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Green road transportation management and environmental sustainability: The impact of population density

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A R T I C L E I N F O

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A B S T R A C T

The objective of the study is to examine the moderating role of population density in the relation between road transportation and environment sustainability of South Asian countries from 1990 to 2014. The study uses environment sustainability (population density) as the outcome (moderator), whereas road infrastructure, road density, energy intensity and transportation energy consumption are explanatory variables. The selection of these variables is motivated by their significance in understanding the relationship between road transportation and environmental sustainability. Road infrastructure and road density capture the physical aspects of transportation systems, while energy intensity and road transportation energy consumption provide insights into the energy efficiency and environmental impact of road transport, respectively. The findings show that a positive impact of road infrastructure and road density exists on environmental sustainability. There is contrarily a negative effect of road transportation energy consumption and energy intensity on environmental sustainability. Population density also harms environmental sustainability. When population density is used as a moderator between road transportation energy consumption, energy intensity and environment sustainability, it increases the coefficients of both energy intensity and road transportation energy consumption, which shows that population density plays an enhancing role between road transportation energy consumption, energy intensity and environment sustainability. The coefficients of road density and road infrastructure changed into a negative from a positive in the presence of population density as a moderator, which states that population density plays an antagonistic role between road density and environmental sustainability. We recommend prioritizing sustainable transportation solutions and policies in densely populated areas. Implementing measures such as promoting public transportation and electric vehicles, and investing in infrastructure that supports active transportation modes like cycling and walking can help mitigate the negative environmental effects of transportation while addressing the challenges posed by population density.

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1. Introduction

The movement of people and other products by motor cars, automobiles, trains, trucks, airplanes, ships, and other vehicle modes are included in the transportation industry. The environment has suffered as a result of the transportation industry's rapid growth. According to estimations, the transportation industry is the second largest source of carbon dioxide (CO_2) emissions from burning fossil fuels. The total amount of emissions from the transportation sector has been rising since 2013. According to the European Commission [1], the sector of transport accounts for 28% of the greenhouse gases (GHG) releases in the United States and 25% of GHG emissions in the European Union, mostly caused by the state of the control systems and the transportation infrastructure (TI). The necessity of greening the transportation system must therefore receive special consideration. It is clear from the backdrop that the transportation sector does not significantly contribute to sustainable development, so immediate action is needed to make the sector more sustainable and green.

Most of the recent literature backed the idea that the transportation system needs to be conducted more sustainably, even if there is still considerable doubt regarding the efficacy of alternative policies. The researchers realized the critical role of green transportation in halting climatic change and other environmental problems. The green transport strategy's overarching goal is to maintain or improve the output from transportation in terms of mobility while simultaneously reducing energy inputs, specifically in terms of the utilization of non-renewable resources. This will decrease emissions, especially CO_2, which will support the sustainability of the environment. It is necessary for both energy use and output to gradually decline over time to make a convincing case for green transportation [2]. According to the above debate, this study argues that road infrastructure (RIN), energy intensity (EIN), road density (RDN) and road transportation energy consumption (RTEC) are among the perilous factors that necessarily need to be examined under the umbrella of road transportation (RT) due to their direct or indirect ties to the green transportation industry, which eventually are translated into general environmental sustainability (ES).

RIN is one of the four essential transportation components, and changes to its configuration may help a road network manage traffic more effectively or even cut down on vehicle emissions. This argument may have the idea that the new RIN will help spread out the rush-hour traffic, which will emissions from certain locations. RIN makes a sizable contribution to the overall carbon releases. Contrariwise, the construction of new TI, rerouting the existing roads and ensuing adjustments to maintenance and rehabilitation are all connected with large GHG emissions. Expenses associated with the development and upkeep of RIN improvements may or may not be offset by the possible reductions in vehicular emissions from enhanced network efficiency [3]. It is crucial to look at whether alterations to the density and the infrastructure that enhance vehicle flow could first reduce tailpipe emissions at the regional level and second equal or exceed the emissions that are caused by the construction of that infrastructure. RDN is another crucial element that has a big impact on ES and carbon emissions caused by traffic.

EIN and RTEC are the essential elements of sustainable transportation that impact the sustainability of the environment as a whole. Fossil fuels are, without a doubt, the primary energy source for the transportation sector in developing economies. Fossil fuels are referred to as the *instruments of the economy*. Still, several drawbacks exist due to their usage, which includes that they cause greenhouse gas (GHG) and ecological variations effects and increase pollution levels that are damaging to people and other living things [4]. If the economies' transportation sectors are consuming a lot of energy, the transportation is not sustainable because it is causing several environmental conflicts.

The population density is a significant component that exacerbates environmental issues as well as acts as a moderating force on the relationship among the study variables in addition to the previously mentioned elements. This may be justified by the number of automobiles on the roads, the demand for fuel increase, and the population growth, speeding up CO_2 emissions. The population density also raises the household income growth rate and spurs more human activity [5]. People require a significant quantity of power in the shape of natural gas, electricity, and coal to work and live continuously. There is a corresponding rise in demand for RIN, RDN, EIN and RTEC with increased population density (PDN). There is thus a growing need to investigate the potential moderating influence of PDN on the relationship between road transportation and the ES of South Asian economies.

South Asia's expanding vehicle population raises the RTEC, adversely affecting ES. However, the CO_2 emission phenomena from road traffic are disregarded in the current discussion surrounding South Asian nations. Therefore, we aim to determine how road traffic affects ES in the South Asian environment. Intriguingly, this study chose the South Asian region as its setting. The issue of ES is progressively worsened due to a rapid expansion in transportation that uses poor fuel. ES is essential in every industry [6]. A rise in the energy demand causes an upswing in coal use [7]. The primary cause of unfavorable climate consequences is the increased use of oil, gas, and electricity in the transport sector [8]. An increase in energy usage highlights the relationship between RTEC and ES. The mean rate of the growth of coal from the year 2000 is 13%, representing a long-term upward trend in coal energy use. The average annual growth rate for natural gas is around 10%. We should stop using road energy or at least downplay its use to stop the catastrophic effects of climate change [9]. Thus, the study aims to examine the relationships between RTEC, RDN, RIN, EIN and ES, with PDN as a moderator.

We provide the following contributions to the debate. First, the primary precursors of economic growth are RTEC and RIN. Instead, these factors also harm the atmosphere despite their economic benefit. The emissions in some countries have decreased as a result of production moving. RTEC and RIN remain major carbon emissions sources, particularly in South Asia. The majority of the quantitative research papers that are now accessible focus on the overall usage of energy from road traffic. As a result, we focus primarily on RIN and RTEC. Second, the greater population needs a lot of energy, such as natural gas, coal, and electricity, to continuously live and work [10]. The economy of South Asia now produces a lot of CO_2 due to its growing population over the past few decades. Examining the regions' ES is necessary given the territories' varied forms of transportation and rising RIN. We thus contribute by examining PDN as a moderator in the relationships of RTEC, RDN, RIN, EIN and ES. Third, other studies used CO_2, GHG, or ecological footprints regarding measuring ES, which needs to be corrected. This study uses a true measure of ES, *adjusted net savings*, by following the preceding studies [6,11]. Fourth, we provide a first attempt to analyze the ES scenario in South Asia using PDN as a moderator. Thus, this study's novelty lies in its emphasis on RTEC and RIN as primary precursors of economic growth and their role in carbon emissions, the examination of population-driven energy demands, the adoption of adjusted net savings as a true measure of ES, and the pioneering analysis of South Asia's ES using PDN as a moderator. These novel contributions enhance the existing knowledge of the complex dynamics between road transportation, population, and ES. This paper has the following structure, which include the "hypotheses development, methods, results, discussion, conclusion and implications."

Deviations in the densification of urban zones are among the key tactics to slow down rapid urban expansion in fast-growing cities. These tactics will undoubtedly influence other urbanized systems, such as transportation. Transportation and PDN are closely related [12]. As a result, it is indispensable to reckon with and examine how these methods affect transportation [13]. A small amount of research has been conducted on the temporary effects of the changes in the population density impacting transportation, especially in rapidly growing and automobile-dependent cities in Asian economies. As a result, we examined the moderating role of PDN in sustainable transportation.

The transport sector's share in environmental degradation is growing in all parts of the world, and its contribution to GHG emissions is significant and consistent. The proportion of CO_2 emissions from the transportation industry and its ongoing expansion have brought environmental stress, transportation activity and economic expansion to the attention of the policymakers. The emphasis is on energy efficacy, scale impacts on the economy and structural changes in the transportation sector. The "*Environmental Kuznets Curve (EKC) hypothesis*" is a useful conceptual framework for addressing environmental issues that are related to GHG and carbon emissions [14,15]. According to the revised EKC theory, the scale effect hypothesis that Grosman and Kruger put forth could initially raise demand for travel and transportation-related occurrences, resulting in a striking upswing in energy usage, specifically for the transport industry [16]. More RT can make the environment worse, which is due to the scale effect of the economy. As a result, the rising energy consumption (EC), as well as increased road transport operations and activities, should be taken into account. The increased EC could increase CO_2 emissions from traffic, given how much the transport system subsidizes the energy-emission bond [17]. Emissions from the transportation sector have a direct influence on the environment, so they contribute more to GHG emissions than other economic sectors [18,19]. We expect a significant relationship between RT and ES based on EKC.

Road infrastructure (RI) development and expansion are related to social welfare, which is developmental and economic prosperity [20]. TI systems, especially roads, are specifically sensitive to environment-related changes. This is due to their vulnerability to environmental conditions [21]. The related growth of the economy and the benefits in regards to the expansion of infrastructure are therefore in danger due to the risks of climate change to roadways. TI is an important economic sector that supports social and economic development and facilitates efficient resource and material allocation [22]. It considerably contributes to economic growth (EGR) via efficiency and productivity channels. It also affects commerce, fuel EC, population, and CO_2 emissions [23]. Increasing urbanization, rising disposable income, variety in leisure activities, unequal energy dispersal and fast growth in the number of private vehicles with strong EGR have caused the need for transportation to increase. However, the environmental impacts of transportation-related operations present serious difficulties. Environmental degradation due to transport growth and its contributions to GHG emissions is significant and consistent worldwide. The policymakers have focused on EGR, transportation activities and environmental stress because of the vehicle industry's contribution to CO_2 releases and its continuous rise [24].

Road infrastructure is important for the economy's growth but also subsidizes poorer environmental quality. South Asian countries face significant threats and challenges from the escalating environmental quality deterioration, notably from the transport sector. The transportation sector's emissions have attracted the academics' attention to climate change and transportation due to its growing contribution to global emissions and consistent development [25]. A large body of studies regarding climate change analyses emphasizes the need to assess the effects of road infrastructure. Threats posed by climate change to existing and proposed infrastructure include significant costs associated with adopting, maintaining and the potential adverse consequences regarding transit, a recurring theme in the research [26].

Transportation and land use are mutually interdependent. Land use and transportation systems are inextricably intertwined [27]. Changes in land use have a considerable impact on travel demand and patterns. Transportation structure influences urban land use patterns and the accessibility of various activities. Various interactions on various periods and components occur due to the complexity of this reciprocal relationship [22]. It is also a dynamic process incorporating changes in the geographical and temporal linkages between land use and transit systems [28]. ES is crucial in the relationship between land use, population, and transportation. It guarantees that the land use and the city's transport networks are premeditated concerning their effects on the environment, economy, and society [29]. An integrated transportation system is urgently required to provide greater livability and sustainability [30]. The influence of road density and transportation planning on travel patterns may additionally be predicted by calculating population and transportation interactions [31]. Planning for proactive sustainability is encouraged by the results of road density and transportation modeling. Attention must be given to the pattern of conjoint convergence to build a holistic strategy to achieve the goals of a sustainable transportation agenda [27].

H1. A significant relationship between RIN and ES exists.

H2. A significant relationship between RDN and ES exists.

Transport is the main subset for ecological deterioration. The direct emission of pollutants results from burning fossil fuels in road vehicles [32]. Andrés and Padilla [33] premeditated 28 European states between 1990 and 2014, discovering that the mix of energy sources and the modes of transportation contributed to higher CO_2 release. Wang et al. [34] investigated a comparison of India and China to show how energy use and CO_2 emissions are related. They noticed that when more cars are on the road, CO_2 emissions increase. Baloch and Suad [35] discovered that Pakistan's growing air pollution resulted from EC for transportation using data from 1990 to 2015. Similar findings were also presented by Zhang et al. [36]. According to Timilsina and Shrestha [25], the causes of air pollution in Asian nations include income and RTEC.

There was a quick increase in the population and EC during this century around the globe, drawing the attention of numerous scholars and environmental experts toward global warming and environmental challenges [37]. Van der Zwaan et al. [38] inspected the endogenous technological revolution's influence on CO_2 releases and carbon tax levels. The greatest significant prospect regarding reducing emissions is the development of non-fossil energy technology. The ideal carbon tax is lower than the typical tax recommended for reducing road energy usage to make transportation sustainable. Sustainable transportation is indispensable for sustainable growth. Transport is relevant to eight of the "17 Sustainable Development Goals (SDGs)" that the United Nations has set as targets for completion by 2030. The advancement of sustainable transportation is necessary to fulfill these SDGs. Sustainable transportation in OECD nations has received a lot of attention. What the OECD countries do may have significant effects on other nations due to their prominent position in the global economy.

Rafiq et al. [39] examined the influence of urbanization and EC on EIN and CO_2 emissions. They highlighted that EC raises conventional levels of both CO_2 emissions and EIN. Urbanization dramatically increases EIN but has no discernible impact on carbon emissions, whereas trade liberalization lowers both CO_2 emissions and EIN. Engo [40] conducted his study on Cameroon's transport-related CO_2 emissions. The results of the study revealed that the transportation sector in Cameroon increases the EIN, which leads to a rise in CO_2 emissions. Hossain et al. [41] identified the components of CO_2 releases linked to a sustainable transportation network; they identified strategies for the long-term growth of Bangladesh's TI. They discovered significant links between population, EIN, economic activities and energy structure.

Shifting the focus to the transport sector's EC, economic growth and technological innovation, Satrovic et al. [42] undertook a study to explore their implications for ES. Examining data from 1990 to 2018, they observed a significant positive relationship between transport EC and the ecological footprint. Furthermore, Ahmad and Satrovic [43] corroborated these findings, demonstrating the efficacy of renewable energy output in mitigating the ecological footprint. In their study, Ahmad and Satrovic [44] examined the role of fiscal decentralization in mitigating the impact of economic complexity and government intervention on energy and carbon efficiency. By considering the presence of real GDP per capita, the authors found empirical evidence indicating a negative relationship between economic complexity and energy efficiency. Moreover, this negative association was more pronounced in countries with lower ES levels. Turning to the realm of ES in the transportation sector, Ahmad and Satrovic [45] sought to evaluate the effectiveness of green taxes over the period spanning from 1994 to 2016. Their investigation revealed that, while green taxes exhibit a neutral impact in the short run, they serve as a catalyst for promoting ES in the long run.

H3. A significant relationship between RTEC and ES exists.

H4. A significant relationship between EIN and ES exists.

Rahman [46] illustrated in his study that increased population is regarded as one of the primary drivers of CO_2 emissions in industrialized and emergent republics. Al Mamun et al. [47] investigated the CO_2 emissions of 136 states from 1980 to 2009 and discovered that population size led to increased CO_2 emissions. Ohlan [48] additionally discovered a positive influence of population on India's CO_2 emissions. Rahman [49] highlighted that PDN and EC positively and greatly impact CO_2 emissions. Understanding the variables that influence EC and the emission of CO_2 is crucial [50]. Rafindadi and Ozturk [51] examined the bond between CO_2 and energy usage. Few studies take PDN into account when analyzing this relationship. The contributions of these elements to EC and CO_2 emissions are additionally unclear. Therefore, they serve as proof of the contentious results [46]. Very few studies examine how PDN affects CO_2 emissions and EC [48]. According to the study by Rahman [46], PDN is a factor that can increase the impact of RT on carbon emissions. This may be justified by the idea that as the population grows, the demand for fuels, energies and transport grows too [5]. The enormous need for traffic routes will necessitate the construction of more road infrastructure. A rise in PDN also results in an upsurge in RDN due to the increased population and the resulting traffic flow cramming. These conditions raise carbon emissions [5], threatening the ES. As the population grows, more energy will be needed to meet the rising energy demands. The need for coal, electricity and gas also rises along with a growth in PDN [52], significantly enhancing carbon emissions.

Damrah et al. [53] studied the dynamic interplay between economic development, EC, population, and ES. By analyzing panel data from 1999 to 2018, the authors found empirical evidence supporting the notion that economic development, EC, and population contribute to heightened environmental degradation. Verbič et al. [54] conducted a comprehensive study utilizing a panel dataset encompassing Southeastern European countries from 1997 to 2020 to investigate the determinants of pollutant emissions. Their analysis revealed that real GDP, population, and energy consumption had unfavorable impacts on ES. As a result, the following hypotheses are postulated in line with the comments above.

H5a. Population density moderates between RIN and ES.

H5b. Population density moderates between RDN and ES.

H5c. Population density moderates between RTEC and ES.

H5d. Population density moderates between EIN and ES."

1.1. Knowledge gap

This study addresses several key knowledge gaps in the literature surrounding ES in South Asia. Despite the economic benefits of RTEC and RIN, their contribution to carbon emissions and their detrimental impact on the atmosphere is often overlooked. While some countries have experienced a decrease in emissions due to the relocation of production, RTEC and RIN remain significant sources of carbon emissions in South Asia, specifically. Currently, the available quantitative research primarily focuses on the overall energy usage in road traffic, neglecting the specific contributions of RTEC and RIN. Therefore, it is necessary to investigate and understand the relationship between these factors and their impact on ES. Additionally, as the population in South Asia continues to grow, there is an increasing demand for energy to sustain livelihoods and economic activities. This population growth has led to a substantial increase in CO_2 emissions within the region over the past few decades. Given the diverse transportation systems and the rising prominence of RIN in South Asia, it is crucial to examine the region's ES comprehensively. This study seeks to contribute by examining the moderating role of PDN in the relationships between RTEC, RDN, RIN, EIN and ES. This approach fills an existing research gap in understanding these factors' nuanced dynamics and interdependencies within the South Asian context. Furthermore, previous studies have employed flawed measures such as CO_2 emissions, GHG emissions, or ecological footprints to assess ES. In contrast, this study adopts a more comprehensive and accurate measure of ES: adjusted net savings. This metric provides a more robust evaluation of the region's sustainability. Finally, this study serves as an initial endeavor to analyze the scenario of ES in South Asia, with PDN acting as a moderator. By investigating the intricate relationships among RTEC, RDN, RIN, EIN and ES, we aim to contribute valuable insights into understanding sustainable development in the region.

2. Methodology

2.1. Data and variables

We provide analysis on the grounds of panel data from 1990 to 2021 by selecting "Five South Asian countries (Pakistan, Nepal, India, Sri Lanka, and Bangladesh) as samples. The period of 1990–2014 was selected for this analysis due to the availability of panel data (as most variables were restricted to 2021) for South Asia. This period allows for a comprehensive examination of the relationship between road transportation and ES, considering the economic and developmental changes over three decades. The data were obtained from the "*National Bureau of Statistics (NBS) and the World Development Indicators (WDI)*." The types of variables and their measures are given in Table 1. All the variables were standardized to convert them into a similar unit.

2.2. Econometric methodology

2.2.1. Cross-sectional dependence (CSD) and slope Heterogeneity (SHTG) tests

A panel CSD test must be conducted due to the growing interdependency trends and the panels of different nations that provide CSD evidence. This study analyzed the CSD test to identify the panel estimating issues and ensure that the estimators are objective, reliable, consistent, and effective. The current study used the "Breusch and Pagan [55] and Pesaran CD CSD tests," among the numerous methods offered by the current discussion, to assess the likelihood of CSD and identify the CSD issue.

In addition to examining CSD, it is imperative to address the issue of SHTG when analyzing panel data. This is due to the expected variation in slope coefficients across different units within the cross-section. Neglecting to account for SHTG can introduce bias into elasticity estimates. In the context of this study, despite the interconnectedness of the selected South Asian countries, there exist notable distinctions among them, manifested through diverse macroeconomic indicators such as per capita CO_2 emissions, energy consumption levels, renewable energy structures, and national income levels. Consequently, it is crucial to acknowledge the potential presence of SHTG concerns. Thus, the study employs Pesaran and Yamagata's [56] SHTG test, which involves estimating two test statistics ($\Delta^{\sim}$ and $\Delta^{\sim}_{\text{Adjusted}}$), assuming homogeneous slope coefficients across the cross-sectional units. Subsequent to the CSD and SHTG analyses, the study proceeds with the panel unit root analysis to further examine the data.

Table 1
Variables.

Variable	Definition/Measurement	Reference	Source
Dependent Variable			
Environment Sustainability (ES)	Adjusted net savings (excluding particular carbon emissions)	Huo et al. [6]	WDI
Independent Variables			
Road Infrastructure (RIN)	"Total length of roads"	Baloch and Suad [35]	NBS
Road Density (RDN)	"Total length of roads/population"	Aljoufie [12]	NBS
Road Transport Energy Consumption (RTEC)	"Road energy consumption (Kg of oil equivalent per capita)"	Baloch and Suad [35]	WDI
Energy Intensity (EIN)	"Road energy consumption/GDP"	Baloch and Suad [35]	WDI
Moderating Variable			
Population Density (PDN)	"Population density (people per sq. km of land area)"	Baloch and Suad [35], Aljoufie [12]	WDI
Control Variable			
Economic Growth (EGR)	"Per capita GDP (current US$)"	Chen and Lin [4]	WDI

Note: "WDI: World Development Indicators, NBS: National Bureau of Statistics; Global Footprint Network".

2.2.2. Unit root test

The unit root test is a statistical method used to demonstrate if time series variables are stationary. The non-stationarity of the time series variables shows the nonappearance of the unit root. This study uses "*lm, Pesaran, and Shin (CIPS) and Levin–Lin–Chu tests.*" This offers precise and useful data concerning the series' order of integration (OI). These panel unit root methods are more stable and performant due to their asymptotic supposition.

2.2.3. Kao engle–granger-based cointegration test

The Kao cointegration approach is utilized because examining the long-term correlations between the series is important before examining the OI of variables. This test uses Pedroni test foundations, incorporating cross-sectional particular intercepts and the same coefficient for the first phase regressor [57].

2.2.4. Fully modified ordinary least square (FMOLS)

We used the FMOLS test to estimate how the predictors will affect ES and to hold the moderating effect of PDN in the long run. This approach can capture serial correlations. This approach is only used when cointegration between the series is seen. Eq. (1) is used to get the FMOLS estimates:

$$Y_{it} = \alpha_i + \acute{X}_{it}\delta + \sum_{j=-q_1}^{j=q_2} L_{ij}\Delta X_{it+j} + \mu_{it'} \tag{1}$$

where, "Y is the outcome variable, X is a vector of the explanatory variables, and L_{ij} are the lag/lead coefficients of the regressors at the first difference."

2.3. Panel causality analysis

Given the identified SHTG issues, the conventional Granger [58] panel causality estimation technique is considered inadequate for this study. Consequently, the Dumitrescu and Hurlin [59] causality method is adopted as an alternative approach. Unlike the Granger [58] approach, the Dumitrescu and Hurlin [59] method specifically addresses concerns pertaining to SHTG within the dataset. This is achieved by computing a test statistic under the alternative hypothesis of causality between two stationary series while accounting for the potential existence of such causality in at least one of the cross-sectional units. By employing this methodology, the study ensures a more suitable and robust analysis of causality relationships.

2.4. Empirical models

The following functional Eq. (2) is utilized to examine how RTEC, EIN, RIN and RDN affect ES following the earlier investigations:

$$ES_{it} = f\left(RTEC_{it,}EIN_{it}, RIN_{it}, RDN_{it}\right) \tag{2}$$

Using the moderating impact to produce the interaction term of specific factors is a typical technique used in the literature [11,60]. Therefore, we adopted similar strategies to create multiple interaction terms that represent the moderating impact of PDN on the relations between the predictors and the outcome. However, the empirical models that are used in the study generally take equations (3)–(7):

$$ES_{it} = f\left(RIN_{it,}RDN_{it}, RTEC_{it}, EIN_{it}, EGR_{it}\right) \tag{3}$$

$$ES_{it} = f\left(RIN_{it,}RDN_{it}, RTEC_{it}, EIN_{it}, RIN_{it} * PDN_{it}, EGR_{it}\right) \tag{4}$$

$$ES_{it} = f\left(RIN_{it,}RDN_{it}, RTEC_{it}, EIN_{it}, RDN_{it} * PDN_{it}, EGR_{it}\right) \tag{5}$$

$$ES_{it} = f\left(RIN_{it,}RDN_{it}, RTEC_{it}, EIN_{it}, RTEC_{it} * PDN_{it}, EGR_{it}\right) \tag{6}$$

$$ES_{it} = f\left(RIN_{it,}RDN_{it}, RTEC_{it}, EIN_{it}, EIN_{it} * PDN_{it}, EGR_{it}\right) \tag{7}$$

Table 2
Descriptive statistics and correlations.

Variables	Med.	Max.	Min.	EGR	EIN	ENS	PDN	RDN	RIN	RTEC
EGR	−0.337	4.633	−0.887	1						
EIN	−0.435	2.761	−1.364	−0.575	1					
ES	0.006	2.489	−2.090	0.170	−0.242	1				
PDN	−0.344	2.478	−0.877	−0.035	−0.552	0.302	1			
RDN	−0.227	2.026	−0.921	0.493	−0.476	0.009	−0.050	1		
RIN	0.176	2.668	−1.405	0.116	−0.349	−0.259	0.236	−0.290	1	
RTEC	0.186	2.205	−2.022	0.500	0.019	−0.175	−0.601	0.106	0.314	1

where, *n* is the total number of observations, and k is the number of predictors. We created a distinct model for the interaction terms to accommodate a higher degree of freedom *(n-k)*.

3. Results

The effect that road transport has on ES is discussed in this section in conjunction with descriptive measures, correlations, unit root, CSD, cointegration and FMOLS tests. The descriptive measures, including the median, smallest, and largest values, and the correlations are depicted in Table 2. The correlation scores are within the threshold level, which shows that there is no issue of multicollinearity. Applying the Pesaran CD and Breush and Pagan LM tests verified the assumption of CSD in the panel data. The outputs in Table 3 illustrate that the probability values for all the variables are below the 0.01 level, which concludes that CSD exists [61]. This demonstrates how the results of other economies in the sample are disrupted when an economy experiences a shock.

The results of the Pesaran and Yamagata [56] test of SHTG for all five models investigated in this study are presented in Table 3. The test statistics exhibited statistical significance at 1%, leading to the rejection of H_0. These findings provide empirical support for the existence of SHTG issues within the dataset. Having established the presence of both CSD and SHTG, the subsequent step entails employing panel data unit root and co-integration estimators. These estimators are utilized to determine the integrating properties of the variables and investigate the potential co-integration among the variables under consideration.

After confirming that the CSD and SHTG issues are present, we looked at the stationary characteristics of the research variables that are taken into account by CIPS and the Levin–Lin–Chu tests. The outputs in Table 4 show no problems with unit roots at the level. All the relevant variables reach significance at the 0.01 level when the test is run at I(1). The findings demonstrate that all series are assimilated in the same order, I(1). Next, we use an appropriate test to confirm the long-term relation of variables after confirming the OI. The Kao test decides whether the variables tend to move in tandem over time. Table 5 contains the output of this test. The Kao test's results are significant at the 0.01 level, indicating the existence of cointegration. The test results show that our variables are interacting over time.

The Kao test validates cointegration between the variables. Thus, FMOLS is used to calculate the long-term association between the variables. The FMOLS outcomes are included in Table 6. Model 1 is run without the product terms, which shows a positive impact of RIN on ES. The coefficient of RIN signifies that a unit rise in RIN will sustain the environment by 1.109 units in the long run. The effect of RDN on ES is also positive, which is described as a one-unit increase in RDN, improving ES by 0.523 units. There is contrarily a negative effect of RTEC on ES, which signifies that increasing RTEC by one unit will decline ES by 0.041 units in the long run. EIN also has a negative impact on ES. The negative coefficient of EIN reports that a unit rise in EIN will demolish the ES by 0.396 units. Moreover, PDN also negatively affects ES, indicating that 1.049 units of ES are decreased against a single unit rise in PDN. Our control variable EGR also shows a negative influence on ES. PDN is used as a moderator between EIN and ES in model 2. The PDN entry increased the coefficient of EIN from 0.396 to 0.442, which shows that PDN plays an enhancing role between EIN and ES. The coefficient of RDN changes into a negative (−1.445) from a positive (0.523) in the 3rd model, which states that PDN plays an antagonistic role between RDN and ES. The PDN entry as a moderator changed the coefficient of RIN from a positive (1.109) to a negative (−1.825) in the 4th model, which signifies that PDN also plays an antagonistic role between RIN and ES. The RTEC coefficient similarly augmented from 0.041 to 0.607, again showing that PDN has an enhancing role between RTEC and ES in the long run when PDN is taken as a moderating factor between RTEC and ES in model 5. Moreover, the adjusted R^2 ranges from 46.8% to 60.8%, which signifies that the regressors define 46.8%–60.8% of the variations in the outcome.

The causal relationships among the variables of interest were examined using the Dumitrescu-Hurlin causality approach, and the results are presented in Table 7. The findings reveal that variables such as RTEC, RIN, EIN and RDN have a causal influence on ES through PDN. Consequently, effective PDN control can be crucial in promoting ES in South Asian countries. Furthermore, bidirectional causal relationships were observed between RTEC and ES, RIN and ES and PDN and ES. This implies that any policy changes

Table 3
Cross-sectional dependency (CSD) and slope heterogeneity (SHTG) tests.

CSD Test Results					
Variables	*Breush-Pagan LM*		*Pesaran CD*		*Decision*
	Test statistics	*P-value*	*Test statistic*	*P-value*	
EGR	238.353***	0.000	15.437***	0.000	*Cross-sectional dependence*
EIN	220.300***	0.000	14.838***	0.000	*Cross-sectional dependence*
ES	77.231***	0.000	3.0423***	0.002	*Cross-sectional dependence*
PDN	244.494***	0.000	15.635***	0.000	*Cross-sectional dependence*
RDN	143.536***	0.000	−2.816***	0.000	*Cross-sectional dependence*
RIN	112.746***	0.000	13.875***	0.000	*Cross-sectional dependence*
RTEC	181.734***	0.000	13.357***	0.000	*Cross-sectional dependence*
Pesaran and Yamagata (2008) SHTG Test Results					
Test Statistics	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*
$\Delta^{\sim}$	15.274***	18.349***	16.061***	19.964***	17.652***
$\Delta^{\sim}_{\text{Adjusted}}$	15.679***	18.788***	16.459***	20.037***	18.037***

"*** significant at 1%."

Table 4
Panel-unit root test.

Panel A: Levin, Lin & Chu Unit Root Test					Decision
Variables	Level		First difference		
	Test statistics	P-value	Test statistic	P-value	
EGR	6.101	1.000	−3.071***	0.001	*I (1)*
EIN	1.034	0.849	−4.598***	0.000	*I (1)*
ES	−1.255	0.104	−4.690***	0.000	*I (1)*
PDN	−1.262	0.100	−3.366***	0.000	*I (1)*
RDN	−0.727	0.233	−8.908***	0.000	*I (1)*
RIN	−0.363	0.358	−8.983***	0.000	*I (1)*
RTEC	3.982	1.000	−2.780***	0.002	*I (1)*
Panel A: Im, Pesaran and Shin Unit Root Test					**Decision**
Variables	**Level**		**First difference**		
	Test statistic	**P-value**	**Test statistic**	**P-value**	
EGR	7.385	1.000	−2.264***	0.011	*I (1)*
EIN	3.300	0.999	−5.421***	0.000	*I (1)*
ES	−0.098	0.460	−4.890***	0.000	*I (1)*
PDN	−0.904	0.182	−2.643***	0.004	*I (1)*
RDN	1.251	0.894	−9.334***	0.000	*I (1)*
RIN	−0.464	0.321	−9.355***	0.000	*I (1)*
RTEC	5.193	1.000	−2.974***	0.001	*I (1)*

"* significant at 0.01".**

Table 5
Kao Cointegration test.

Model 1		Model 2		Model 3		Model 4		Model 5	
Test statistic	P-value	Test statistic	P-value	Test statistic	P-value	Test statistic	P-value	Test statistic	P-value
−3.548	0.000	−4.010	0.000	−3.725	0.000	−3.863	0.000	−3.702	0.000
"Cointegration exists"		*"Cointegration exists"*		*"Cointegration exists"*		*"Cointegration exists"*		*"Cointegration exists"*	

Table 6
FMOLS (dependent: ES).

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
RIN	1.109*** (0.000)	1.153*** (0.000)	1.047* (0.103)	−1.825*** (0.000)	1.111*** (0.000)
RDN	0.523*** (0.000)	0.520*** (0.000)	−1.445*** (0.011)	0.394*** (0.000)	0.551*** (0.000)
RTEC	−0.041*** (0.000)	−1.107*** (0.000)	−0.284 (0.831)	−0.874*** (0.000)	−0.607*** (0.000)
EIN	−0.396*** (0.000)	−0.442*** (0.000)	−0.383 (0.448)	−0.501*** (0.000)	−0.472*** (0.000)
PDN	−1.049*** (0.000)	−1.027*** (0.000)	−1.943** (0.020)	−0.469*** (0.000)	0.455*** (0.000)
EGR	−0.157*** (0.000)	−0.158*** (0.000)	−3.439** (0.032)	−0.175*** (0.000)	−0.161*** (0.000)
PDN*EIN	–	−0.120*** (0.000)	–	–	–
PDN*RDN	–	–	−1.780* (0.076)	–	–
PDN*RIN	–	–	–	−1.853*** (0.000)	–
PDN*RTEC	–	–	–	–	−1.264*** (0.000)
R^2	0.491	0.495	0.547	0.608	0.533
Adj. R^2	0.468	0.4686	0.527	0.587	0.508

"***, ** and *: significant at 0.01, 0.05 and 0.10, respectively."

Table 7
The dumitrescu-hurlin panel causality test results.

Variables	EGR	EIN	ES	PDN	RDN	RIN	RTEC
EGR	–	6.922***	8.326***	10.009***	8.088***	12.342***	6.573***
EIN	2.942***	–	5.827***	6.301***	5.196***	4.333***	5.690***
ES	3.487***	9.674***	–	8.0595***	11.355***	8.061***	10.481***
PDN	2.672**	3.998***	7.903***	–	1.394	1.037	4.396***
RDN	4.570***	1.092	6.490***	7.579***	–	4.091***	8.067***
RIN	7.067***	8.863***	4.087***	12.647***	9.968***	–	7.666***
RTEC	5.952***	11.744***	5.636***	1.032	5.271***	6.471***	–

"*** and **: significant at 0.01 and 0.05, respectively."

implemented concerning RTEC, RIN, or PDN will impact ES. In summary, the control of PDN affects the predictors and has a significant influence on ES in South Asia.

4. Discussion

The movement of people and other things by different vehicle modes is included in the transportation industry. The environment has suffered due to the transport sector's rapid growth. According to estimations, the transportation industry is the second largest source of CO_2 released from the sweltering of vestige fuels. The total amount of emissions from the transportation sector has been rising since 2013, mostly caused by the state of the control systems and TI. The necessity of separating transportation from CO_2 must therefore receive special consideration. It is clear from the backdrop that the transportation sector does not significantly subsidize sustainable development, which needs immediate action to make it more sustainable. Thus, using data from 1990 to 2014, we analyzed the effect of PDN on the association between road transport and ES in South Asian nations. The study is novel as it uses a true measure of ES. It further tests how PDN moderates between road transportation and ES. Framing in EKC theory, we find a significant effect of road transportation on ES, which the PDN further moderates. Thus, we contribute to the EKC by examining the moderating role of PDN in road transportation and ES relations.

The findings show a positive impact of RIN on ES, which signifies that RIN causes the sustaining of the environment in South Asian economies, which leads to accepting our H_1. The effect of RDN on ES is also positive, which states that RDN improves ES in the long run, so H_2 is supported. The results support the findings of the other related studies [21,24,25,27,31]. The positive impact of RIN and RDN on ES indicates that a well-planned and well-maintained RIN can improve transportation efficiency, reducing travel time and fuel consumption. This, in turn, can reduce GHG emissions, air pollution and other harmful environmental impacts of transportation. RIN helps improve access to public transportation, making it easier for people to use buses and trains rather than personal cars. This reduces the number of cars on the road, which helps to reduce traffic congestion, air pollution and GHG emissions [24]. RDN can be designed to minimize the fragmentation of natural habitats, protect important ecosystems, and reduce habitat destruction. RIN can be planned and developed in ways that support sustainable land use. This can include developing green spaces and natural areas, providing important ecological benefits, such as carbon sequestration and supporting biodiversity [31]. Overall, RIN and RDN can contribute positively to ES by reducing GHG emissions and air pollution, protecting natural habitats, and supporting sustainable land use. However, it is imperative to note that RIN's design, development, and maintenance must be carefully planned and managed to ensure that they maximize these positive impacts while minimizing negative impacts.

There is contrarily a negative effect of RTEC on ES, which indicates that RTEC declines ES in the long run. Thus, the H_3 of the study is sustained. EIN also has a negative impact on ES, which reports that EIN demolishes the ES in South Asia, so H_4 is also accepted. The above results are identical to prior scholars' findings [33–36,39,41–45]. The negative impact of RTEC and EIN on ES is justified in such a way that road transport is a significant contributor to GHG emissions, with the majority of emissions coming from burning fossil fuels, such as gasoline and diesel. These emissions contribute to climate change, which can have wide-ranging negative impacts, such as severe weather and ecosystem disruptions. Road transport is also a foremost source of pollution, which negatively impacts human health, ecosystems, and the environment [41–45]. Exhaust emissions from vehicles contain pollutants (like nitrogen oxides) that can contribute to respiratory problems, cardiovascular disease and other health issues. Building and maintaining roads requires significant land use, which can result in habitat destruction, fragmentation, and loss of biodiversity. This can negatively impact the ecosystem services these habitats provide, such as carbon sequestration, water filtration and nutrient cycling [33]. Overall, RTEC and EIN have significant negative impacts on ES. Developing and implementing strategies to reduce these impacts is important, such as promoting cleaner, more sustainable energy sources, investing in public transportation, and promoting sustainable land use planning.

PDN also negatively affects ES by describing that ES will be declined against a rise in PDN which is in line with prior studies [53, 54]. It increases the coefficient of RTEC, which shows that PDN plays an enhancing role between RTEC and ES when PDN is used as a moderator between RTEC and ES. The coefficient of EIN has similarly augmented, again showing that PDN has an enhancing role between EIN and ES in the long run when PDN is taken as a moderating factor between EIN and ES. The entry of PDN as moderator changed the coefficient of RIN from a positive to a negative, which signifies that PDN also plays an antagonistic role between RIN and ES. The coefficient of RDN also changes into a negative from a positive in the presence of PDN as moderator, which states that PDN plays an antagonistic role between RDN and ES. Thus, the significant role of PDN as a moderator leads to the support of H_5. It was discovered that the population size led to a decline in ES. PDN is a factor that can increase the impact of RT on ES. This may be justified in a way that the demand for energy, fuels and transportation grows as the population grows. The enormous need for traffic routes will necessitate the construction of more road infrastructure. An upsurge in PDN also results in an escalation in RDN due to the increased population and the resulting traffic crowding. These conditions tend to raise carbon emissions, threatening the ES. As the population grows, further energy will be needed to meet the rising energy demand. The need for coal, energy and gas also rises, increasing carbon emissions and growth in PDN, so the resulting ES declines.

Our analysis also reveals economic meaning for the relationship between road transportation, PDN and ES. Investments in road infrastructure and density positively impact sustainability by facilitating efficient mobility. However, RTEC and EIN have negative effects, emphasizing the need for improved energy efficiency and reduced carbon emissions. The negative impact of PDN on ES highlights the challenges in balancing resource consumption with environmental preservation. PDN as a moderator enhances the relationship between RTEC, EIN and ES, calling for targeted policies to mitigate adverse environmental impacts. Densely populated areas face difficulties in achieving sustainability, indicated by the shift of RDN and infrastructure coefficients from positive to negative. Integrated planning and policies considering PDN are crucial for balancing economic growth, efficient transportation, and environmental protection.

Our findings support the EKC hypothesis, a useful conceptual framework for addressing the environmental issues related to GHG and carbon emissions. According to the revised EKC theory, the scale effect hypothesis could initially raise the demand for travel and transportation-related activities, resulting in a striking rise in energy consumption for transport and several other sectors. More RT can make the environment worse, which is due to the scale effect of the economy. As a result, the rising energy consumption, as well as the increased road transport operations and activities, should be considered. The increased energy consumption could result in increased CO_2 emissions from traffic, given how much the transportation system contributes to the energy and emissions nexus. Emissions from the transportation sector have a direct influence on the environment. As a result, they contribute more to GHG emissions than other economic sectors, so the ES demolishes. Thus, we conclude a significant moderating role of PDN in the link between road transportation and ES.

5. Conclusion and policy implications

Transportation emissions have been on the rise due largely to the poor condition of the sector's control systems and transport infrastructure. Therefore, giving special attention to the need to decouple transportation, population and ES is crucial. Our findings show the positive impact of RIN and RDN on ES, highlighting the need for sustainable road development practices and greater awareness of the environmental impact of transportation systems. We show the negative impact of RTEC and EIN on ES, highlighting the need for sustainable transportation policies and investment in alternative modes of transportation. We also find that PDN strengthens the negative impact of RTEC and EIN on ES, suggesting the need for a coordinated and integrated approach to sustainable transport that considers PDN, RTEC and EIN. The results also confirm that PDN converts the positive effect of RIN and RDN on ES to a negative. It would require a concerted effort from city planners, policymakers, and individuals to find sustainable transportation solutions to improve environmental and societal outcomes.

The present study has some suggestions for the policymakers of South Asian Economies. First, the study suggests the government invest some money into building green road infrastructure. This action might lead to deterioration in the short run but will favor the ES in the long run. This is true because the traffic rush will be divided, reducing traffic-generated carbon emissions when there is more infrastructure. Road infrastructure will also decrease the amount of traffic in this area, allowing for a considerable improvement in the characteristics of the traffic flow and a decrease in the environmental harm brought on by road travel. Second, the study suggests to the government of South Asian economies introduce environmentally friendly or energy-efficient fuels for vehicles. This will reduce transport-generated emissions by making the sector green and positively contribute to the overall ES by making the transport sector more sustainable. Third, the governments should encourage public transport usage to reduce the traffic generated emissions. Fourth, governments should pay taxes and subsidies to adjust the transport costs of green energy. They should also provide incentives to stimulate public and commercial clean and renewable technology, promote and improve green infrastructure, including urban road transport networks, and pass legislation to progressively decarbonize all the economic sectors, including the transport sector.

This study has several limitations that warrant further investigation in future research. Firstly, the transportation industry encompasses both public transportation systems and private automobile companies, yet this study needs to differentiate between the two. Future studies should contrast these entities and determine which is more energy and cost-efficient in promoting ES. Secondly, this study focuses on a regional analysis of South Asian nations, omitting a country-by-country examination. It would be valuable to conduct a more granular analysis at the individual and national levels better to understand the relationship between road transport and ES. Such an approach could provide insights into specific country contexts and capture variations in policies and practices within each nation. Furthermore, it is important to acknowledge the significant intra-city variance in transportation patterns and its potential impact on ES. Exploring this variation in greater detail through additional research could yield more nuanced and fruitful policy implications for urban areas. Additionally, the generalizability of the findings to countries with different growth rates should be explored. Comparative studies involving nations at varying stages of development could offer valuable insights into the applicability of the relationships investigated in this study. Lastly, future research could consider the strong interdependence between variables such as RTEC, RIN and ES to enhance empirical results. Exploring the effects of these variables on other aspects, such as economic growth, health spending, financial development, and automotive use, could provide a more comprehensive understanding of the complex dynamics at play.

Author contribution statement

Ashraf Ud Din: conceived and designed the experiments; Imran Ur Rahman: performed the experiments; Rakan Radi Alhrahsheh: analyzed and interpreted the data; Heesup Han, Sunghoon Yoo: contributed reagents, materials, analysis tools or data; Jian Ming: Analyzed and interpreted the data and wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] European Commission (EC), EURL Lm Technical Guidance Document for Conducting Shelf-life Studies on Listeria Monocytogenes in Ready-to-eat Foods, 2014. Available online, http://www.fsai.ie/uploadedFiles/EURL%20Lm_Technical%20Guidance%20Document%20Lm%20shelf-life%20studies_V3_2014-06-06%20(2).pdf.
[2] D. Banister, Sustainable urban development and transport-a Eurovision for 2020, Transport Rev. 20 (1) (2000) 113–130.
[3] A.M. Fraser, M.V. Chester, Transit system design and vulnerability of riders to heat, J. Transport Health 4 (2017) 216–225.
[4] S.C. Chen, C.P. Lin, The impact of customer experience and perceived value on a sustainable social relationship in blogs: an empirical study, Technol. Forecast. Soc. Change 96 (2015) 40–50.
[5] E.W.F. Peterson, The role of population in economic growth, Sage Open 7 (4) (2017), 2158244017736094.
[6] W. Huo, M.R. Ullah, M. Zulfiqar, S. Parveen, U. Kibria, Financial development, trade openness, and foreign direct investment: a battle between the measures of environmental sustainability, Front. Environ. Sci. 77 (2022).
[7] D. Shen, M. Xia, Q. Zhang, E. Elahi, Y. Zhou, H. Zhang, The impact of public appeals on the performance of environmental governance in China: a perspective of provincial panel data, J. Clean. Prod. 231 (2019) 290–296.
[8] A.E. Dingil, J. Schweizer, F. Rupi, Z. Stasiskiene, Updated models of passenger transport-related energy consumption of urban areas, Sustainability 11 (15) (2019) 4060.
[9] F. Wang, W. Cai, E. Elahi, Do green finance and environmental regulation play a crucial role in the reduction of CO_2 emissions? An empirical analysis of 126 Chinese cities, Sustainability 13 (23) (2021), 13014.
[10] B. Peng, Q. Huang, E. Elahi, G. Wei, Ecological environment vulnerability and driving force of Yangtze River urban agglomeration, Sustainability 11 (23) (2019) 6623.
[11] A.U. Din, J. Ming, A. Vega-Muñoz, G.S. Sepúlveda, N. Contreras-Barraza, Population density: an underlying mechanism between road transportation and environmental quality, Front. Environ. Sci. 10 (2022).
[12] M. Aljoufie, M. Zuidgeest, M. Brussel, M. van Maarseveen, Spatial–temporal analysis of urban growth and transportation in Jeddah City, Saudi Arabia, Cities 31 (2013) 57–68.
[13] M. Palm, B. Gregor, H. Wang, B.S. McMullen, The trade-offs between population density and households′ transportation-housing costs, Transport Pol. 36 (2014) 160–172.
[14] U. Al-Mulali, I. Ozturk, The investigation of environmental Kuznets curve hypothesis in the advanced economies: the role of energy prices, Renew. Sustain. Energy Rev. 54 (2016) 1622–1631.
[15] S.A. Sarkodie, V. Strezov, Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries, Sci. Total Environ. 646 (2019) 862–871.
[16] S.A. Sarkodie, The invisible hand and EKC hypothesis: what are the drivers of environmental degradation and pollution in Africa? Environ. Sci. Pollut. Control Ser. 25 (22) (2018) 21993–22022.
[17] S. Erdogan, I. Okumus, A.E. Guzel, Revisiting the Environmental Kuznets Curve hypothesis in OECD countries: the role of renewable, non-renewable energy, and oil prices, Environ. Sci. Pollut. Control Ser. 27 (19) (2020) 23655–23663.
[18] A.S. Alshehry, M. Belloumi, Study of the environmental Kuznets curve for transport carbon dioxide emissions in Saudi Arabia, Renew. Sustain. Energy Rev. 75 (2017) 1339–1347.
[19] S. Solaymani, CO2 emissions patterns in 7 top carbon emitter economies: the case of the transport sector, Energy 168 (2019) 989–1001.
[20] M.J. Koetse, P. Rietveld, The impact of climate change and weather on transport: an overview of empirical findings, Transport. Res. Transport Environ. 14 (3) (2009) 205–221.
[21] L.A. Bollinger, C.W.J. Bogmans, E.J.L. Chappin, G.P. Dijkema, J.N. Huibregtse, N. Maas, L.A. Tavasszy, Climate adaptation of interconnected infrastructures: a framework for supporting governance, Reg. Environ. Change 14 (3) (2021) 919–931.
[22] Y. Kuştepeli, Y. Gülcan, S. Akgüngör, Transportation infrastructure investment, growth and international trade in Turkey, Appl. Econ. 44 (20) (2012) 2619–2629.
[23] M.A. Beyzatlar, M. Karacal, H. Yetkiner, Granger-causality between transportation and GDP: a panel data approach, Transport. Res. Pol. Pract. 63 (2014) 43–55.
[24] Y. Habib, E. Xia, S.H. Hashmi, Z. Ahmed, The nexus between road transport intensity and road-related CO2 emissions in G20 countries: an advanced panel estimation, Environ. Sci. Pollut. Control Ser. 28 (41) (2021) 58405–58425.
[25] G.R. Timilsina, A. Shrestha, Transport sector CO2 emissions growth in Asia: underlying factors and policy options, Energy Pol. 37 (11) (2009) 4523–4539.
[26] M.R. Oswald, S. McNeil, Climate change adaptation tool for transportation: mid-Atlantic region case study, J. Transport. Eng. 139 (4) (2013) 407–415.
[27] A. Alonso, A. Monzón, Y. Wang, Modeling land use and transport policies to measure their contribution to urban challenges: the case of Madrid, Sustainability 9 (3) (2017) 378.
[28] S.L. Shaw, X. Xin, Integrated land use and transportation interaction: a temporal GIS exploratory data analysis approach, J. Transport Geogr. 11 (2) (2003) 103–115.
[29] United Nations, The Sustainable Development Goals Report, UN, New York, NY, USA, 2016.
[30] M. Wegener, Land-use transport interaction models, Handbook of regional science (2021) 229–246.
[31] J. De Vos, The influence of land use and mobility policy on travel behavior: a comparative case study of Flanders and The Netherlands, J Trans Land Use 8 (1) (2015) 171–190.
[32] P.N. Kishimoto, V.J. Karplus, M. Zhong, E. Saikawa, X. Zhang, X. Zhang, The impact of coordinated policies on air pollution emissions from road transportation in China, Transport. Res. Transport Environ. 54 (2017) 30–49.
[33] L. Andrés, E. Padilla, Driving factors of GHG emissions in the EU transport activity, Transport Pol. 61 (2018) 60–74.
[34] H. Wang, X. Ou, X. Zhang, Mode, technology, energy consumption, and resulting CO2 emissions in China's transport sector up to 2050, Energy Pol. 109 (2017) 719–733.
[35] M.A. Baloch, S. Suad, Modeling the impact of transport energy consumption on CO2 emission in Pakistan: evidence from ARDL approach, Environ. Sci. Pollut. Control Ser. 25 (10) (2018) 9461–9473.
[36] S. Zhang, H. Ren, W. Zhou, Y. Yu, C. Chen, Assessing air pollution abatement co-benefits of energy efficiency improvement in cement industry: a city-level analysis, J. Clean. Prod. 185 (2018) 761–771.
[37] R. Sabouni, H. Kazemian, S. Rohani, Carbon dioxide capturing technologies: a review focusing on metal-organic framework materials (MOFs), Environ. Sci. Pollut. Control Ser. 21 (8) (2014) 5427–5449.
[38] B.C. Van der Zwaan, R. Gerlagh, L. Schrattenholzer, Endogenous technological change in climate change modeling, Energy Econ. 24 (1) (2002) 1–19.
[39] S. Rafiq, R. Salim, I. Nielsen, Urbanization, openness, emissions, and energy intensity: a study of increasingly urbanized emerging economies, Energy Econ. 56 (2016) 20–28.
[40] J. Engo, Decoupling analysis of CO2 emissions from the transport sector in Cameroon, Sustain. Cities Soc. 51 (2019), 101732.
[41] M. Hossain, S. Chen, A.G. Khan, Decomposition study of energy-related CO2 emissions from Bangladesh's transport sector development, Environ. Sci. Pollut. Control Ser. 28 (4) (2021) 4676–4690.
[42] E. Satrovic, A. Cetindas, I. Akben, S. Damrah, Do natural resource dependence, economic growth and transport energy consumption accelerate ecological footprint in the most innovative countries? The moderating role of technological innovation, Gondwana Res. (2023), https://doi.org/10.1016/j.gr.2023.04.008.
[43] M. Ahmad, E. Satrovic, Modeling combined role of renewable electricity output, environmental regulations, and coal consumption in ecological sustainability, Ecol. Inf. 75 (2023), 102121.
[44] M. Ahmad, E. Satrovic, Role of economic complexity and government intervention in environmental sustainability: is decentralization critical? J. Clean. Prod. (2023), 138000.

[45] M. Ahmad, E. Satrovic, How do transportation-based environmental taxation and globalization contribute to ecological sustainability? Ecol. Inf. 74 (2023), 102009.
[46] M.M. Rahman, Do population density, economic growth, energy use and exports adversely affect environmental quality in Asian populous countries? Renew. Sustain. Energy Rev. 77 (2017) 506–514.
[47] M. Al Mamun, K. Sohag, M.A.H. Mia, G.S. Uddin, I. Ozturk, Regional differences in the dynamic linkage between CO2 emissions, sectoral output and economic growth, Renew. Sustain. Energy Rev. 38 (2014) 1–11.
[48] R. Ohlan, The impact of population density, energy consumption, economic growth and trade openness on CO2 emissions in India, Nat. Hazards 79 (2) (2014) 1409–1428.
[49] M.M. Rahman, Exploring the effects of economic growth, population density and international trade on energy consumption and environmental quality in India, Int. J. Energy Sect. Manag. 14 (6) (2020) 1177–1203.
[50] M.M. Rahman, S.A.K. Mamun, Energy use, international trade and economic growth nexus in Australia: new evidence from an extended growth model, Renew. Sustain. Energy Rev. 64 (2016) 806–816.
[51] A.A. Rafindadi, I. Ozturk, Natural gas consumption and economic growth nexus: is the 10th Malaysian plan attainable within the limits of its resource? Renew. Sustain. Energy Rev. 49 (2015) 1221–1232.
[52] P.S. Chinowsky, A.E. Schweikert, N. Strzepek, K. Strzepek, Road infrastructure and climate change in Vietnam, Sustainability 7 (5) (2015) 5452–5470.
[53] S. Damrah, E. Satrovic, M. Atyeh, F.A. Shawtari, Employing the panel quantile regression approach to examine the role of natural resources in achieving environmental sustainability: does globalization create some difference? Mathematics 10 (24) (2022) 4795.
[54] M. Verbič, E. Satrovic, A. Mujtaba, Assessing the driving factors of carbon dioxide and total greenhouse gas emissions to maintain environmental sustainability in southeastern europe, Int. J. Environ. Res. 16 (6) (2022) e105.
[55] T.S. Breusch, A.R. Pagan, The Lagrange multiplier test and its applications to model specification in econometrics, Rev. Econ. Stud. 47 (1) (1980) 239–253.
[56] M.H. Pesaran, T. Yamagata, Testing slope homogeneity in large panels, J. Econom. 142 (1) (2008) 50–93.
[57] C. Kao, M.H. Chiang, B. Chen, International R&D spillovers: an application of estimation and inference in panel cointegration, Oxf. Bull. Econ. Stat. 61 (S1) (1999) 691–709.
[58] C.W. Granger, Investigating causal relations by econometric models and cross-spectral methods, Econometrica: J. Econom. Soc. 37 (3) (1969) 424–438.
[59] E.I. Dumitrescu, C. Hurlin, Testing for Granger non-causality in heterogeneous panels, Econ. Modell. 29 (4) (2012) 1450–1460.
[60] A. Aibai, X. Huang, Y. Luo, Y. Peng, Foreign direct investment, institutional quality, and financial development along the Belt and Road: an empirical investigation, Emerg. Mark. Finance Trade 55 (14) (2019) 3275–3294.
[61] A.H. Samadi, Institutions and entrepreneurship: unidirectional or bidirectional causality? J Global Entrepreneurship Res 9 (1) (2019) 1–16.