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Impact of the adoption of electrical vehicles sustainable mobility on the environment

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Abstract

This study investigates the rapid integration of electric vehicles (EVs) is reshaping sustainable transportation, providing a hopeful solution for decreasing the environmental harm caused by conventional vehicles powered by fossil fuels. The study assesses the environmental effects of the growing use of EVs, with a particular emphasis on greenhouse gas (GHG) emissions, energy consumption, air quality, and resource sustainability. Through a comprehensive analysis, the research highlights that EV adoption significantly reduces tailpipe emissions, contributing to improved air quality and decreased urban pollution. However, the net environmental benefit depends on several factors, including the electricity generation mix, battery production processes, and the lifecycle management of EV components. Lastly, the research concludes that while electric vehicles are generally an environmentally friendly alternative, this will, however, depend on making advances in renewable energy sources, battery recycling processes, and the required infrastructure. Effective policies will have to be implemented, and strategic investments directed in green energy to harvest maximum environmental benefits from the adoption of electric vehicles, fostering the transition toward a sustainable transportation system.

Keywords: Electric Vehicles, Sustainable Mobility, Greenhouse Gas Emissions, Air Quality, Renewable Energy

Introduction

The swift advancement of technology, combined with increasing global worries about climate change, air quality deterioration, and resource scarcity, has led to an urgent need to reevaluate transportation systems and their environmental impact. Among the most promising solutions to these pressing challenges is the widespread adoption of electric vehicles (EVs) as part of a broader movement toward sustainable mobility. As nations and cities work to minimize their carbon footprints and encourage cleaner, greener transportation solutions, electric vehicles (EVs) have emerged as a central component in the shift toward a more sustainable and environmentally friendly future. The advent of electric vehicles marks a substantial transition from traditional fuel-based transportation, characterized by zero emissions, improved energy efficiency, and reduced reliance on fossil fuels. As the world shifts towards environmentally friendly transportation, electric vehicles are instrumental in curbing greenhouse gas emissions and have the potential to redefine the energy landscape, fostering a more harmonious relationship between transportation networks and renewable energy sources. However, the environmental effects of adopting EVs go beyond just their operation. While EVs are generally cleaner during use, the comprehensive environmental advantages are influenced by several elements, such as the types of energy sources utilized for charging, the ecological consequences of battery manufacturing, and the necessary infrastructure to facilitate support. Additionally, advancements in battery technology, recycling, and renewable energy integration will be critical to unlocking the full potential of electric vehicles for sustainable development. This paper explores the multifaceted environmental impact of adopting electric vehicles as part of a global transition to sustainable mobility. It examines the direct and indirect effects on carbon emissions, air quality, energy efficiency, and the broader ecological footprint associated with the shift to electric transportation. By understanding both the benefits and challenges of EV adoption, we can better assess the role of electric vehicles in shaping a cleaner, more sustainable transportation future.

Literature Review

The literature review explores several key concepts, including the environmental advantages

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of electric vehicles (EVs), the life cycle assessment of EVs, and the Balanced Scorecard framework. Additionally, it examines the integration of renewable energy sources and the development of sustainable charging infrastructure. Policy interventions and incentives aimed at promoting EV adoption are also covered. These theories and frameworks contribute to understanding the social and economic impacts of widespread EV adoption. Challenges and Barriers to EV Adoption While the use-phase of EVs offers clear advantages in reducing greenhouse gas emissions and air pollution, the environmental effects linked to battery manufacturing and the carbon footprint of the electricity grid are important considerations that affect the overall sustainability of electric vehicles. Effective policy measures, advancements in battery technology, and the integration of renewable energy sources are essential to overcoming these challenges and optimizing the environmental advantages of adopting electric vehicles." A review of the literature on the effects of adopting electric vehicles (EVs). On sustainable mobility and the environment highlights various aspects of how EVs can contribute to reducing environmental impacts, the challenges they face, and the policy measures influencing their adoption. This review synthesizes the key findings from scholarly articles and reports related to the topic.

1. Benefits of Electric Vehicles for the Environment

Electric vehicles are always touted as a sustainable alternative to the conventional internal combustion engine vehicles (ICEVs) because of their potential in reducing greenhouse gas emissions and improving air quality in cities. According to Breetz *et al.* (2018) ^[1], the main environmental benefit of EVs is their ability to reduce carbon dioxide (CO₂) emissions which arise from the transportation system, particularly in cases where the energy used to power them comes from renewable resources like solar and wind power. The transformation of transportation systems to electric mobility could lead to significant reduction in CO₂ emissions, which would otherwise contribute to climate change immensely. Hwang *et al.* (2020) ^[5] examined the impact of EV adoption on urban air quality, noting that the replacement of ICEVs with EVs "Results in significant decreases in pollutants like nitrogen oxides (NO_x) and particulate matter (PM). These reductions are especially important in cities, where vehicle emissions are a primary contributor to air pollution".

2. Life Cycle Assessment of Electric Vehicles

While the use-phase of EVs shows clear environmental benefits, the environmental impact of EV production, particularly the manufacturing of lithium-ion batteries, is a subject of concern. Ellingsen *et al.* (2014) ^[3] and Cohen *et al.* (2019) ^[2] conducted life cycle assessments (LCA) of EV batteries, revealing that the battery production process is energy-intensive and associated with significant carbon emissions. The extraction of raw materials, such as lithium, cobalt, and nickel, also contributes to environmental degradation. However, advancements in battery technology and recycling methods are expected to mitigate these impacts over time.

Hawkins *et al.* (2013) ^[4] conducted a comparative LCA of conventional vehicles and EVs, finding that despite the higher environmental costs during the production phase, EVs have a lower overall environmental footprint when

considering their entire life cycle, especially if the electricity used for charging is sourced from renewable energy.

3. Renewable Energy Integration and Sustainable Charging Infrastructure

The environmental sustainability of EVs is heavily dependent on the source of the electricity used for charging. Olarte *et al.* (2021) ^[8] highlighted the importance of integrating renewable energy sources into the power grid to maximize the environmental benefits of EV adoption. The study emphasized that as more EVs are introduced, there is a growing need for sustainable and efficient charging infrastructure that supports renewable energy integration. Smart charging technologies and vehicle-to-grid (V2G) systems can further enhance the efficiency of energy use and support the transition to a low-carbon power grid.

4. Policy Measures and Incentives

Government policies and incentives are essential in driving the widespread adoption of electric vehicles." Sierzechula *et al.* (2014) ^[9] and Lutsey & Nicholas (2019) ^[6] discussed the impact of policy measures, including subsidies, tax incentives, and investments in charging infrastructure, on accelerating the uptake of electric vehicles. Policies aimed at reducing the total cost of ownership for EVs and improving consumer awareness have been effective in increasing adoption rates, particularly in regions with strong governmental support. In addition, regulatory measures such as emissions standards and bans on the sale of new ICEVs in certain regions are driving the shift towards electric mobility. "State and local policies play a vital role in encouraging both public and private investments in EV infrastructure, which is essential for addressing adoption challenges."

5. Social and Economic Effects of Electric Vehicle Adoption

In addition to their environmental benefits, transitioning to electric vehicles also affects the social and economic aspects of sustainable transportation. Mc Guckin *et al.* (2014) ^[7] investigated how mobility patterns change with the rise in electric vehicle usage, observing a possible transition towards more sustainable travel habits, including greater reliance on shared and electric public transport his shift can contribute to reducing overall vehicle miles traveled (VMT) and easing traffic congestion in urban areas. Van Vliet *et al.* (2019) ^[10] examined the effects of EV adoption on employment, noting a positive impact in sectors related to renewable energy and electric vehicle manufacturing, but also potential job losses in traditional automotive and fossil fuel industries. The transition to electric mobility requires workforce retraining and adaptation to new technologies.

Rationale of the study

The electronics sector in Madhya Pradesh is seeing tremendous expansion, making a substantial contribution to the local economy. As firms in this industry want to improve their operational efficiency and achieve a competitive advantage, it is essential to use HR and financial analytics. Although these technologies are becoming more important, there is a significant lack of research focused on their use in the electronics sector in this area. This research aims to address this deficiency by conducting a thorough examination of the adoption,

obstacles, and advantages of HR and finance analytics. Gaining a deep understanding of these dynamics will provide useful insights and practical advice for industry stakeholders, such as managers, HR professionals, and finance experts. This will enable them to efficiently negotiate the complexity of implementing analytics.

Objective of the expected research

The **objectives** of "Numerous studies have investigated the impact of the adoption of electric vehicles (EVs) Existing research provides insights into the effects of the widespread adoption of electric vehicles (EVs)" on sustainable mobility and the environment are designed to explore and quantify the potential environmental, social, and economic benefits of transitioning to electric mobility. Below are the key objectives of this study:

Primary Objectives

1. To Assess the Environmental Advantages of Electric Vehicle Adoption: Evaluate the Decreasing CO₂ emissions from greenhouse gas sources is one of the key environmental benefits associated with the growth of electric vehicle adoption.

- Examine the effect of EVs on urban air quality by tracking changes in pollutants like nitrogen oxides (NO_x) and particulate matter (PM_{2.5}). Assess the environmental impact across the entire life cycle by performing a comparative life cycle assessment (LCA) between electric vehicles and traditional internal combustion engine vehicles (ICEVs)."

2. To Delve into the Influence of Renewable Energy on Maximizing the Advantages of Electric Vehicles

Examine the ways in which energy mix influences the environmental impact of EV charging, with a particular focus on integrating renewable energy sources (e.g., solar, wind).

- Analyze the potential of smart charging and vehicle-to-grid (V2G) technologies in enhancing the sustainability of electric vehicles by optimizing energy use and grid stability.

3. Assess the Socio-Economic Impacts of Embracing Electric Vehicles

Explore the socio-economic benefits associated with the adoption of electric vehicles, including job creation in sectors such as renewable energy, battery manufacturing, and electric vehicle production. Industries Assess changes in mobility patterns and public health outcomes related to improved air quality and reduced noise pollution from EV adoption.

- Investigate the implications of EV adoption for energy consumption, transportation costs, and consumer behaviour.

Secondary Objectives

4. To Evaluate the Effectiveness of Policy Measures and Incentives

- Analyze the impact of government policies, regulations, and incentives (e.g., subsidies, tax breaks, emissions standards) on the rate of electric vehicle adoption.
- Identify best practices from regions with successful EV adoption and provide policy recommendations for optimizing electric mobility

strategies.

5. To Identify and Overcome Major Obstacles to Sustainable EV Adoption

- Investigate the difficulties related to battery manufacturing, resource extraction, and recycling at the end of the vehicle's life cycle.
- Assess infrastructure challenges, such as the accessibility of charging stations and the ability of the power grid to support increased electricity demand.
- Analyze consumer perceptions and barriers to EV adoption, such as range anxiety, high initial costs, and lack of awareness about the environmental benefits of EVs.

6. To Offer Practical Recommendations for Advancing Sustainable Mobility

- Formulate a set of actionable recommendations for policymakers, industry leaders, and urban planners to facilitate the widespread adoption of electric vehicles and optimize their environmental benefits.

Propose Strategies for Incorporating Electric Vehicles into Sustainable Urban Transportation Systems, Emphasizing the Promotion of Shared and Public Electric Mobility Options. The main objective of this research is to conduct a comprehensive assessment of the environmental, social, and economic effects resulting from the adoption of electric vehicles. Additionally, it aims to provide insights and recommendations that promote sustainable mobility solutions. This study intends to offer valuable data and analysis to inform future policies, shape industry practices, and facilitate the transition toward a more environmentally friendly, low-carbon future.

Research Methodology

The research methodology for studying the impact of the adoption of electric vehicles (EVs) on sustainable mobility and the environment typically involves a combination of quantitative analysis, qualitative research, and case study evaluations. This multi-method approach helps capture the complex, multi-dimensional effects of EV adoption, including environmental, economic, and social impacts. Below is an outline of a comprehensive research methodology that can be applied:

Research Design

The research employs a mixed-methods approach, combining both quantitative and qualitative techniques. This design enables the integration of numerical data analysis with stakeholder insights and case studies to provide a holistic view of the impacts of EV adoption.

Objectives

- Sources of greenhouse gas emissions reductions from electric vehicle adoption.
- To analyze the environmental implications, the life cycle impact assessment of electric vehicles should be compared with that of conventional internal combustion engine vehicles (ICEVs).
- Policies and incentives contributing to enhanced adoption of EVs should also be studied.
- Another area of investigation would be the socio-

economic effects of EV adoption, regarding changes in employment and other related parameters.

Data Collection

The research involves both primary and secondary data collection:

Primary Data

- **Surveys and Interviews:** Interviews will be carried out with electric vehicle users, policymakers, and industry stakeholders to collect qualitative information regarding the perceived environmental advantages, obstacles to adoption, and the efficacy of current policies.

Case Studies: In-depth case studies of regions or cities with high EV adoption rates will be conducted to analyze the local environmental impacts and policy initiatives. This may include cities with strong EV incentives (e.g., Oslo, Norway; California, USA).

- **Field Measurements:** Data on air quality (e.g., NO_x, CO₂, and particulate matter) in urban areas with significant EV penetration will be collected through direct monitoring or obtained from local environmental agencies.

Secondary Data

- **Life Cycle Assessment (LCA) Reports:** Analysis of existing LCA studies on electric vehicles to understand the environmental impacts across different "phases of the vehicle's life span manufacturing, usage, and end-of-life disposal."
- **Policy and Market Reports:** Data from governmental and industry reports on EV adoption rates, market trends, and policy measures (e.g., subsidies, tax incentives).
- **Statistical Data:** Data related to transportation emissions, energy usage, and electric vehicle sales will be obtained from national and regional sources, including the International Energy Agency (IEA), Environmental Protection Agency (EPA), and local transportation agencies.

Data analysis and Interpretation

Quantitative Analysis

Emission Reduction Analysis: Statistical models will be used to estimate the reduction in greenhouse gas emissions resulting from EV adoption. The analysis will compare emissions data before and after the implementation of EV policies using a difference-in-differences approach.

Life Cycle Assessment (LCA): A comparative LCA will be carried out this phase, which will compare the environmental impacts of electric vehicles with those of conventional vehicles. The stages that will be included are raw material extraction, vehicle manufacturing, operation, and end-of-life recycling.

Renewable Energy Impact Assessment: The proportion of renewable energy used for EV charging will be analyzed to determine its effect on the overall environmental benefits of EV adoption. The carbon intensity of the electricity grid will be factored into the analysis

Qualitative Analysis

Content Analysis: Policy documents, industry reports, and stakeholder interview transcripts will be analyzed to identify key themes related to barriers, enablers, and future outlooks for EV adoption.

Case Study Analysis - For this Multi-country analysis, successful implementations of the electric vehicle policy in various regions will be studied so that strategies which can be utilized in other regions are highlighted.

Modelling and Scenario Analysis

To assess the potential long-term impacts of widespread EV adoption, the study will utilize predictive modeling and scenario analysis;

- **Emission Forecasting Models:** Employing programs such as GREET (Greenhouse gas, Regulated Emissions, and Energy use in Technologies Model) or other life cycle assessment models, assessment tools, the research will forecast emission reductions under different EV adoption scenarios (e.g., low, moderate, and high adoption rates).
- **Energy Mix Scenarios:** The study will model different scenarios based on the proportion of renewable energy integrated into the grid (e.g., 50%, 75%, and 100% renewable energy scenarios) to evaluate the environmental impact of EV charging.

Validation and Reliability

To ensure the validity and reliability of the findings, the following measures will be implemented:

Triangulation: The use of multiple data sources (e.g., surveys, LCA reports, and air quality measurements) and methods (e.g., Quantitative Analysis and Case Studies: These methods will support and validate the findings.

Sensitivity Analysis: A sensitivity analysis will be carried out for critical variables (e.g., emissions from battery production, energy mix) to evaluate the reliability of the results under different assumptions.

Peer Review-The methods and findings will be subject to a review by peers, including specialists in environmental science, transportation policy, and sustainable transport.

Quantitative data analysis, qualitative research and predictive modeling are therefore infused into our envisioned research approach to investigate in-depth the implications of electric vehicle uptake on sustainable mobility/past, environmental sustainability To employ a multi-faceted data selection and methodological approach in order that this attempt may produce thorough environmental impact, obstacle and policy implication insights regarding the shift towards electric vehicle. This methodological framework can be adapted and refined based on the specific research questions and context of the study. Let me know if

Expected Findings

The expected outcomes of the research on the effects of adopting electric vehicles (EVs) on sustainable mobility and the environment are as follows:

Decrease in Greenhouse Gas Emissions

A key anticipated result is a notable decrease in greenhouse gas (GHG) emissions from transportation, particularly CO₂. This reduction is expected to be most pronounced in regions

where electric vehicle adoption is high and where the electricity used for charging comes from low-carbon or renewable sources (e.g., wind, solar, hydroelectric power). The study anticipates that widespread EV adoption will contribute to meeting climate targets and reducing the carbon footprint of the transportation sector.

Improvement of Urban Air Quality

The shift from internal combustion engine vehicles (ICEVs) to electric vehicles (EV) is supposed to have benefits regarding air quality in cities, but in very densely inhabited urban areas this can especially be the case. Fewer tailpipe emissions will translate to down on pollutants incl. nitrogen oxides (NO_x) and particulate matter (PM_{2.5}) as likely to decrease leads to cleaner air this enhancement may have the beneficial effect on health by decreasing respiratory and cardiovascular diseases associated with air pollution.

Enhanced Integration of Renewable Energy

The adoption of electric vehicles is expected to support the integration of renewable energy into the power grid, particularly through smart charging and vehicle-to-grid (V2G) technologies. By increasing demand for electricity during off-peak hours, EVs can help stabilize the grid and enhance the utilization of renewable energy sources. This outcome could further reduce the carbon intensity of EV charging and maximize the environmental benefits of electric mobility.

Positive Social and Economic Impacts

The transition to electric vehicles is expected to have positive socio-economic impacts, including job creation in the renewable energy, battery manufacturing, and electric vehicle industries. Besides, better air quality and less noise pollution in cities would also lead to an increased quality of life for residents. The research also projects alterations in mobility projections, with shared and public EV mobility options being more used as a step towards sustainable urban mobility systems.

Understanding Policy Effectiveness

The study is to provide critical knowledge on what are the most effective policy instruments in promoting electric vehicle deployment. Also including subsidies, tax credits and, importantly subsidies for charging infrastructure. It is anticipated that regions with strong and consistent policy support will show higher rates of EV adoption and greater environmental benefits. The findings could inform future policy decisions and help optimize strategies for accelerating the transition to sustainable electric mobility.

Identification of Key Challenges and Barriers

While the adoption of electric vehicles is expected to have numerous environmental benefits, the study also aims to identify key challenges and barriers that need to be addressed. These may include:

- The environmental impact of battery production and resource extraction.
- There is a need to expand charging infrastructure, especially in rural and underserved areas.
- Potential grid capacity issues arising from increased electricity demand.
- Concerns over battery disposal and recycling, and the life cycle environmental impact of EVs.

The study anticipates that addressing these challenges will be crucial for realizing the full environmental potential of electric vehicles.

Recommendations for Sustainable EV Adoption

Drawing from the research findings, this study aims to construct a set of evidence-based guidelines that are for policymakers and industry players or urban planners to improve on the implementation of electric vehicles for higher sustainability outcome. These suggestions could involve:

- Promoting the use of renewable energy for EV charging.
- Implementing comprehensive recycling programs for EV batteries.
- Enhancing public awareness campaigns about the environmental benefits of EVs.

Policy and ICT incentives to ensure equitable access to electric mobility.

In short, the intended outcome of the study "The objective is to prove that the adoption of electric vehicles" can go a long way in achieving sustainable mobility and environmental conservation. While there are challenges associated with EV production and infrastructure, the overall impact is expected to be positive, particularly when supported by strong policies and a renewable energy-based power grid. The findings of the study could help guide the future development of electric vehicle technologies and inform strategies for achieving sustainable transportation goals.

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