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IMPACT OF ROAD TRANSPORTATION MANAGEMENT ON ENVIRONMENTAL SUSTAINABILITY IN ASIA COUNTRIES: ROLE POPULATION DENSITY

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Article Info

Abstract

By applying the EKC theory to population density, we can better understand the relationship between road transportation and environmental sustainability and discover ways to mitigate its adverse effects. This study utilizes a "balanced panel dataset" of Pakistan, Bangladesh, Nepal, Sri Lanka, and India from 1990 to 2014 to achieve its objectives. The majority of variables included in the study were not accessible until 2014. Due to a lack of available data, other South Asian nations were excluded. The dataset was provided by the World Development Indicators (WDI), Global Footprint Network (GFN), and the National Bureau of Statistics (NBS). This study employs the unit root test and Panel OLS Regression statistical techniques. At the 0.05 level, all independent variables are statistically significant. The findings suggest that road infrastructure, road density, and population density enhance environmental sustainability, while road transport energy consumption diminishes it. Population density and road transport energy consumption are also detrimental to environmental sustainability. However, the study also highlights the crucial role of the public, developers, planners, and legislators in achieving sustainable transportation and urban development goals. Their compliance, participation, and cooperation are essential in developing more inclusive, egalitarian, and effective sustainable transportation and urban development policies. The study's recommendations include community member inclusion in the planning process and promoting stakeholder partnerships through public input and feedback.

Keywords: *Environmental Sustainability, Road Transport Energy Consumption, Road Infrastructure; Road Density, Population Density.*

Introduction

The UN General Assembly approved the 17 SDGs (2030 Agenda for Sustainable Development) in September 2015. SDGs are a global call to take action against poverty, protect the environment, and promote peace and prosperity (Rühm et al., 2023). They are trying to solve the most significant problems in the world and change the lives of others forever. Indicators are included to track progress as well as the goals. By 2030, the SDGs must be achieved by governments, corporations, civic society, and people (Saxena et al., 2021). The Millennium Development Objectives (MDGs) were eight objectives set with a 2015 deadline in 2000. The SDGs further take forward and learn from their achievements and lessons learned. The SDGs cover economic growth, environmental sustainability, peace, and justice, whereas the MDGs focus on poverty reduction and social development (Menton et al., 2020). SDG development must be measured to guarantee success. The UN monitors progress using goal indicators. These metrics help governments, civil society groups, and other stakeholders track progress and identify gaps (Saner et al., 2020). Finally, the SDGs need enormous funding. The UN predicts that fulfilling the SDGs would cost $5-7 trillion annually. To fulfill the SDGs by 2030, novel finance strategies, public and private investment, and international collaboration are needed (Miralles-Quirós & Miralles-Quirós, 2021).

Over several decades, more people have lived in cities than rural regions. According to the UN, 54% of the world's population lived in cities in 2014, and 66% will by 2050 (Hanberry, 2022). Cities are hubs of economic activity, innovation, and cultural interchange. Hence, urbanization affects sustainable development. Social inequality, environmental sustainability, and access to housing, water, and sanitation are all issues of urbanization (Adedeji, 2023). Goal 11 demands investments in urban infrastructure, sustainable mobility, direct service access, and urban planning and management. Local communities, civil society groups, and business sector players must participate to ensure stakeholder needs and viewpoints are considered. Population growth and urbanization increase city housing, infrastructure, and other essential services (Arfanuzzaman & Dahiya, 2019). Urban development difficulties include meeting this demand sustainably and equitably. Public transit, affordable housing, and renewable energy are needed to achieve this aim. It also demands urban design that considers all citizens, especially the most disadvantaged and disenfranchised. It includes safe and inexpensive housing, good water and sanitation, excellent healthcare, and education. Sustainable cities and communities need infrastructure, services, social inclusion, inequality reduction, and community resilience (Jewett et al., 2021). It improves catastrophe readiness and response, societal cohesiveness, and public space access (Jayakody et al., 2022).

Furthermore, climate change, air pollution, and congestion are caused by transportation. Transportation emissions cannot prevent climate change, air pollution, and public health problems. Developing nations' poor infrastructure and suboptimal transportation networks can hinder economic progress and impair lifestyles (Leal Filho et al., 2019). For sustainable mobility, we need public transit, cycling, and walking, as well as low-emission cars and fuels—integrated planning and management of sustainable transportation for all users, including their most vulnerable and excluded. Road transport is a primary sustainable concern in South Asia (Rasul et al., 2021; Khan et al., 2020). Rapid Economic and urbanization have boosted demand for transportation, especially personal automobiles, which have led to traffic congestion, Air pollution, and greenhouse gas emissions. South Asia faces significant transportation industry problems, including poor infrastructure, road safety, and (lack of) access to disadvantaged and vulnerable communities (Mukherjee et al., 2023). To resolve these issues (Kamarudin et al., 2022), South Asian Governments are investing in public transit, bicycles, and walking infrastructure, funding the construction of low-emission cars and fuels. India's National Electric Mobility

Mission Plan and Smart Cities Mission target to sell 6–7 million electric and hybrid vehicles by 2020.

Population density exceptionally influences road transportation's environmental sustainability (X. Li et al., 2022). Transportation demand and environmental consequences are driven by population density. When the population density is high, traffic, air pollution, and greenhouse gas emissions will rise, a problem that may affect public health and the environment (Abdul Jabbar et al., 2022). Policymakers and urban planners may better construct more sustainable transportation networks and promote sustainable urban development by understanding population density and transportation-related environmental consequences. Second, road transportation research advances the understanding of policy actions and technical improvements that could reduce the environmental impact of transportation. Research can help us establish the best forms of encouraging public transit, cycling, walking, and low-emission cars and fuels (Fabre et al., 2023). Finally, research on road transportation's environmental effect may improve the knowledge of the public and policymakers about sustainable transportation measures. The exposure of transportation's environmental and social implications may further promote research in sustainable transportation policy and practice.

Although considerable study on South Asian nations is required (Li et al., 2021; Fang et al., 2022), road transportation greatly influences environmental sustainability. Additional comparative studies of road traffic's environmental effects in specific South Asian countries, such as India, Bangladesh, and Sri Lanka, are required (Shi et al., 2020). More research and study across social, economic, and political dimensions that drive transportation-related environmental consequences is needed on sustainable transportation practices in these countries (Hamid et al., 2023). Current research on policy interventions and technical advancements toward sustainable transportation in these South Asian countries and the obstacles to their acceptance and adoption are critical (Fang et al., 2022). Studies on how these South Asian nations have been influenced by their transportation-related environmental implications on public health, economic development, and social inequality must be studied. Polity solutions that support sustainable mobility for social and economic needs at the regional level (Tödtling et al., 2022) should understand these linkages. Therefore, this study aims to examine road transportation's impact on environmental sustainability in these selected South Asian countries and the role of population density.

Theoretical Framework and Hypothesis Development

Environmental Kuznets Curve

This hypothesis stands that as the economy progresses and more industries continue to evolve, environmental degradation increases. However, as civilizations flourish in wealth and climate becomes an issue, environmental degradation decreases (Ogwu, et al., 2023). In the context of this title, the theory may suggest that in a growing population density and economic development scenario, road transportation's decreased negative environmental impact on the environment must initially increase (Febriyanti et al., 2022). Nevertheless, with further development and wealth, societies may opt for better transportation practices and reduce harmful effects (Stefaniec et al., 2021). The EKC hypothesis predicts that environmental quality will begin declining as countries expand economically, and then later, it will improve beyond a threshold income level. With this idea, economic development and environmental sustainability are studied. With population density increases, traffic on roads will rise, increasing the amount of greenhouse gases and air pollution (Ward et al., 2021). However, the road transportation that is increasing in countries enables EKC theory to state that with the growth of countries and growing more affluent, they may invest in cleaner technologies and alternative modes of transportation such as public transport or electric vehicles to counteract the environmental impacts of road transportation (Ozturk, et al., 2023). Thus, taking the EKC theory to population density, we can implicationally understand the variability of road transportation and environmental sustainability and ways of minimizing the detrimental effects.

Hypothesis Development

Road transport energy consumption

Road traffic decreases the environment by consuming energy and emitting greenhouse gases. Transportation is responsible for the most significant energy use in many nations, especially in cities (Martiskainen et al., 2021). This necessitates road transportation sustainability (Klumpp & Zijm, 2019). Vehicle transportation could become more sustainable through fuel economy. The energy utilization per distance of a vehicle is known as fuel efficiency. That means less fuel has to be used to travel the same distance, resulting in a better fuel economy and less fuel consumption and greenhouse gas (Liu et al., 2019). Road transportation can become environmentally friendly if we promote biofuels, electric automobiles, and hydrogen fuel cell vehicles. Fuel generated from renewable sources has lower emissions and reduces greenhouse gas emissions from transportation. Based on the potential reduction of energy consumption and greenhouse gas emissions of road transportation, the premise for fuel economy improvement and promotion of alternative fuels could improve environmental sustainability (Deenapanray & Khadun, 2021). What effective policy interventions and technical breakthroughs would be most sustainable for road transportation needs further study (Hainsch et al., 2022). The research suggests that road transportation, in terms of fuel efficiency, affects lower energy consumption and greenhouse gas emissions, which should be studied in the future. Alternative fuels used in road transportation also offer environmental benefits. Renewable electric cars have zero tailpipe emissions and lower lifetime emissions than gasoline cars. These include ethanol and biodiesel, renewable fuels that emit less than fossil fuels and which can lower transportation greenhouse gas emissions (Andersson & Börjesson, 2021). In this regard, the following hypothesis is developed.

H1: RTEC negatively related to ES.

Road infrastructure

Road transport infrastructure plays a pivotal role in the sustainability of the transportation system. Road and highway design can impact land use, water quality, air pollution, and greenhouse gas emissions (Nowak, 2019). Therefore, These adverse impacts need to be minimized through developing sustainable road infrastructure to reduce them and improve environmental sustainability (Khan et al., 2019). For such infrastructure, sustainable roads may be used as eco-friendly materials and building techniques (Miao et al., 2023). Permeable pavement prevents stormwater from discharging, and recycled road materials replace landfills and facilitate reduced energy use.

In addition to this, sustainable mobility can be promoted because designing routes for bicycles and pedestrians reduces the demand for single-occupant cars. Road construction and maintenance should favor renewable energy sources (Olabi et al., 2022). Roadways could have solar panels creating renewable energy nearby, and geothermal systems could provide heat and excellent structures nearby. The layer of roadside flora removes CO_2 and reduces greenhouse gas emissions. The idea is that environmentally friendly materials, construction methods, and renewable energy sources in road construction and maintenance help create sustainable road infrastructure that can make itself more environmentally sustainable (An et al., 2021). Policy interventions and technology improvements still need to be discovered for sustainable road infrastructure, and further study is needed (Bosona, 2020). In this regard, the following hypothesis is developed.

H2: RI is positively related to ES.

Road Density

The environmental sustainability (Yao et al., 2022) is greatly influenced by road density, i.e., the length of roads per unit of land area. As road density increases, greenhouse gas emissions, air and water pollution, and ecosystem fragmentation increase. Therefore, strategies that reduce these consequences and promote environmental sustainability (Bouraima et al., 2023) might be necessary for high-road-density regions. Too much road density might incur environmentally costly effects. However, public transit and active mobility, such as bicycling or walking, reduce those effects. Regions of high road density may reduce greenhouse gas emissions and air pollution by reducing single-occupant cars and supporting sustainable mobility (Viscelli et al., n.d.) by proper land use planning and management to mitigate the environmental consequence of excessive road density. Compact and mixed-use construction reduces long-distance travel and contributes to sustainable mobility (Nainwal, 2021). They may decrease stormwater runoff and improve water quality by providing green roofs and bioswales.

However, these solutions may only work depending on the location of the high road density. Rural areas may not tempt many to use sustainable mobility measures since travel lengths are limited and there is less public transit in their respective areas (Shah et al., 2021). As a result, high-road-density areas present unique challenges that call for distinctive management strategies. By implementing sustainable transportation and effective land use planning and management, excessive road density can be reduced to ensure environmental sustainability (Li et al., 2021). It is important to stress the need for these distinctive management approaches in high road density areas. Thus, the following hypothesis is suggested:

H3: RD is negatively related to ES.

Moderating Role Population Density

High population density may raise transportation infrastructure requirements, road transport renewable energy consumption, and environmental consequences (Zhang et al., 2021). Thus, population density moderate road transport energy consumption and environmental sustainability (Adams et al., 2020). Reducing road transport energy consumption and environmental sustainability through greenhouse gas emissions (Xu et al., 2019) may be achieved via population density. Greenhouse gases are released by fossil fuel combustion in cars. In crowded areas, vehicles may be alleged to release more greenhouse gases. Car emissions could be exacerbated in high-population areas by congestion and stop-and-go traffic. Road transport energy consumption demonstrates a weak link to environmental sustainability, moderated by population density and temporal correlation through land use and natural resources (Luan et al., 2022). Such high population density increases the demand for land to build transportation infrastructure, deforestation, habitat loss, and other environmental damage. Transportation infrastructure development and upkeep requires energy and natural resources (Avtar et al., 2019). The relationship between road transport energy consumption and environmental sustainability is moderated by population density. This underscores the urgent need for further study to understand the moderating effect of population density on road transport energy consumption's environmental implications in the high population locations (Zhongxiu et al., 2023). In this regard, the following hypothesis is developed.

H4: PD moderates the relationship between RTEC and ES.

Based on this theoretical framework and the development of hypotheses, the following conceptual framework for the investigation is proposed.

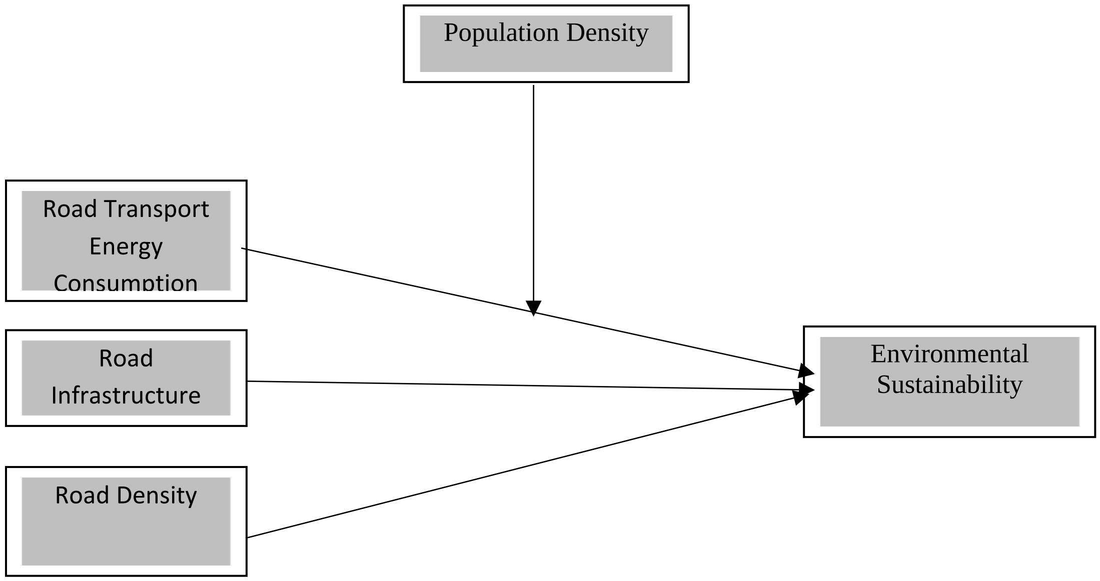

Figure 1. Conceptual Framework

Methodology

Population and Data

This study investigates the impact of population growth on carbon emissions in the context of South Asian STP. The region's numerous transportation options and growing road infrastructure make STP a crucial area of study. The data for this research was provided by Pakistan, Bangladesh, Nepal, Sri Lanka, and India, with Afghanistan, Bhutan, and Maldives being excluded due to data constraints.

This research employs a robust 'balanced panel dataset' of Pakistan, Bangladesh, Nepal, Sri Lanka, and India from 1990 to 2014, a method that ensures the reliability and accuracy of the study's findings. Most variables included in the study were only available till 2014. Due to data shortages, other South Asian states were excluded. The World Development Indicators (WDI), Global Footprint Network (GFN), and National Bureau of Statistics (NBS) provided the dataset.

Measurement of Variables

This research consists of explanatory, moderator, and outcome factors. Environment Sustainability measures the study's result. Road transportation energy usage, infrastructure, and density are the explanatory variables. This research modifies population density. Table 1 lists the proxy measures and data sources for the variables used in the study.

Table 1 Measurement of variables

Variable	Measurement	Notation	Source
Dependent Variable			
Environment Sustainability	"Adjusted net saving (ANS) (excluding particular carbon emissions)"	(ENS)	WDI
Independent variables			
Road Transport Energy Consumption	"Road energy consumption (Kg of oil equivalent per capita)"	(RTEC)	WDI
Road Infrastructure	Total length of roads	(RIN)	NBS
Road Density	"Total length of roads / population"	(RDN)	WDI

Moderating variable			
Population Density	"Population density (people per sq. km of land area)"	(PDN)	WDI

Model Specification

ENS= α0 + β_1RTEC + β_2RIN+β_3RDN+β_4PDN+eit **(1)**

Whereas, Environment Sustainability, Road Transport Energy Consumption, Road Infrastructure, Road Density, Population Density and error (eit)

Unit Root Test

OLS regression can overstate time series trends (Series, 2021). The Augmented Dickey-Fuller (ADF) test rejects the null hypothesis of stationarity by evaluating variables at level, first difference, and second difference. OLS regression requires stationarity. ADF test:

$$\triangle Y_t = \alpha_0 + \alpha_1 Y_{t-1} + \sum_{j=1}^{k} d_j \triangle Y_{t-1} + \varepsilon_t \quad (2)$$

The ADF test equation uses pure white noise error and starting difference (Duan et al., 2022). Unlike a0, Yt is time-dependent. Ideal, the dependent variable delays are k. A variable is stationary if its coefficient value is smaller than the critical value (Pata & Isik, 2021).

Panel OLS Regression Analysis

Panel OLS Regression examines cross-sectional and time-series panel data (Kropko & Kubinec, 2020). It considers data-specific individual and temporal effects when assessing the relationship between a dependent variable and one or more independent variables. Panel OLS Regression assumes the error term is independent and identical across people and time (Baetschmann et al., 2020). The independent variable-dependent variable relationship, a key aspect, is required to be stable across people and time, ensuring the reliability of the analysis. OLS regression analyzes independent and constant term coefficients. Panel OLS Regression Analysis works well for recurring samples (Dang & Lanjouw, 2023). It can track factors impacting the dependent variable over time. Finance, economics, and sociology use it. This research depends on environmental sustainability. Road transportation energy consumption, road infrastructure, and population density explains the variable. Population density, which affects road traffic and environmental sustainability, moderates.

Results and Discussion

Panel Unit Root Test

Table 2 Augmented Dickey-Fuller test statistic (Panel Unit Root Test)

Variable	P-value at 1st difference ADF - Fisher Chi-square	Decision rule for rejection of null hypothesis p-value less than 0.05
Environment Sustainability (Dependent variable)	0.0000**	Data is stationary
Road Transport Energy Consumption	0.0000**	Data is stationary
Road Infrastructure	0.0000**	Data is stationary
Road Density	0.0000**	Data is stationary
Population Density	0.0006**	Data is stationary

Source: Author's estimation

Note: 1*, 5**, 10*** % level of significance

Table 2 displays unit root test findings for data series on environment sustainability, road transport, energy consumption, road infrastructure, and population density. The unit root test's null hypothesis is that the data series is non-stationary with a unit root, trend, or random walk (Traoré & Diop, 2021). All data series reject the null hypothesis of non-stationarity with p-values around 0.0000. Thus, all data series are stationary. Time series analysis estimates means, variances, and correlations using stationarity. Non-stationary data series give erroneous regression findings and estimates. Thus, statistical analysis and modeling may exploit these stable data series.

Panel OLS Regression

Table 3 Panel Least Square Method (OLS) (Fixed affect model)

Factor	Coefficient value	Adjusted R-value	Significant value	Decision rule for rejection of null hypothesis p-value less than 0.05
Road transport energy consumption	-0.282550	0.863951	0.0000*	Supported
Road Infrastructure	0.283923		0.0000*	Supported
Road Density	-2.254723		0.0000*	Supported
Population Density	4.917253		0.0000*	Supported
Moderating Effect 1 (Road transport energy consumption* Population Density)	-0.155570		0.0000*	Supported
Dependent variable: Environmental Sustainability				

Source: Author's estimation
Note: 5*, 10** % level of significance

The Hausman test is a statistical test used in econometrics to determine whether a dataset should use random effects or fixed effects model (Joshi & Wooldridge, 2019). The test compares the difference in estimated coefficients and standard errors of the two models (Hill et al., 2020). The random effects model is unsuitable if the coefficient difference is statistically significant. The fixed effects model is preferred. The random effects model is more efficient if the difference is slight. Panel data analysis, which tracks the same people or entities over time, uses the Hausman test (Bliese et al., 2020). The Hausman test showed a p-value <0.005. This study uses a fixed-effect model.

A fixed effect panel OLS regression analysis is shown in Table 3, a robust and reliable methodology for this type of research. The dependent variable is environmental sustainability, while the independent variables are road transport energy consumption, road infrastructure, road density, population density. The estimated regression coefficients for each independent variable are in the coefficient value column. Notably, a one-unit increase in road transport energy consumption is found to decrease environmental sustainability by 0.282550 units, a significant finding. The model's goodness of fit, measured by the modified R-value column, indicates how well the independent variables explain the variance in the dependent variable (Fey et al., 2023). The model explains 86.4% of the variance in Environmental Sustainability with a value of 0.863951. The significant value column displays each independent variable's p-value, which indicates whether the coefficient is statistically significant at the 0.05 level. Harrison et al. (2020) says that if the p-value is less than 0.05, then the coefficient is statistically significant, and that can be used to reject the null hypothesis. Also, the table gives the corresponding decision rule of rejecting the null hypothesis. If the p-value is less than 0.05, this means that if the independent variable does not affect the dependent variable - this is a rejected null hypothesis. The asterisk (*) next to their p values shows all independent variables statistically significant at 0.05. The findings indicate that road infrastructure, road density, and population density improve environmental sustainability, whereas road transport energy consumption decreases. Road transport energy consumption and population density also negatively impact environmental sustainability.

Discussion

H1, Road transport energy consumption has a negative coefficient value of -0.282550, suggesting it is unsustainable. It implies that road transport energy usage reduces environmental sustainability. Transportation energy consumption is a significant source of greenhouse gas emissions, contributing to climate change and other environmental issues. The statistically significant p-value of 0.0000 suggests that road transport energy consumption and environmental sustainability are not random. It suggests that the negative association between these factors is true to themselves and persistent.

Since transportation is a significant energy consumer and greenhouse gas emitter in many nations, the negative link between road transport energy consumption and environmental sustainability is not unexpected. In 2019, 24% of worldwide energy-related CO2 emissions came from transportation, according to the International Energy Agency. The negative coefficient value for road transport energy consumption in this research implies that lowering transportation energy consumption might improve environmental sustainability (Raihan & Tuspekova, 2022). "Improve energy efficiency and increase the use of renewable energy in the transport sector" is a UN Sustainable Development Goal (SDG 7.3). Walking, cycling, and public transit are essential since vehicle transport energy consumption harms the environment (Fan & Harper, 2022). These modes cut transportation energy usage and greenhouse gas emissions while improving public health and traffic flow. Transportation energy reduction may involve land use and urban design adjustments. Compact, mixed-use building patterns may minimize long-distance travel and encourage sustainable mobility (Deweerdt & Fabre, 2022).

H2, Road infrastructure's 0.283923 coefficient implies a favorable association between environmental sustainability and road infrastructure. As road infrastructure develops, environmental sustainability increases. It supports the premise that well-designed and maintained transportation infrastructure may enable sustainable mobility modes, decrease energy consumption and greenhouse gas emissions, and improve public health and safety. The statistically significant p-value of 0.0000 suggests that road infrastructure and environmental sustainability are not random. The positive association between these factors is genuine and can be seen and duplicated.

These results imply that road infrastructure investment may increase environmental sustainability. Road infrastructure design, placement, and context may affect environmental sustainability (Jouzdani & Govindan, 2021). Road infrastructure favoring cars over other means of transportation may increase energy consumption and greenhouse gas emissions, damaging the environment (Andersson & Börjesson, 2021). Road infrastructure may improve environmental sustainability depending on its design and location. For instance, pedestrian and bicycle infrastructure may be more environmentally friendly than automotive infrastructure. Infrastructure in densely populated regions with adequate public transit may better promote sustainable mobility alternatives. Road infrastructure may help the environment, but it can also harm it. Roads may cause deforestation, habitat fragmentation, and soil erosion. Cars contribute to air pollution, greenhouse gas emissions, and other environmental issues. Road infrastructure improves environmental sustainability, highlighting the necessity of transportation infrastructure investment for sustainable development (Khan et al., 2019). The UN Sustainable Development Goals (SDGs) include a goal to "develop quality, reliable, sustainable and resilient infrastructure, including regional and trans-border infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all" (SDG 9.1). Transportation infrastructure investment may encourage sustainable development due to the beneficial association between road infrastructure and environmental sustainability (Erdogan, 2020). However, transportation planning and design must emphasize sustainable modes and infrastructure that benefit the environment and society (Grabowski et al., 2022).

H3, Road density negatively affects environmental sustainability, as shown by its coefficient value of -2.254723. It is surprising since other roads should improve access to sustainable transportation options and infrastructure. Pouring more cars onto the roads may also increase air pollution, greenhouse gas emissions, and other environmental issues if there is high road density. The p-value of 0.0000 was statistically significant, indicating no random negative association between road density and environmental sustainability.

It suggests these factors are honestly and repeatably negatively associated with one another. The empirical association between road density and environmental sustainability strengthens the idea that transportation infrastructure can create good and bad environmental repercussions (Prus & Sikora, 2021). While roads can help enable sustainable mobility, they can also generate air pollution, greenhouse gas emissions, and habitat fragmentation. Because road density harms environmental sustainability, promoting sustainable transportation modes and infrastructure reduces automotive dependence and mitigates the environmental effects of transportation (Ogryzek et al., 2020). The objective of the UN Sustainable Development Goals (SDGs) is to "promote sustainable transport systems and sustainable mobility, including the development of public transport systems and improve road safety" (SDG 11.2). It may also contribute to urban sprawl and habitat fragmentation, thus negatively affecting environmental sustainability (Gounaridis et al., 2020). That can hurt biodiversity and ecosystem services crucial to ecosystems' health and resilience. Roadways' design, location, and context may affect environmental sustainability transitionally. Imagine highways touting sustainable modes of transportation, such as biking or walking, instead of highways that provide automotive traffic.

H4, the population density coefficient of 4.917253 indicates its favorable link between population density and environmental sustainability. More specifically, population density offers environmental sustainability. Sustainable transportation in high-density urban settings can reduce energy consumption and greenhouse gas emissions and increase public health and safety. As the population density and environmental sustainability are seemingly non-coincidentally correlated, the statistically significant p-value also $p < 0.0000$ indicates it.

The results demonstrate that urban population density has positive implications for environmental sustainability. Walking, cycling, public transit, and more efficient land and resource use (Ali et al., 2021) might be encouraged in high-density urban settings. Compact and mixed-use development patterns also occur in high-density urban environments and make use of the compactness of land, including decreasing long-distance travel and promoting sustainable mobility. Sustainable transportation and infrastructure: In high-density urban areas, we should encourage walking, cycling, and public transport. It can be achieved with public transit infrastructure, pedestrian and bicycle-friendly streets and public spaces, and mixed-use building patterns that minimize out-of-town travel. Energy efficiency and renewable energy should be prioritized in high-density urban regions (Kumaraswamy et al., 2023). Achieving this can be high energy efficiency building codes in tandem with incentives for developers to use renewable energy sources such as solar and wind power or public investments in energy-efficient infrastructure, like district heating and cooling. To design and locate sustainable high-density urban regions (Liu, 2023), all these need to work together — the developers, the planners, the legislators, and the community members.

H5, the negative (i.e., a lower positive coefficient value of -0.155570 for the moderating impact of Road Transport Energy consumption density) means that densely populated metropolitan regions are less environmentally sustainable than less densely populated ones. It shows that environmental sustainability improves when transportation energy consumption and population density grow. Surprisingly, high-density metropolitan regions are less affected by the environmental implications of vehicle transport energy consumption. Road Transport Energy Consumption*Population Density moderates owing to its statistically significant p-value of 0.0000. These two factors will affect road transport energy consumption and environmental sustainability.

Sustainable transportation modes and infrastructure can be supported by high-density urban locations that mitigate the environmental impacts of road transport energy use (Miotti et al., 2023). Public transit that can provide multifaceted, high-capacity mobility may be better served by metros, less susceptible to vehicle reliance, and promote healthier mobility patterns in high-density metropolitan areas. Compact, mixed-use development patterns that reduce long-distance travel and support sustainable mobility may exist in high-density urban environments (Bibri et al., 2020). It is countered that none of the other models produce a sustainable transportation policy or infrastructure for those high-density urban regions. Public transport, pedestrian and bicycle-friendly infrastructure, and building patterns that restrict car dependency are possible in high-density urban areas. SDGs 7 (Affordable and Clean Energy), 9 (Industry et al.), and 11 (Sustainable Sanctity) are negatively moderated by Road Transport Energy Consumption*Population Density. High-density metropolitan areas can reduce fossil fuel consumption and encourage clean and renewable energy sources for SDG 7 by providing sustainable transportation modes and infrastructure. Several SDGs are strongly linked to road transport energy consumption, population density, and environmental sustainability, which require sustainable transportation modes and infrastructure to meet these targets (Nundy et al., 2021). A combination of transportation planning and design may provide more sustainable and livable cities that benefit social and environmental well-being and can reach the SDGs (Prus & Sikora, 2021).

Concluding Remarks

Designing and siting high-density urban areas for environmental sustainability requires considering transportation, land usage, energy, water, and waste management. It appears from road transport energy consumption, population density, and environmental sustainability that the promotion of sustainable transportation modes and infrastructure that support compact, mixed-use development that strategically incorporates sustainable energy, water, and waste management practices, as well as public participation and collaboration can contribute to the creation of more sustainable, livable urban communities. The negative moderating effect of road transport energy consumption and population density shows that strengthening sustainable transportation modes and infrastructure in high-density urban regions might minimize the environmental implications of road transport energy consumption. The positive coefficient value for population density shows that increasing urban population and densities may improve environmental sustainability. Road density negatively affects environmental sustainability, suggesting that urban energy, water, and waste management methods might offset transportation's environmental implications. Public engagement and cooperation may promote inclusive, egalitarian, and successful sustainable transportation and urban development policies.

Managerial Implications

Firstly, road transport energy consumption, population density, and environmental sustainability affect SDG 7 (Affordable and Clean Energy), SDG 9 (Industry et al.), and SDG 11 (Sustainable Cities and Communities). Urban areas may achieve these objectives by fostering sustainable transportation modes and infrastructure, compact, mixed-use development, sustainable energy, water, waste management, and public engagement and cooperation. The SDGs should be integrated into urban development policies and tracked over time.

Secondly, developers, planners, legislators, and community members must collaborate to achieve sustainable transportation and urban development objectives. Public engagement and cooperation may promote inclusive, egalitarian, and successful sustainable transportation and urban development policies. Practical consequences include including community people in planning, encouraging public input and feedback, and fostering stakeholder partnerships.

Thirdly, road density negatively affects environmental sustainability, suggesting that urban energy, water, and waste management methods might offset transportation's environmental implications. Examples include energy-efficient infrastructure, renewable energy, water efficiency, and waste reduction initiatives. Promote solar and wind power, green construction, water conservation, and recycling.

Theoretical Contributions

According to the EKC hypothesis, as prosperity and economic growth rise, environmental degradation declines as societies become more environmentally aware and invest in cleaner technology and practices. Road transportation energy consumption, population density, and environmental sustainability may be examined using the EKC theory. High-density urban areas may be more robust regarding the environmental implications of road transport energy use. Hence, population density matters. High-density urban areas may have policies and regulations that promote sustainable transportation modes and infrastructure, such as public transportation, pedestrian and bicycle-friendly infrastructure, and mixed-use development patterns that reduce automobile travel. Thus, road transport energy consumption and population density may have a negative moderating effect, implying that high-density urban areas may be more tolerant of the environmental implications of road transport energy consumption. EKC theory helps explain road mobility, environmental sustainability, and population density. The theory suggests that as economic development and population density increase, road transport energy consumption and negative environmental impacts may initially increase but eventually decrease as societies become more environmentally conscious and invest in cleaner technologies and practices. High-density urban regions may be more robust to the environmental implications of road transport energy consumption and more inclined to encourage sustainable transportation modes and infrastructure.

Limitations of Study

Firstly, this research examined five South Asian nations; hence, its conclusions may not apply to other South Asian situations. Future studies might apply These results to other advanced countries with various demographic, economic, and environmental aspects. Secondly, the research used secondary data, which may need to be more accurate. Surveys, interviews, and observations might be used to study population density, transportation, and environmental sustainability. Lastly, future studies might compare industrialized and emerging nations to understand how population density and transportation infrastructure affect environmental sustainability. It might identify excellent practices and strategies for sustainable development in both developed and developing countries.

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