

A Comparative Analysis of Traditional Roadways vs. Electric Vehicle (EV) Roads: Environmental, Infrastructure, And Technological Perspectives

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Abstract

As the global transportation sector seeks to address pressing environmental challenges and transition towards sustainable mobility solutions, the comparative analysis between Traditional roadways and Electric Vehicle (EV) roads emerges as a critical area of investigation. This paper presents a comprehensive comparative analysis of traditional road infrastructure and EV road infrastructure from environmental, infrastructure, and technological perspectives. From an environmental standpoint, the analysis evaluates the life cycle environmental impacts, including greenhouse gas emissions, air and noise pollution, and resource consumption associated with traditional roadways and EV roads. It examines the potential for EV roads to mitigate environmental impacts through reduced fossil fuel dependency, lower emissions, and integration with renewable energy sources. Infrastructure comparisons encompass the design, construction, maintenance, and operation of traditional roadways versus EV roads. Factors such as pavement materials, structural integrity, durability, and lifecycle costs are scrutinized to assess the performance and resilience of each infrastructure type. Additionally, the analysis explores the implications for urban planning, land use, and transportation networks in accommodating EV road infrastructure. Technological perspectives delve into the advancements and innovations driving both traditional roadways and EV roads. It examines the integration of smart technologies, intelligent traffic management systems, and renewable energy solutions in enhancing the functionality, efficiency, and sustainability of road infrastructure. Furthermore, the analysis explores the implications of EV road technologies, such as dynamic wireless charging systems and vehicle-to-grid communication, on future transportation systems. Through a systematic comparison of traditional roadways and EV roads, this study provides insights into the environmental, infrastructure, and technological implications of each infrastructure type. By elucidating the benefits, challenges, and opportunities associated with EV road adoption, policymakers, urban planners, and transportation stakeholders can make informed decisions to advance sustainable transportation solutions and mitigate environmental impacts in the transition to electric mobility.

Keywords: Transportation Sector, Environmental Challenges, Sustainable Mobility, Traditional Roadways, Electric Vehicle (EV) Roads, Comparative Analysis, Environmental Impact, Infrastructure Comparison, Technological Perspectives, Electric Mobility.

1. Introduction

The growing concern over environmental degradation and the need for sustainable transportation has led to increased interest in electric vehicles (EVs) and the development of EV [1-3]

Infrastructure. This paper seeks to assess the differences between traditional roadways and those designed specifically for EVs. The significance of this research lies in its holistic

examination of the environmental impact, infrastructure requirements, and technological advancements associated with traditional roadways and Electric Vehicle (EV) roads. By systematically evaluating these dimensions, the study aims to contribute crucial insights for informed decision-making in the context of sustainable transportation. Understanding the environmental consequences, including air and noise pollution, greenhouse gas emissions, and the potential reductions offered by EV roads, will guide policymakers and urban planners in adopting eco-friendly transportation solutions. Analyzing the infrastructure needs for both traditional and EV road systems will provide essential data for efficient resource allocation, taking into account factors such as fueling stations, maintenance, and [4] charging infrastructure. Furthermore, exploring technological advancements in road construction will shed light on the integration of smart technologies and innovative materials, paving the way for more efficient and resilient transportation networks. In essence, this research serves as a comprehensive guide for stakeholders, offering valuable insights into the multifaceted aspects of traditional and EV road development, ultimately contributing to the advancement of sustainable and technologically advanced transportation solutions.

2. Methodology

There aren't many comprehensive case studies or empirical data specifically comparing traditional roadways to electric vehicle (EV) roads due to the relatively early stage of EV road development. However, there are some ongoing pilot projects and studies that provide valuable insights into the Potential benefits and challenges of EV roads compared to conventional roads. Here are a few examples: [5]

Sweden's Electric Road System (ERS) Pilot:

- **Overview:** Sweden has been at the forefront of EV road development with its Electric Road System (ERS) pilot project. The project involves the construction of a 2-kilometer stretch of electrified road equipped with overhead power lines that charge specially equipped trucks while

they are in motion.

- **Data and Findings:** Initial data from the pilot project showed promising results in terms of energy efficiency and emission reductions. The ERS demonstrated the potential to reduce fuel consumption and CO2 emissions by enabling hybrid trucks to operate in electric mode while on electrified road segments. [6]

Dynamic Wireless Charging Trials:

- **Overview:** Several trials and pilot projects have been conducted to test dynamic wireless charging technology for electric vehicles. These projects involve installing wireless charging systems embedded in road surfaces or at charging points along highways and urban roads.
- **Data and Findings:** Empirical data from dynamic wireless charging trials have shown the feasibility of charging electric vehicles while they are in motion, eliminating the need for frequent stops to recharge. These trials have provided insights into the efficiency, reliability, and safety of dynamic wireless charging systems in real-world conditions.

2.1 Environmental Impact

To understand the environmental impact of EV roads in comparison with traditional roads we will have to see the comparison of electric vehicles with traditional vehicles. As it promotes the adoption of electric vehicles, further reducing emissions indirectly. [7]

Table 1 Growth in The Number of EVs Sold in The Last Few Years

Year	Number of EVs sold (Million)
2017	1.0
2018	2.0
2019	3.0
2020	4.0
2021	6.0

2022	10.0
2023	14.0

The above table 1 shows the increase in the purchase of EVs to reduce emissions. To understand environmental effects of traditional & Ev roads following table 2 are given-[8]

Table 2 Environmental Impact: Traditional Roads

Aspect	Description
Air Pollution	<ul style="list-style-type: none"> - Vehicle emissions contribute to air pollution with pollutants such as nitrogen oxides (NOx), volatile organic compounds (VOCs), particulate matter (PM), and carbon monoxide (CO). - Traffic congestion and road dust also add to air pollution.
Noise Pollution	<ul style="list-style-type: none"> - Traffic noise from vehicle engines, tires, and aerodynamic effects affects health and quality of life. - It can lead to annoyance, sleep disturbance, stress, and hearing impairment.
Greenhouse Gas Emissions	<ul style="list-style-type: none"> - Transportation, including traditional roadways, is a significant source of greenhouse gas emissions such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). - These emissions contribute to climate change and global warming.

Table 3 Environmental Impact: EV Roads

Aspect	Description
Potential Reduction in Emissions	<ul style="list-style-type: none"> - Electric vehicles (EVs) produce zero tailpipe emissions when powered by electricity, leading to reductions in air pollutants and greenhouse gases. - EV roads promote the adoption of electric vehicles, further reducing emissions indirectly.
Environmental Implications of EV Infrastructure	<ul style="list-style-type: none"> - Materials and manufacturing of EV infrastructure have environmental impacts such as energy consumption and pollution. - Energy consumption for charging depends on the sources of electricity, with renewable energy offering benefits.

2.2 Infrastructure Requirements

Infrastructure requirements for traditional roadways include fueling stations for vehicles and maintenance/upkeep facilities to ensure the proper functioning and safety of the road network. [9]

Infrastructure requirements for electric vehicle (EV) roads primarily revolve around charging infrastructure and the maintenance of both charging stations and roadways. The table 3 are given Environmental Impact: EV Roads.

Table 4 Infrastructure Requirements - Traditional Roads

Aspect	Description
Fueling Stations	<ul style="list-style-type: none"> - Types: Traditional roadways require fueling stations to provide gasoline, diesel, or alternative fuels for vehicles. <ul style="list-style-type: none"> - Distribution: Fueling stations are strategically located along roadways. - Infrastructure: Fueling stations consist of fuel storage tanks, dispensers, pumps, payment systems, and amenities. - Regulatory Compliance: Fueling stations must comply with safety, environmental, and fuel quality standards.
Maintenance and Upkeep	<ul style="list-style-type: none"> - Routine Maintenance: Includes pothole patching, crack sealing, pavement marking, roadside vegetation control, and litter removal. - Pavement Rehabilitation: Techniques such as resurfacing, milling, overlaying, and reconstruction. - Bridges and Structures: Maintenance to ensure structural integrity and safety. - Winter Maintenance: Snow plowing, salting, and de-icing in cold climates - Traffic Management: Temporary traffic control measures during maintenance activities.

Table 5 Infrastructure Requirements: EV Roads

Aspect	Description
Charging Infrastructure	<ul style="list-style-type: none"> - Types: Static Charging Stations and Dynamic Wireless Charging Systems. <ul style="list-style-type: none"> - Distribution: Strategically deployed along EV roads at key points. - Infrastructure: Consists of power supply equipment, charging connectors, control systems, and payment terminals. - Capacity and Compatibility: Scalable and adaptable to accommodate different EV models and charging speeds. <ul style="list-style-type: none"> - Energy Source: Powered by renewable energy sources to minimize environmental impact.
Maintenance of Charging Stations and Roadways	<ul style="list-style-type: none"> - Routine Maintenance: Inspection, cleaning, and software updates for charging stations and equipment. - Fault Diagnosis and Repair: Timely resolution of equipment malfunctions and communication errors. - Roadway Maintenance: Similar to traditional roadways, including pothole repair and snow removal. - Integration with Traffic Management: Coordination for temporary traffic control measures during maintenance activities.

Table 6 Approximate Number of Fueling Infrastructures in India

Type of Fueling Infrastructure	No. of Stations in India	Percentage of Total Infrastructure
Electric Vehicle (EV) Stations	934	Small, but rapidly growing
Compressed Natural Gas(CNG) Stations	6159	Significant role in transportation
Petrol Stations (Gas Stations)	Varies	Dominant refueling infrastructure

2.3 Technological Advancements

Technological advancements in traditional roadways have seen a range of incremental improvements aimed at enhancing safety, efficiency, sustainability, and user experience. Implementation of intelligent traffic management systems that utilize sensors, cameras, and data analytics to monitor traffic flow, detect congestion, and optimize signal timing. Integration of real-time traffic information and adaptive signal control to improve traffic flow, reduce congestion, and enhance safety at intersections. Development of advanced road surface materials with improved durability, skid resistance, and noise reduction properties. The table 4 are given infrastructure requirements - traditional roads. Application of innovative pavement technologies such as porous asphalt, rubberized asphalt, and permeable concrete to enhance drainage, reduce storm water runoff, and mitigate flooding. Integration of communication technologies and infrastructure-to-vehicle (I2V) connectivity to support connected and autonomous vehicle operations. Deployment of dedicated short-range communication (DSRC) and cellular vehicle-to-everything (C-V2X) technologies to enable vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication. Installation of advanced safety features such as rumble strips, reflective markers, and barrier systems to improve visibility, delineation, and guidance for drivers. Adoption of automated warning systems, dynamic message signs, and variable speed limits to alert drivers to hazardous conditions, inclement weather,

and construction zones. Implementation of green infrastructure solutions such as vegetated roadside

buffers, bios wales, and permeable pavements to manage storm water runoff, improve water quality, and enhance roadside aesthetics. The Table 5 are given infrastructure requirements: EV roads integration of renewable energy technologies such as solar panels and wind turbines into roadside infrastructure to generate clean energy and offset energy consumption. Utilization of data-driven techniques such as remote sensing, pavement condition surveys, and geographic information systems (GIS) to assess road conditions, prioritize maintenance needs, and optimize asset management strategies. Implementation of predictive maintenance approaches and condition-based monitoring systems to detect signs of deterioration, prevent failures, and prolong the lifespan of road infrastructure. Development of smart mobility applications, real-time navigation systems, and traveler information services to provide users with up-to-date traffic updates, alternative route suggestions, and personalized travel recommendations. Integration of amenities such as electric vehicle charging stations, rest areas, and roadside attractions to enhance the comfort and convenience of road users. Technological advancements in EV roads focus on integrating smart technologies and leveraging advancements in electric vehicle (EV) technology to enhance functionality, efficiency, and

sustainability. **Dynamic Wireless Charging:** EV roads incorporate dynamic wireless charging systems embedded in road surfaces, allowing continuous charging of EVs while in motion. Smart induction coils embedded in lanes communicate with receivers installed on EVs to optimize charging efficiency and vehicle range. EV roads enable bidirectional communication between EVs and the electrical grid, allowing vehicles to feed excess energy back to the grid during peak demand periods. V2G technology enhances grid stability, supports renewable energy integration, and provides additional revenue streams for EV owners. The table 6 are given approximate number of fueling infrastructures in India. **Smart Energy Management Systems:** EV roads deploy smart energy management systems to optimize charging operations, balance energy supply and demand, and minimize grid impacts. These systems utilize data analytics, artificial intelligence, and predictive algorithms to optimize charging schedules, manage load distribution, and prioritize renewable energy usage. EV roads leverage Internet of Things (IoT) connectivity to enable real-time monitoring, remote control, and data exchange between EVs, charging infrastructure, and smart grid components. IoT sensors, actuators, and communication devices facilitate seamless integration and interoperability across diverse technologies. EVs incorporate advanced lithium-ion battery technology with higher energy density, longer lifespan, and faster charging capabilities. Innovations in battery chemistry, materials science, and manufacturing processes improve energy efficiency, reduce charging times, and extend driving range. EV roads deploy fast-charging infrastructure capable of delivering high-power charging rates to recharge EV batteries quickly. Ultra-fast chargers with power levels exceeding 350 kW enable rapid charging sessions, allowing EVs to replenish battery capacity in minutes rather than hours. EVs feature V2X connectivity capabilities that enable communication with other vehicles, infrastructure, and smart grid systems. V2X technology supports features such as vehicle-to-vehicle (V2V) communication, vehicle-to-infrastructure (V2I) communication, and vehicle-to-

grid (V2G) interaction, enhancing safety, efficiency, and grid resilience. EVs integrate autonomous driving technologies such as adaptive cruise control, lane-keeping assistance, and automated parking systems. These features enhance vehicle safety, reduce driver workload, and enable hands-free operation in certain driving scenarios. Overall, technological advancements in EV roads aim to create intelligent, interconnected transportation ecosystems that support electric mobility, renewable energy integration, and sustainable urban development. By harnessing the potential of smart technologies and electric vehicle innovations, EV roads pave the way for a cleaner, safer, and more efficient transportation future. [10]

Conclusion

The implications for future transportation strategies are significant, driven by the advancement of electric vehicle (EV) roads and the broader transition toward sustainable transportation systems. Here are several key implications:

- Decarbonization of Transportation
- Energy Transition and Grid Integration
- Urban Planning and Infrastructure Development
- Mobility as a Service (MaaS)
- Data-driven Decision Making
- Policy and Regulatory Frameworks
- Equity and Accessibility

By adopting these recommendations, transportation agencies, policymakers, and stakeholders can promote sustainable roadway development that enhances mobility, fosters economic prosperity, protects the environment, and improves quality of life for communities. In the comparative analysis of traditional roads versus EV roads, several areas warrant further exploration and investigation to deepen understanding and inform decision-making. Here are some key areas for further exploration:

- Life Cycle Assessment (LCA) Cost-Benefit Analysis
- Performance and Durability
- Energy Efficiency and Renewable Energy

Integration

- User Experience and Acceptance
- Policy and Regulatory Frameworks
- Long-Term Impacts and Future Scenarios

By delving deeper into these areas of exploration, researchers, policymakers, and industry stakeholders can gain valuable insights into the benefits, trade-offs, and opportunities associated with traditional road infrastructure and EV road infrastructure, ultimately informing decision-making and guiding the transition to sustainable transportation systems.

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