanced across these groups to reduce emissions. It has also been observed that transport competitiveness is strongest in the fourth group in reducing emissions, followed by group-3 and group-2, respectively. This process also indicates that the countries falling in a high volume of CO₂ groups have relatively improved transportation quality, which helps in mitigating the transportation sector's emissions.

The moderation of transport competitiveness is summarised in Table 6 and figure-5. The inverted U shape EKC is confirmed in group-1, having low carbon emissions. The moderation of transport competitiveness is discussed for linear and non-linear industrial growth. The linear moderation (transport competitiveness) highlights changes in the turning point of EKC for sustainability analysis. While the non-linear moderation (transport competitiveness)

flattens/steepens EKC and generates sufficient evidence for sustainability analysis. In quantile group-1, linear moderation shifts the turning point of the inverted U shape EKC towards the right side, while non-linear moderation flattens EKC. This similar behavior is also evident in the first portion of the figure-5. In quantile group-2, the moderator changes the turning point of U shape EKC towards the left side and flattens the EKC curve. In the third and fourth groups, the turning point of the U shape EKC is shifted towards the right and left side, respectively, with further flattening in the EKC curve as shown in Figure 5. The flattening of EKC specifies the extension of the sustainability period in which the industrial sector growth will continue to mitigate emissions for a longer period.

The key finding of the moderation analysis is the flattening of the EKC curve which highlights the importance of transport sector management to mitigate emissions. The empirical findings suggest that linear moderation helps in creating environmental sustainability in group-3, while non-linear moderation reduces the sensitivity of emitting emissions in all groups and thereby resulting in environmental sustainability. The results also implicate that moderation of transport competitiveness is highly effective in reducing emissions at higher levels of industrial growth. An improvement in fuel efficiency in the transport sector can be helpful in reducing emissions. The optimum journey management of road, sea and aviation transportation can reduce the uses of petroleum fuel, which ultimately reduces emissions. The policies to accelerate the use of sustainable/clean fuels in various transportation modes can exert a positive impact on the environment. It is evident that increasing the quality of transport services directly increases its competitiveness and ultimately the moderation of transport competitiveness addresses sustainability. The reduction of climate atrocities and the promotion of clean energy in production/transportation sectors are the key goals of SDGs. The promotion of green energy-based technologies and innovations helps conserve the natural ecology of the environment. Carbon taxing and rebates on various modes of transportation are very effective tools to contain emissions.

Table 6: Moderation of transport competitiveness for Changes in EKC

Groups	Category	EKC Authenticated	TC relation with CO ₂	Movement of Turning Point	Linear Moderation Confirms	Flattening / Steepening	Non-Linear Moderation Confirms
Group-1	Low CO ₂	Inverted U Shape	Increase	Right Side	Unsustainability	Flattening	Sustainability
Group-2	Low Medium CO ₂	U Shape	Decrease	Left Side	Unsustainability	Flattening	Sustainability
Group-3	High Medium CO ₂	U Shape	Decrease	Right Side	Sustainability	Flattening	Sustainability
Group-4	High CO ₂	U Shape	Decrease	Left Side	Unsustainability	Flattening	Sustainability

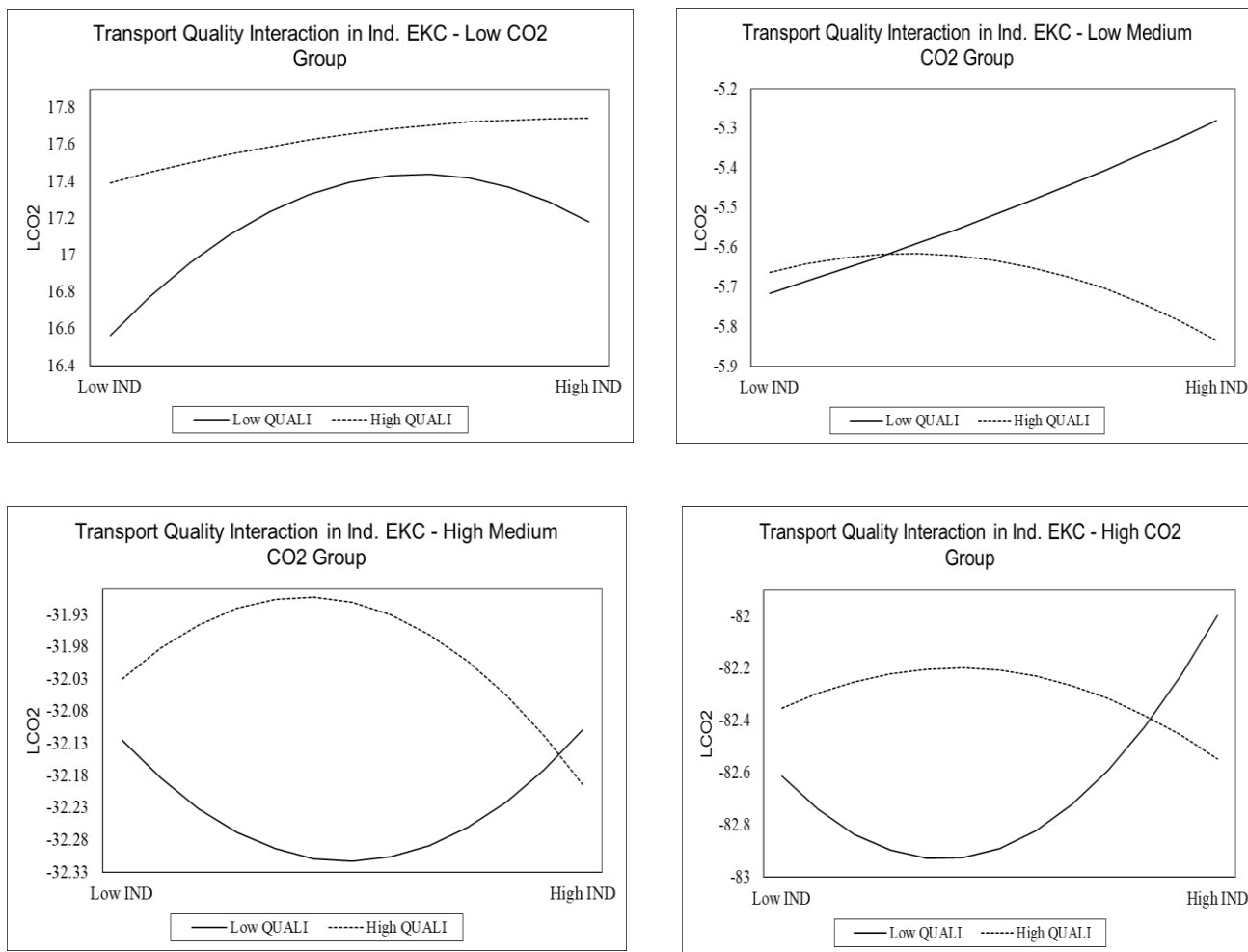


Figure 5: Moderation Impact of transport competitiveness/Quality

5. Conclusions and Policy Implications

The sixth assessment report on the environment issued by IPCC has declared that human influence is responsible for GHG emissions. The transportation sector has more than a quarter share of global carbon emissions. It is worthwhile and need of the hour to study this phenomenon to mitigate carbon emissions. This research study has identified a research gap in terms of transport competitiveness which has not been much used previously as a moderator for sustainability analysis by using industrial EKC based on transport sector emissions from a global perspective. After identifying research, the study used transport competitiveness to moderate industrial-induced EKC for assessing environmental sustainability with a special focus on industrial growth and transport sector emissions.

Transport competitiveness measures the expansion of the transport network and assesses the quality of various modes of transportation. Summarizing the first objective, transport competitiveness inclines to significantly reduce emissions in the second, third and fourth groups. This process specifies that enhancing the quality of transportation services is critical in mitigating emissions. However, in group-1, transport competitiveness increases emissions, indicating that industrial growth extensively uses various modes of transportation, which increases emissions. Regarding the study's second objective, the industrial U shape EKC has been authenticated in group-2, 3, and 4, while in group-1, the inverted U shape EKC is confirmed. However, for the third

objective, the moderation of transport competitiveness indicates the changes in the turning point and flattening of the industrial EKC. Institutional quality and planned population expansion have also been observed in managing carbon emissions.

The estimated results bring out that reliance on unmanaged industrial growth and expanding transportation sector have dire consequences in terms of environmental pollution. The validation of U shape EKC across the majority of the quantile groups raises sustainability issues. However, the moderation analysis indicates that there is a need of further improvement in the quality of transportation services through pursuing cost efficiencies and environmental protection policies. The movement from the use of fossil fuel to clean energy and improvement in fuel efficiency in all modes of transportation can help in reducing CO₂ emissions. The planned urban growth may help in reducing road sector emissions. Carbon taxing and rebates on transportation are notable measures to promote green technologies in the transport sector. The investments/budgetary allocations for technological innovations may also help in identifying the cost efficiency of renewable/sustainable fuels in the transport sector. All measures together can increase transport quality which may enhance transport competitiveness and subsequently moderation (transport competitiveness) may ensure environmental sustainability.

The study results are useful for urban planners, donor agencies, and economic planners. The manufacturers of different transportation modes need to replace the old technology based on fossil fuels with hybrid green electric vehicles to mitigate carbon emissions in the future. Similarly, in the industrial sector, the traditional production techniques are required to replace with clean and green technologies to mitigate carbon emissions. This study suffers from limited availability of data. The future researchers can extend this work through engaging the moderation role of other indicators like governance, financial expansion and renewable energy for assessing environmental sustainability by using industrial-induced EKC.

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