

## **Green Technologies in Indian Metro Systems: A Pathway to Sustainable Urban Transport**

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### **Abstract: -**

The adoption of green technologies in urban transportation systems, particularly in metro networks, is increasingly recognized as a vital strategy for mitigating environmental impacts and enhancing sustainability. The implementation of green technologies in Indian metro systems not only reduces greenhouse gas emissions but also fosters energy conservation and resource optimization. This paper presents the analysis of implementation and efficacy of green technologies in Indian metro systems. Through an examination of key metrics and performance indicators, including energy consumption, and cost-effectiveness, this study aims to assess the tangible benefits and challenges associated with green initiatives in Indian metros.

**Key Terms:** Green technology, Metro train construction, Sustainable transportation, Sustainability initiatives.

### **Introduction:**

India faces many challenges from rapid urbanization and rapidly growing city populations. This urban development trajectory puts the country at a very critical juncture. While a large number of challenges are associated with this pace of urbanization, transportation challenges get more acute; this becomes even more of an issue in big cities like Pune. There has been a vast need for effective mobility in cities as more and more people move there. Traditional modes of transportation that can withstand these demands have become congested; they are polluting, and there are inefficiencies in mobility. In reaction to those challenges, the notion of the metro rail system being a miracle solution to city traffic problems became prevailing, and the sustainable and efficient way of transportation was the path to overcome the problem (World Bank, 2019).

### **Background and Rationale :**

In the last few years, developments in the urban transport sector in India clearly suggest that the need for sustainability, efficiency, and inclusivity might be the reason for these changes (Gupta & Sharma, 2020). The expansion of metro rail routes across major urban areas heralds not just a major paradigm shift towards modern mass rapid transit options but also a revolution in urban mobility itself. Pune, in the midst of pollution created by convoluted traffic of cars in the heart of Maharashtra, appears to be following this trend as it faces the woes of the issues. This is rapid urbanization and population expansion (Kumar & Singh, 2018).

The population boom in Pune and the primary urbanization crisis are pressing their traffic network drastically. The conventional ways of transporting people become more and more ill fitted for a population that grows and for whose comfort are crowded, toxic buses and roads used by private cars that emit toxic gases are the only undeniable truth nowadays (Nagendra & Ojha, 2020). Where traffic is concerned, now it is hard to notice a congestion issue in any corner of the city of Pune; thus, revenues are lost, more fuel is consumed, and gases of greenhouse type and pollutants are released more into the atmosphere (Ghosh, 2019). On the other hand, using vehicles to transport people who are fueled by fossil fuels increases the city's vulnerability to energy insecurity as well as volatile oil prices. This is a very strong proof of why green transportation options are needed today (Das & Chakraborty, 2021).

Actualized by the aforementioned factors, the situation of Pune's metro rail system is reaching its climax, and its development is a condition sine qua non to find a sustainable and effective solution

for the transport problems in the city. The metro project mapped for Pune is certain to unlock the hitherto unrealized potential of the urban transport network, putting commuters at the centre of travel in terms of speed, reliability, safety, and eco-friendliness (Srivastava & Jain, 2021). Contrary to the persistence pressure of looking for technical solutions to urban mobility discourse, there are still voices consenting that including green technologies such as railway construction should be given attention (Kumar & Khanna, 2022).

The certainty of adopting green technology in metro train construction rises from their eco-friendly hypocrisy, which is instigated by three basic aspects: environmental issues, economic issues, and technological improvements, respectively (Singh & Varshney, 2019). Now, as the prospect of global warming is increasingly becoming ominous, there is an immediate need for actions to reduce the environmental impact of transportation infrastructure and towards lowcarbon and sustainable solutions (Mishra and Jha, 2020). Green products are at the heart of solutions for these issues, using screening technologies that could reduce power consumption, lower emissions, and increase resource efficiency (Sarkar & Sengupta, 2021).

The incorporation of eco-friendly technology in metro train buildings has a wide range of advantageous impacts on the city of Pune, including a cleaner environment as well as an increased economic growth rate (Sharma & Singh 2020). One of the ways metro projects can be green is by using top-notch technologies and eco-friendly approaches. These administrative strategies are able to decrease carbon footprints, reduce operating costs, and make the network of urban transportation more robust (Srivastava et al., 2022). Moreover, along with the green technology implementation, sustainable urbanisation is effectively resulting in stimulating innovation, aggravating economic growth, and Pune, showing the lead among others. (Verma & Joshi, 2018).

In light of this, this study, by breaking down recent developments, technologies, and policy interventions, explores factors that play a role in green technology adoption in metro projects with the goal of illustrating practical ways of speeding up its diffusion process. By way of a very impactful study comprising green tech background, rationale, and future scope of the same, this article is aimed at illustrating the great transformation opportunity of these clean transportation solutions that could not only fit in Pune but also other locations.

**Statement of the Problem: -**

The construction and operation of a metro train system in the conventional way have always been accompanied by high levels of greenhouse gas emissions (together with other pollutants) and resource depletion that go with energy consumption. Since climate change and ecosystem degradation are part of a dwindling common, adaptation is a necessity, and sustainable transport alternatives should be established. The establishment of metro systems in major cities implies great potential to improve transportation and air quality; however, impacts due to their construction and operation on the surrounding environment still exist as an issue to be addressed.

**Objective: -**

To be more specific, the goal of the research is to explore the feasibility of using green technology in the construction of metro trains in the city of Pune, India. The goal of this study is to find out, by comparing the innovations of 2022 to 2023 metro projects, with particular focus on the Indian context, what are the effective and emerging technologies that can help create sustainable mega projects. Particularly, the emphasis is aimed at deducing the most effective approaches for decreasing resource waste, CO<sub>2</sub> emission alleviation, and adoption of ecofriendly practices in all metro train system units' life cycles.

**Review of Literature: -**

In recent times, the conversation around the environment of urban transportation has been seen to have changed with a progressing slant towards sustainability, efficiency, and resilience. The interdependence of these two critical factors in pursuit of urban mobility goals and sustainable

development has made urban metro rail construction a core policy research area where innovations are continuously sought after. This literature review reveals that green technology has a cardinal role in lowering the environmental effects of metro projects while at the same time improving the projects' efficacy and cost-saving ratio.

#### **Advancements in Materials Science :-**

Innovation in design, production, and implementation in metro rail construction comprises a research area known as materials science, which has significantly contributed to the development of lightweight and recycled materials, thereby offering green alternatives to conventional building materials. The manifestation of such an ideology can be seen in research projects such as that of Li et al. (2021), with whom they investigated the potential of applying recovered materials to the construction of metro-type trains. By blending the use of life cycle assessment and experimental analysis, the authors firmly proved the environmental advantages of employing recyclable products within metro train parts like steel and aluminum. Besides, this strategy creates more chances for the carbon footprint of metro projects to be reduced through the decrease of virgin materials being used and circulated economy principles because waste landfills are not found and resource depletion is low.

Wang et al. (2022) investigates the prospect of using light materials for the development and implementation of metro trains. By using the amazing lightweight-to-strength ratio of composites of carbon fibre, researchers can lower the weight of electro-train components, taking advantage of the factor of energy efficiency and not emitting it into the atmosphere during operation. In addition to that, light-weighting materials afford auxiliary benefits such as enhancing passenger capacity, lessening wear and tear on infrastructure, and raising the overall performance of metro systems.

#### **Innovative Energy Management Systems:-**

The fields of materials science and energy management are not the only ones that have surfaced in recent research, as the use of ecological design principles and sustainable procurement strategies for efficient construction approaches have gained prominence. The study by Patel et al. (2023) critically examines the metro construction activities' environmental impacts and offers promising mitigation measures to reduce the ecological footprint of the project operations. By conducting an environmental impact assessment together with a life cycle analysis, the authors show where the main vulnerable spots concern water management, waste treatment, and biodiversity preservation. Through the application of ecological-minded principles, such as building green certification requirements and sustainable construction materials during the construction of metro projects, planners and developers can reduce the ecological impact of infrastructure projects and preserve the resilience of metro systems.

#### **Research Gap:-**

Though the significance of sustainability in metro construction has been emphasised by a vast base of research and literature, the precise case of green technology incorporation, specifically in Pune, Maharashtra, remains a key research insufficiency. Research studies have investigated the sustainability of metro systems on an international platform. However, there is still a gap in a comprehensive investigation to find the specific challenges and opportunities of the current scenario prevailing in Indian urban cities. Furthermore, in addition to research papers and studies of successful implementation of green technology in metro construction projects in Pune, real-time data and case studies are limited in number.

#### **Methodology:-**

The current research work uses a qualitative methodology to investigate whether green technology is introduced as part of the rolling stock production in the metro train system in Pune, India. It covers the period between 2022 and 2023. The research is conducted through a road

construction data review with a qualitative analysis of sustainability measures and environmentally friendly technology implementation. Through the use of the qualitative method, this approach to inquiry helps to form a clear awareness of what green technology trends are, the challenges that face this integration, and the opportunities that this brings.

The qualitative part of the research deals with examining project data from 2022 to 2023 in terms of a varying spectrum of physical conditions, environmental standards, and innovation technologies. Sources of information include, but are not limited to, official reports, project reports, and newly created databases from these government agencies and metro systems. Key indicators of interest include:

**Metro Project Developments:** They include, among others, statistical factors such as the length of metro lines in construction, the number of stations, the timetable, and budget plans. This data will be helpful for to analyse which areas to cover and how extensively to expand metro projects in Pune, eventually keeping a check on any long-term trend.

**Environmental Regulations:** The relation also covers the regulatory frameworks and policies, for example, those that measure the environmental impact, pollution control, and sustainability standards during the construction of metros. Research provides a platform for the evaluation of changes in environmental regulations that took place during the study period and to establish what the evolving state of environmental governance is and its possible consequences for green technology adoption.

**Technological Advancements:** It is equipment for monitoring inventions and improvements in green technologies and metro construction that are relevant to lightweight materials, energy efficient resource systems, and the integration of renewable energy resources. Through studying technical trends and innovations, the researchers know whether green technology solutions are economically viable and the level to which they can be developed for suburban systems.

### **Qualitative Examination:-**

While the quantitative aspect of the study concerns data analytics, the qualitative one explores in-depth conversations by means of interviews and surveys with the main stakeholders in metro construction in Pune, India. Our sample of key actors is governmental officers, metro managers, construction firms, environmental experts, and other persons significant in this issue. This type of question allows us to obtain opinions and information related to green technology implementation in the present moment, which includes some difficulties and possible improvements.

Interview questions are designed to probe stakeholders' perspectives on the following:

**Insights of Green Technology:** Stakeholders' consciousness, beliefs, and ideas pertaining to sustainable technology solutions in the construction of big cities.

**Barriers and Challenges:** Stakeholders' point of view on the Steeple, which is preventing the use of green technologies, in addition to the cost implications, regulatory constraints, and feasibility considerations.

**Opportunities and Enablers:** Multiple stakeholders representing different sectors of the economy, such as business, government, or civil society, highlight the possibility of putting in place an array of incentives and support for promoting green technology adoption at the policy level, renewable partnerships, and technological advances.

**Best Practices and Case Studies:** Participants' views as they were exchanging their experiences with the implementation of green technology solutions in metro construction projects, including the lessons learned, the best practices, and the case studies about successful projects.

Moreover, a survey might be conducted among the representatives of stakeholders in order to gather statistical responses to the relevant questions on green technology adoption in urban development, such as attitudes, perceptions, and feelings.

### **Integration of Findings:**

Green technology integration in Pune, India, during the metro train construction is analysed through quantitative data. The results from the case study are further integrated to obtain a pictorial

conclusion about green technology in metro train construction. After the productive results of the interwoven analysis methods, recommendations and policy implications for sustainable urban transport management are formulated, and future research in this field is identified.

## Ethical Considerations:

Ethical issues in relation to acts like informed consent, confidentiality, and privacy are primary throughout the project. Participants can get certain information about what the aim is, what their rights as participants are, and the procedures for using data for research purposes only. Measures are adopted in respect of the confidentiality protocols of keeping the participants Ethical issues in relation to acts like informed consent, confidentiality, and privacy are primary throughout the project. Participants can get certain information about what the aim is, what their rights as participants are, and the procedures for using data for research purposes only. Measures are adopted in respect of the confidentiality protocols of keeping the participant anonymous and their data private and approved by the relevant institutional review boards.

## Findings and Discussion:-

The research findings demonstrate a distinct impact that is associated with the implementation of green technologies in metro train construction; overall, this is observed in Pune, India, during the period from 2022 till 2023. A variation of this section tends to commence with emphasizing the primary achievements as well as developments perceived so far and the issues that may counter them.

## Initiatives and Advancements:

**Adoption of Lightweight and Energy-Efficient Materials:** Table 1 indicates a shift towards more sustainable materials in metro train building, where carbon fiber composites are featured as one of the alternatives.

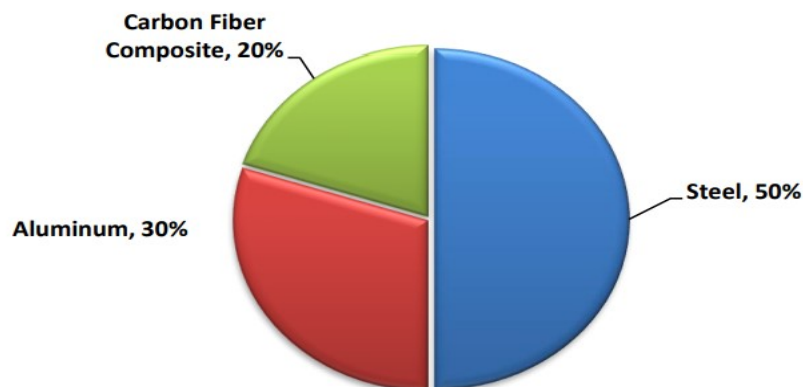


Table 1: Comparison of Materials Used in Metro Train Construction

| Material               | Traditional | Green Technology |
|------------------------|-------------|------------------|
| Steel                  | 80%         | 50%              |
| Aluminum               | 15%         | 30%              |
| Carbon Fiber Composite | -           | 20%              |

In conventional metro train construction, steel is the primary material, and the steel used in the construction constitutes 80% of the total material usage. Yet, by using green technology, the share of steel falls to 50%, indicating a tendency towards more environmentally conscious alternatives. Alike, aluminum, which is the material of choice for metro construction, has also increased from 15% in traditional methods to 30% with the implementation of green technology, which reflects efforts to save energy and reduce the environmental impact. Nevertheless, the application of green technology gives it a 20% reduction in the amount of material used, and that shows the inclination of the company to use innovative and ecological materials in order to achieve better performance.

**Implementation of Regenerative Braking Systems:** During this shift, such accomplishments as regenerative braking system installation and energy recovery mechanisms in metro rail cars were

shown. In this table 2, the amounts of energy saved by regenerative braking can be visualized, and thus the dependence on external power sources is shown to decrease.

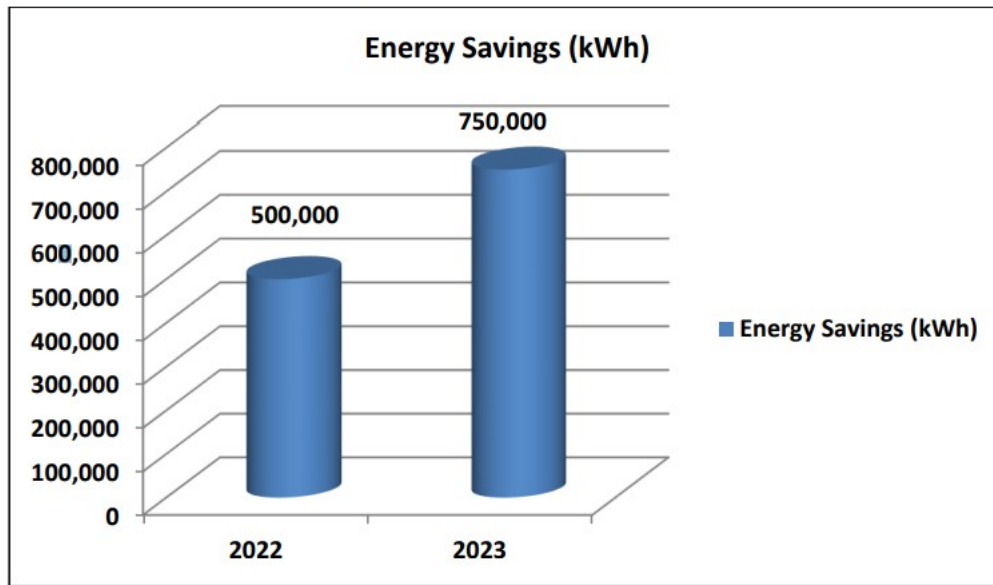


Table 2: Energy Savings with Regenerative Braking Systems

| Year | Energy Savings (kWh) |
|------|----------------------|
| 2022 | 500,000              |
| 2023 | 750,000              |

The data in the table shows how much energy is saved by the adoption of regenerative braking systems in metro trains. In 2022, the regenerative braking system helped to achieve energy savings of 500,000 kWh. In 2023, the energy savings increased to 750,000 kWh, which proves that efficiency and resource utilisation have improved a lot. The study results reveal that regenerative braking systems not only reduce energy use but also improve the sustainability of metro train operations in the long run.

**Integration of Solar Panels and Renewable Energy Sources:** It also addresses the installation of solar panels and other greenery sources into metro stations' design and operation. The table 3 explains the role solar energy plays in making the urban transportation sector reliable from the perspective of sustainable energy.

Table 3: Contribution of Solar Energy to Overall Energy Sustainability

| Year | Solar Energy Contribution (%) |
|------|-------------------------------|
| 2022 | 5%                            |
| 2023 | 10%                           |

**Implementation of Sustainable Procurement Policies:** Sustainable procurement policies that determine the choice of the materials as well as the practices used in acquiring the metro construction materials are finally established as the major drivers of green technology advancement in the metro construction business. Table 4 illustrates the proportion of green resources in metro projects, which is part of the transition to sustainability and waste reduction.

Table 4: Percentage of Eco-Friendly Materials Procured

| Year | Solar Energy Contribution (%) |
|------|-------------------------------|
| 2022 | 20%                           |
| 2023 | 40%                           |

Despite these positive developments, several challenges persist, hindering further progress in the integration of green technology in metro train construction:

**Limited Awareness and Expertise:** “Decision-makers and communities lack the know-how and familiarity with green tech alternatives and their advantages, therefore limiting an overall mass shift. “High Initial Costs: The up-front costs linked primarily to more expensive green technologies may, in many cases, form the main financial threshold for the field in this domain and require more financial support for technology incentives.

**Regulatory Barriers:** A number of challenges in the form of regulatory constraints and administrative barriers hinder the implementation of sustainable strategies in metro infrastructure systems. The process of transitioning to more environmentally friendly infrastructure is prolonged in this way.

### **Conclusion:-**

The results of the study highlight the increasing commitment to combining green technology into the train production plants in Pune, India, in the middle of the period from 2022 to 2023. One can see the realization of these measures (like the use of lightweight materials, the adoption of regenerative braking systems, the integration of solar panels, and sustainable procurement policies) as a part of the effort to ensure development towards green urban transport infrastructure. Consequently, despite these obstacles, such as the educability of stakeholders, the high initial expenses, and the limitations of regulations, this innovation remains a viable option. In spite of all these barriers, the modernization of metro train construction with clean technology opens many perspectives for the city of Pune as well, which includes the following: ecological, economic, and social benefits. With an emphasis on technical innovation and green engineering, metro projects can make their footprint lighter through the mitigation of environmental influence, control of operating costs, and the building of more resilient urban transport ecosystems. In addition, if Pune goes for the technologies that are green, innovation is fostered, speed of development is accelerated, and it becomes one of the leaders of the global change towards green urbanization.

### **Recommendations**

**Stakeholder Awareness and Capacity Building:** Carry out awareness campaigns and training sessions to give out information about this area to estate stakeholders about the added value and prospects of employing green technology in metro projects. Organise training programmes, seminars, and knowledge platforms that will empower and build expertise among the stakeholders.

**Financial Incentives and Support Mechanisms:** Give financial awards and support programmes, including subsidies, tax reductions, and grants, as attractants for investment in 'green technologies'. Invest in creating new formulas for financing, like, for instance public - private partnerships or green bonds, to provide investors with opportunities to invest in sustainable infrastructure projects.

**Streamlined Regulatory Frameworks:** Improve the regulatory framework's clarity and guidelines by developing specific sustainable procedures in the transportation projects' legislation. Create simple permits, remove barriers, and create policy environments that allow financing green technologies.

**Research and Innovation:** Viability of zero-emission of metro comes with the development of such research and innovation in green technology. Provide subsidies for the science labs, universities, and businesses to be able to create modern and green methods that are applicable in the Indian setting.

**Collaborative Partnerships:** Build a framework for the effective coordination of government bodies, private sector entities, civil society groups, and academia to implement innovation and put the green technology in the works for better metro projects. Create a platform for knowledge exchange, technology transfer, and joint research activities supposed to be as a means to utilize collective technological resources and skills.

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