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GREENING THE ROAD AHEAD: PIONEERING INNOVATION IN SUSTAINABLE TRANSPORTATION

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ABSTRACT

This research paper "Greening the Road ahead: Pioneering Innovation in Sustainable Transportation delves into the multifaceted concept of sustainability and emphasizes the pivotal role of green technology in steering us towards a more sustainable future. With a specific focus on the transportation industry in India, the paper sheds light on the sector's significant contribution to air pollution and greenhouse gas emissions. It underscores the pressing need for green transportation solutions to mitigate these environmental impacts. The paper emphasizes the importance of urgently acting in harnessing technology to drive sustainable progress, particularly in India's transportation sector, which is projected to expand at a compound annual growth rate of 5.9%. The paper implements ETOP analysis to study the opportunities and threats in the green transportation industry. It points out the various challenges faced by the users and potential users of the industry. And also gives solutions and suggestions to overcome the challenges or part thereof.

Keywords: sustainability, green technology, transportation industry, environmental impact, opportunities and threat

1. INTRODUCTION

Sustainability is a social goal aimed at ensuring long-term co-existence on Earth, with three dimensions: environmental, economic, and social. It encompasses not only natural resources but also social and economic resources. The most often quoted definition comes from the UN World Commission on Environment and Development: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Green technology is the application of science and technology to create environmentally friendly products and services. It aims to reduce ongoing harm to the environment, repair existing damage, and promote regeneration. It includes renewable energy, sustainable transportation, waste management, recycling, and energy efficiency solutions. Green technology's ultimate goal is to not only lessen ongoing environmental harm but also to repair existing harm and encourage regeneration. It includes all actions taken to improve the environment and sustainably utilize Earth's natural resources.

ISSN No: 2394-059X
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Green technologies, which range from solar panels to sophisticated waste management systems, seek to replace conventional methods with more sustainable ones while also reducing carbon emissions and conserving natural resources. Moreover, they have the capacity to generate regenerative solutions that are able to mend and restore our ecological balance, surpassing simple mitigation in order to promote a more robust and thriving environment.

Although the terms environmental tech, clean tech, and green tech are sometimes used synonymously, they have different purposes. Any technology that aims to lessen human effects on the environment generally and is sustainable or environmentally friendly is referred to as "**green tech**." **Clean technology**, on the other hand, aims to enhance environmental performance, frequently through more eco-friendly and efficient production methods. Climate tech, often known as **environmental tech**, focuses on solving problems brought on by climate change that is caused by humans.

India's transportation infrastructure, with a 5.9% compound annual growth rate, is the fastest-growing sector in the nation. However, it also contributes significantly to air pollution and greenhouse gas emissions. The **sustainability of transportation systems** is a major concern for urbanization, as the widespread use of public and personalized vehicles has destroyed the global environment. In today's society, the necessity for sustainable transportation options has grown. It is impossible to overlook the detrimental effects of traditional transportation on the environment, public health, and standard of living. We can build a more sustainable transportation system that reduces environmental damage, increases mobility, and promotes community well-being by embracing technology and creative thinking.

Therefore, the expansion of the transportation system should focus on green or sustainable transportation for global sustainability.

The evolution of technology in transportation:

1. Horse and carriage
2. Steam engine
3. Automobiles
4. Aviation
5. Hyperloop
6. Electric Vehicles

Over the last few years, **Electric Vehicles** have captured the imagination of people in many parts of the world. The capacity of electric vehicles (EVs) to lower greenhouse gas emissions is one of their biggest benefits. EVs have zero tailpipe emissions, which means they don't release any harmful pollutants like carbon dioxide (CO2), nitrogen oxides (NOx), or particulate matter, in contrast to conventional internal combustion engine vehicles. Air quality and public health may be significantly impacted by this emission reduction, especially in heavily populated urban areas.

2. LITERATURE REVIEW

2.1 Etukudoh, N. E. A., Adefemi, N. A., Ilojianya, N. V. I., Umoh, N. a. A., Ibekwe, N. K. I., & Nwokediegwu, N. Z. Q. S. (2024). A Review of sustainable transportation solutions: Innovations, challenges, and future directions. *World Journal of Advanced Research and Reviews*, *21*(1), 1440–1452. https://doi.org/10.30574/wjarr.2024.21.1.0173

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The necessity for sustainable transportation options is covered in the paper, with particular attention paid to electric cars, alternative fuels, public transportation, and creative mobility ideas. It draws attention to the efficiency benefits of well-planned public transportation infrastructure and the notable advancement in rechargeable battery-powered electric vehicles. But there are still issues including restricted infrastructure, financial concerns, and changing consumer behaviour.

2.2 Mohapatra, S., Mohanachandran, D., Dwivedi, G., Kesharvani, S., Harish, V. S. K. V., Verma, S., & Verma, P. (2023). A Comprehensive Study on the Sustainable Transportation System in India and Lessons to Be Learned from Other Developing Nations. *Energies, 16*(4), 1986. https://doi.org/10.3390/en16041986

Cheaper and faster transportation is required due to the growing population, larger travel distances, and shorter travel times. However, while selecting affordable public transportation, environmental concerns are frequently disregarded. In order to demonstrate that sustainability extends beyond the use of cleaner fuel and the alteration of road materials, this paper looks at sustainable transportation in India and other developing countries.

2.3 Dr. Vidya Prakash Hattangadi (2023). "What is ETOP Analysis?". https://www.linkedin.com/pulse/what-etop-analysis-dr-vidya-prakash-hattangadi/

Environmental threat and opportunity profile (ETOP) analysis gathers information about events and their relationships within an organization's internal and external environments, aiding management in determining its future course.

A company can enhance its competitive advantage and performance in a market setting by taking advantage of external opportunities. Anything in the external environment that could negatively impact performance or goal-achieving is considered an external threat.

2.4 United Nations. (2021). *Sustainable transport, sustainable development*. Interagency report for second Global Sustainable Transport Conference. https://sdgs.un.org/sites/default/files/2021-10/Transportation%20Report%202021_FullReport_Digital.pdf

Sustainable development is fundamentally dependent on sustainable transportation, which aims to achieve universal access, improved safety, decreased impact on the environment and climate, increased resilience, and increased efficiency. Sustainable transportation not only offers infrastructure and services for the movement of people and goods, but it also acts as a cross-cutting accelerator to accelerate progress toward other important objectives like the eradication of poverty in all its forms, the reduction of inequality, the empowerment of women, and the fight against climate change. As such, it is essential to fulfill both the Paris Climate Change Agreement and the 2030 Agenda for Sustainable Development.

2.5 Panday, Aishwarya & Bansal, Hari. (2013). Green Transportation in India: Need Analysis and Solution. 10.1109/CARE.2013.6733755.

This paper discusses the environmental impact of IC engine-powered cars and fossil fuels, highlighting the need for alternative transportation technologies and green vehicles in India.

2.6 Banister, D. (2005). "Unsustainable Transport: City Transport in the New Century" (1st ed.). Routledge. https://doi.org/10.4324/9780203003886

This book explores the relationship between transportation and sustainable urban development, covering topics such as public policy, institutional and organizational barriers to change, and an examination of the big picture.

ISSN No: 2394-059X
Peer Reviewed & Refereed Journal (IF: 7.25)
Journal Website www.nrjhrm.in

2.7 *The role of Technology in Advancing sustainable transportation Initiatives - FasterCapital*. (n.d.). FasterCapital. https://fastercapital.com/content/The-Role-of-Technology-in-Advancing-Sustainable-Transportation-Initiatives.html

This paper covers the need for sustainable transportation solutions and the evolution of technology in transportation with an emphasis on Electric Vehicles (EVs). It also discusses the various new technologies available in the sustainable technology domain and the advancements in the public transportation industry. It gives the analytics for the revolutionization of transportation planning.

2.8 India's transition to green transport. (n.d.). Drishti IAS. https://www.drishtiias.com/daily-updates/daily-news-editorials/india-s-transition-to-green-transport

India's Transport Infrastructure Overview:

1. Roads: Dominant mode of transportation, carrying 85% of passenger traffic and aiding the industrial sector.
2. Ports and Shipping: 13 major ports along over 7500 km of coastline, significantly improving foreign trade. Seaborne foreign trade is 95% by volume and 67% by value.
3. Railways: India's main artery, providing both freight and passenger transportation. The 4th largest railway network in the world and 2nd largest in Asia under single management.
4. Civil Aviation: Emerging as one of the fastest-growing industries, India becoming the 3rd largest domestic aviation market globally and is expected to surpass the UK by 2024.

3. OBJECTIVES

1. To study the impact of green transportation on the environment using ETOP analysis.
2. To analyze the transportation industry in India with particular emphasis on green transportation.
3. To find the opportunities and threats in the green transportation industry and suggest improvements.

4. METHODOLOGY

1. **Research Design**: Descriptive, Analytical, & Correlational
2. **Source of Data:** Secondary data: Webpages, journals, research papers, books, etc
3. **Method used:** Thorough analysis of the secondary data collected
4. **Type of data:** Qualitative and Quantitative

5. ANALYSIS & INTERPRETATION

India, the fastest-growing economy and the most populous country globally, aims to achieve net zero carbon emissions by 2070. However, its rapid urbanization and energy demand pose challenges. Road transportation, which accounts for 12% of CO2 emissions, could double by 2050 if not addressed. Despite recent bus initiatives and metro rail focus, India only meets one-quarter of the metric per bus per thousand population.

Decarbonisation of public transportation was initiated due to poor air quality in major metro cities, but rapid urbanization and energy demand could change the future scenario.

ISSN No: 2394-059X
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Journal Website www.nrjhrm.in

5.1 OPPORTUNITIES

1. Electric Vehicles Adoption

India's electricity vehicle industry is rapidly growing, with a significant increase from 53,387 registered vehicles in 2013 to 28,30,565 in 2023. The country's automotive industry is expected to play a crucial role in transitioning towards green energy, with a projected 49% CAGR between 2022 and 2030. By 2030, annual sales of EVs may exceed one crore units, creating five crore direct and indirect jobs.

2. Enhanced Public Transit

The government has taken up a number of initiatives to induce sustainable measures in the public transportation sector of the country. several of these measures can be listed as such:

1. Conversion to CNG
2. FAME- 'Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles'
3. National Electric Bus Program
4. EV30@30- at least 30% of new vehicle sales be electric by 2030
5. PM E-Bus Sewa Scheme
6. Light Rail System

3. Smart Mobility Solutions

The Internet of Things (IoT) is being used to create connected transportation networks, enabling data-driven decision-making for route optimization and traffic management. Ridesharing and micro-mobility options are reducing individual car usage, while research in autonomous vehicles aims to reduce accidents, improve traffic flow, and optimize energy usage.

5.2 THREATS

1. Financial Barrier

Although electric vehicles have several advantages over fossil fuel vehicles, their economic benefits are limited by expensive manufacturing and infrastructure costs, battery replacement expenses, and strict commercial and financial management regulations. It is more difficult for these vehicles to be widely used due to the fragmented nature of the e-bus market and the lack of funding sources, including subsidies and incentives. These elements provide investment risks and financial problems in addition to the daily running expenses of power and the capital costs associated with modifications to the grid infrastructure.

2. Infrastructural Barrier

The use of electric buses necessitates the placement of charging stations strategically; nevertheless, convenient and reliable charging is hampered when these are absent from heavily trafficked locations. Complex repair processes, unstable power supplies, a lack of service centers, and irregular charging techniques are some of the challenges facing the conversion of buses to electric vehicles. Other major obstacles are the lack of domestic production of electric buses and insufficient infrastructure for charging them. In order to promote the use of electric vehicles, a study conducted in Turin sought to improve the infrastructure for charging them.

ISSN No: 2394-059X
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Journal Website www.nrjhrm.in

3. Social Barrier

Lack of promotion, customer ignorance, awareness campaigns, and inefficient marketing tactics all contribute to the adoption of electric buses. The problem is additionally exacerbated by societal elements like knowledge, technology, and environmental consciousness. Significant problems are also posed by social variables such as inadequate information exchange, low awareness of fuel-related savings, restricted promotion, and consumer perception of product quality.

4. Technological Barrier

Low awareness, information gaps, and ambiguity about performance problems present problems for electric buses. Widespread adoption is hampered by low power and range, design problems, and a shortage of replacement components and specialized tools. Adoption is further hampered by the limited battery life and lack of operating data. Two other major obstacles are the limited availability of electric bus models and the expensive cost of permanent magnet motors. The development of electric vehicles is further hampered by the costly and unpredictable cost of rare-earth elements. The potential advantages of electric buses are yet unclear in spite of these difficulties.

5. Institutional Barrier

Because of the low market demand and quickly changing technology, electric buses have a poor resale value, which puts prospective users at risk and financially unpredictable. Their adoption is further impeded by limited options and unfamiliar funding and procurement methods.

6. Policy Barrier

Insufficient government coordination, insufficient incentives, and a lack of a coherent policy framework are impeding the development of electric buses in India. Manufacturers find it difficult to collaborate with stakeholders, follow local legislation, and negotiate procurement procedures. Furthermore impeding the expansion of electric buses include uncontrolled public transportation networks, informal transportation, and a lax regulatory environment. The expansion of electric buses is further hampered by limited land and insufficient tax incentives.

6. CHALLENGES AND SOLUTIONS FOR SUSTAINABLE TRANSPORTATION

In India, flooding is a serious problem, especially in the megacities. Building the entire urban ecosystem—including the structural, physical, social, and economic infrastructure—to meet population demands is the goal of the smart city concept. Cities can accomplish this by gradually constructing extensive infrastructure and adding layers of knowledge.

Urban rail has become more and more popular in car-dependent regions like the US and Australia as well as densely populated areas like Asia, Europe, and the Middle East. around the past 20 years, China and India have opened around 25 high-capacity urban train lines (metro rail), and an additional 25 are currently being built. However, traditional government grants and fare-box money continue to make support for rail transportation difficult.

Urbanization increases the economic prospects available to disadvantaged groups, especially women, by giving them access to a greater variety of jobs and enabling them to engage in the quickly expanding industrial and service sectors. The body of research on gender and transportation aspects is growing, highlighting the differences between men's and women's

ISSN No: 2394-059X
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travel behaviors because of cultural norms, stereotypes, income disparities, and safety concerns.

Pollutants emitted by various transportation sectors in India:

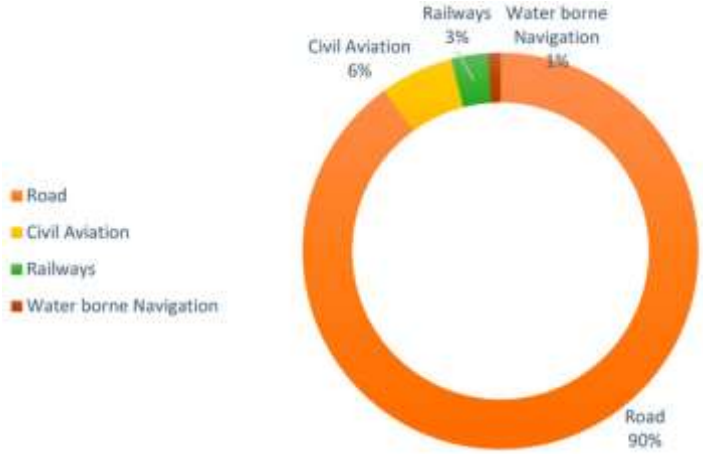

Figure 1: Pollutant emissions by various transportation sectors of India

Safer and faster public transportation should be the main emphasis of policy in order to ensure sustainable transportation in India's cities and rural areas. This can stop the emergence of two-wheelers dominating small towns, four-wheelers taking over large cities, and cars, including electric vehicles (EVs), becoming the norm.

One problem is that India has fewer train services than roadways. Since the early 1980s, two standards have been set for reducing the environmental impact of road transportation in India: reducing the amount of personalization of automobiles and increasing the emission profile of current vehicles by utilizing cleaner fuels. The Delhi metro has demonstrated beneficial benefits on the environment, as seen by a 34% decrease in carbon monoxide emissions in the vicinity of busy crossings.

Although more approaches must be used, the government is taking action to guarantee sustainability in transportation networks. In crowded urban regions, it is essential to align paratransit and non-motorized rapid transit lines in order to shift a large number of personal transportation modes to sustainable alternatives.

6.1 Case Study

Due to Singapore's dedication to public transportation, the number of single cars driven has significantly decreased. Residents are more likely to choose public transportation because of the bus network's dependability, accessibility, and convenience, which reduces carbon emissions and traffic congestion. The effective bus system in Singapore is proof of the revolutionary effects of well-thought-out, state-of-the-art public transportation. The TransMilenio rapid transit system in Colombia, South America, is an example of how creative public transportation solutions may be used to meet the problems caused by urbanization.

ISSN No: 2394-059X
Peer Reviewed & Refereed Journal (IF: 7.25)
Journal Website www.nrjhrm.in

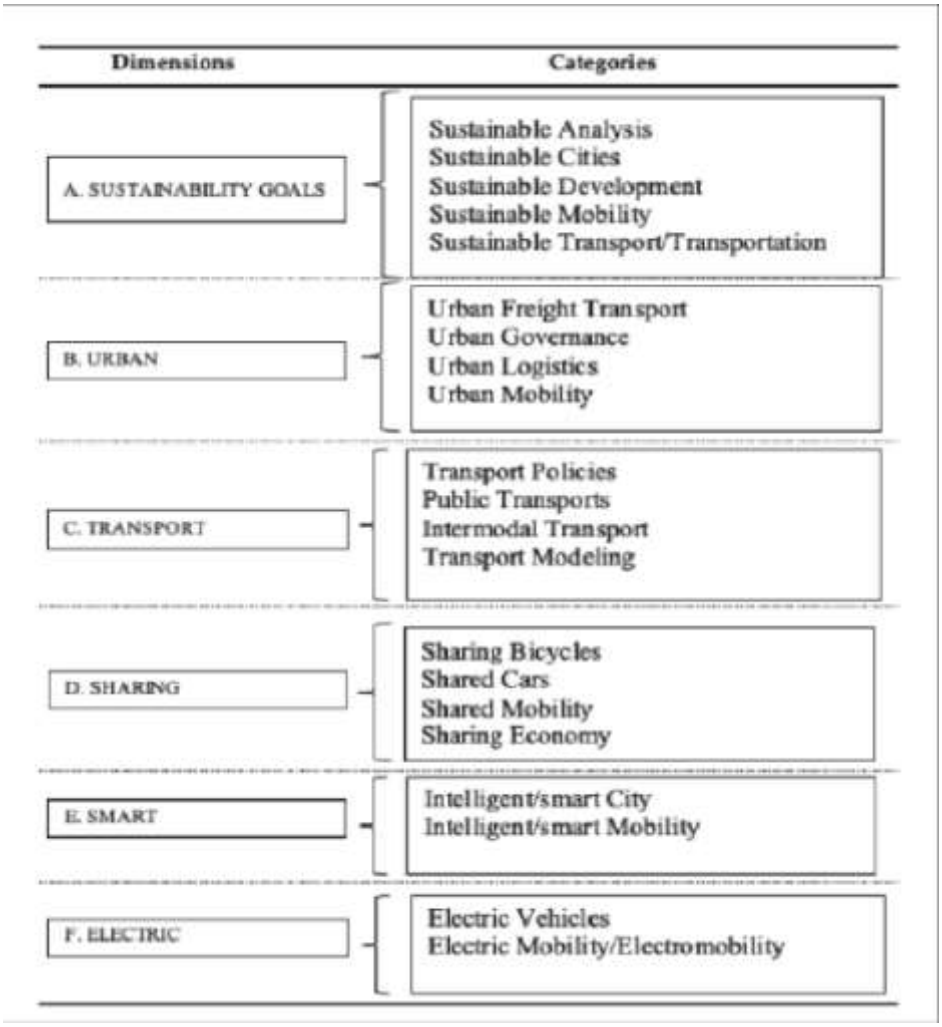

Figure 2: Schematic of sustainable transport dimension and categories

7. SUGGESTIONS

1.1 Intelligent Transportation System (ITS):

1. To empower users to be better informed and make safer, more coordinated, and "smarter" use of transport networks, a change toward an intelligent transport system is required.
2. Intelligent traffic control, electronic toll collecting, and V2X communication are a few examples.

1.2 Awareness Towards Green Travel Habits:

1. Intense public awareness campaigns on the negative impacts of the escalating transportation issues must be started. encouraging increased usage of non-motorized vehicles, maintaining their cars properly, adopting safer driving techniques, etc.
2. Campaigns of this kind will motivate people to adopt "Green Travel Habits," which would reduce the amount of pollution and harm caused by travel.

ISSN No: 2394-059X
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Journal Website www.nrjhrm.in

1.3 Resilience, Equity, and Sustainability in Transport (REST):

1. Resilience: Rethinking and regaining trust in public transportation is necessary. This includes adding more buses, e-buses, bus corridors, and bus rapid transit systems along with digitizing public transportation.
2. Equity: Last-mile rail and road connectivity ought to be given top priority, with the northeast area receiving particular consideration.
3. Sustainability: Biofuels should take the place of fossil fuels, electric vehicles should be encouraged, and emission regulations should be strengthened.
4. To fully profit from electric vehicles, a number of electric freight lanes must be developed in order to encourage electrification.

1.4 Manufacturing Hub in Green Mobility:

1. India has the potential to establish itself as a low-cost, zero-carbon manufacturing hub for green mobility, while simultaneously achieving its objectives of economic development, job creation, and enhanced public health. This can be achieved through appropriate policy support, industry action, market generation, increased investor interest, and acceptance.

8. CONCLUSION

The transport sector, responsible for 30% of global energy consumption, is vital for economic development and human well-being. India's transport infrastructure is inadequate to meet growing mobility needs, and unsustainable activities can lead to air quality degradation, greenhouse gas emissions, climate change threats, and habitat loss. Sustainable transport is essential for India's mobility sector. The paper emphasizes the importance of analyzing environmental threats and opportunities, recognizing the need for green transportation, and understanding the relationship between transportation and sustainable urban development. Integrating sustainable practices into the transportation sector is crucial for addressing environmental and social challenges responsibly and effectively.

The research report concludes by highlighting the vital role that India's transportation industry plays and by stressing the pressing need for sustainable methods to solve social and environmental issues. Given that the transportation industry uses 30% of the world's energy, it is clear that unsustainable practices can result in dangers to climate change, habitat loss, emissions of greenhouse gases, and deterioration of air quality. Prioritizing sustainable transport projects is made even more crucial by the fact that India's transportation infrastructure is inadequate to fulfil the country's expanding mobility needs.

The importance of examining environmental risks and possibilities in the transportation industry, together with the demand for environmentally friendly transportation options, is emphasized in the article. Additionally, it emphasizes the relationship between sustainable urban development and transportation, stressing how important it is to incorporate sustainable practices into the transportation industry in order to responsibly and effectively mitigate social and environmental concerns.

In order to advance environmentally friendly transportation, lower emissions, and improve the overall quality of the environment, policymakers, urban planners, and stakeholders in the transportation sector must give top priority to the implementation of sustainable initiatives. This document is a call to action for the inclusion of sustainable transportation practices in urban development plans and policy frameworks. By doing this, India can promote economic

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development and enhance human well-being while addressing the urgent social and environmental issues brought on by the transportation industry.

The study report essentially argues for a paradigm change in favour of sustainable transportation as a vital part of India's mobility industry. It draws attention to the necessity of teamwork in advancing the shift to more environmentally friendly, economically viable transportation systems that are consistent with sustainable development concepts.

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