

Sustainable Urban Mobility Transition in Pakistan: Environmental and Economic Evidence from Motorcycle Electrification in Islamabad

Hammad Naeem Khan Sadozai (Corresponding Author)

Department of Environmental Sciences International Islamic University, Islamabad

Email: hammadnks@gmail.com

Muhammad Momin Khan Niazi

Department of Environmental Sciences International Islamic University, Islamabad

Ahmad Mujtaba Khan Sadozai

Department of Architecture, COMSATS University Islamabad

Ahmad Hassaan Khan Sadozai

Department of Electrical Engineering, COMSATS University Islamabad

ABSTRACT

Urban transport systems in Pakistan are increasingly characterized by high motorcycle dependence, contributing to rising greenhouse gas emissions and urban air pollution. This study provides empirical evidence on the environmental and economic implications of motorcycle electrification within the framework of sustainable urban mobility transition. Using 2023 fleet data from Islamabad, emission factor analysis and lifecycle cost modeling were conducted to assess the impact of replacing internal combustion engine motorcycles with electric alternatives. The results indicate that full electrification of the existing motorcycle fleet could eliminate more than 128,000 tons of carbon dioxide annually at the metropolitan level, alongside the removal of nitrogen oxide emissions from tailpipe sources. Economic analysis demonstrates that although electric motorcycles involve higher initial purchase costs, lower fuel and maintenance expenditures generate long-term cost advantages for households. The projected additional electricity demand represents a manageable share of national generation capacity, suggesting technical feasibility under current infrastructure conditions. While electrification offers substantial climate and economic co-benefits, implementation requires coordinated governance mechanisms, affordability support, and integration with ongoing energy sector reforms. The findings support Pakistan's commitments under Sustainable Development Goals 7, 11, and 13 and position motorcycle electrification as a scalable pathway for sustainable urban mobility transition.

KEYWORDS: Green Mobility, Urban Decarbonization, Sustainable Cities, Air Quality Improvement, Climate Mitigation, Energy Security In Pakistan

Introduction

Background

Rapid urbanization and motorization have significantly transformed the environmental profile of Pakistani metropolitan centers over the past two decades. The transport sector is recognized globally as a major contributor to greenhouse gas emissions and urban air pollution (IPCC, 2021). In developing countries, rising vehicle ownership has intensified fossil fuel consumption and deteriorated air quality (Hidalgo & Huizenga, 2013). Among urban transport modes in Pakistan, motorcycles constitute the most widely used and economically accessible form of mobility, particularly for lower- and middle-income households. While this expansion has enhanced urban connectivity and economic participation, it has simultaneously increased fossil fuel dependency and localized pollutant emissions. Islamabad, as the federal capital and a rapidly expanding metropolitan center, reflects broader national trends in motorcycle dependence. Internal combustion engine motorcycles dominate the two-wheeler fleet, relying almost entirely on imported petroleum fuels. Pakistan's heavy reliance on fuel imports places additional pressure on foreign exchange reserves and national energy security (Government of Pakistan, 2022). In this context, electric mobility has emerged as a strategic alternative within Pakistan's broader sustainable development and energy reform discourse. Globally, transport electrification is increasingly recognized as a pathway toward climate mitigation and sustainable urban development (Bueckers et al., 2014; Hawkins et al., 2012). Electric two-wheelers have demonstrated substantial emission reduction potential in densely populated cities due to their lower operational emissions and higher energy efficiency. In Pakistan, policy momentum accelerated with the introduction of the Electric Vehicle Policy 2020–2025, which sets targets for electric vehicle adoption and aims to reduce transport-sector emissions (Government of Pakistan, 2019).

Problem Statement

Despite growing policy attention, academic literature in Pakistan has largely concentrated on electric cars, renewable energy expansion, or national-level energy transition frameworks. The two-wheeler segment, despite being the dominant mode of personal transport, remains comparatively underexamined. Existing studies frequently discuss vehicular emissions in aggregate terms (Shah & Zeeshan, 2016), yet city-level emission quantification combined with lifecycle economic assessment of motorcycle electrification remains limited. Moreover, empirical analyses that position a metropolitan case study as a scalable governance model for other Pakistani cities are scarce. This gap is significant because motorcycles represent the most practical and immediately scalable segment for electrification within Pakistan's transport ecosystem. Without robust environmental and economic evidence at the urban scale, policy interventions risk remaining aspirational rather than operational. Accordingly, this study evaluates the environmental and economic implications of replacing internal combustion engine motorcycles with electric motorcycles in Islamabad using 2023 fleet data. By integrating emission factor-based analysis with cost-of-ownership assessment, the study quantifies potential reductions in greenhouse gases and criteria pollutants alongside long-term economic feasibility. Beyond technical evaluation, the analysis situates motorcycle electrification within Pakistan's commitments to Sustainable Development Goals 7, 11, and 13. By positioning Islamabad as a representative

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

metropolitan model, the study contributes to understanding how motorcycle electrification can support sustainable urban mobility transitions across Pakistan. The findings aim to inform policymakers, urban planners, and energy governance institutions seeking evidence-based pathways toward environmentally and economically viable transport reform.

Objectives

There are two main objectives of this research:

Assessing the environmental impact in terms of emissions associated with operating ICE motorcycles and the reduction in such emissions that can be achieved through the introduction of electric motorcycles.

The evaluation of the economic impacts brought forth by the operation of ICE motorcycles and assessing electric motorcycles as a viable alternative

Literature Review

Motorcycle Electrification and Urban Decarbonization

Transport electrification is widely recognized as a structural mechanism for urban decarbonization and climate mitigation. The transport sector accounts for a substantial share of global energy-related carbon dioxide emissions, making it central to emission reduction strategies under international climate frameworks (IPCC, 2021). Electrification shifts emissions from decentralized combustion engines to centralized power generation systems, enabling efficiency gains and potential integration with renewable energy sources (IEA, 2022). Within this transition, electric two-wheelers occupy a distinctive position in developing economies. In cities where motorcycles dominate mobility patterns, electrification of this segment offers disproportionately high mitigation potential relative to investment scale (Buekers et al., 2014; Will et al., 2021). Unlike private passenger vehicles, motorcycles typically operate on short-distance urban routes, which enhances the efficiency of electric drivetrains.

Lifecycle assessment studies indicate that electric motorcycles generate lower greenhouse gas emissions compared to internal combustion engine motorcycles, particularly when evaluated across fuel production, vehicle operation, and maintenance phases (Hawkins et al., 2012; Del Pero et al., 2018). Even in contexts where electricity grids remain partially fossil-based, centralized generation combined with higher conversion efficiency often produces lower net emissions per kilometer travelled. These findings suggest that two-wheeler electrification can function as a transitional decarbonization pathway in emerging economies undergoing gradual energy sector reform.

Transport Emissions and Urban Air Quality in Pakistan

Urban air pollution remains a persistent environmental challenge in Pakistan. Vehicular emissions contribute significantly to concentrations of nitrogen oxides, particulate matter, and carbon dioxide in major metropolitan centers (Shah & Zeeshan, 2016; Alvi et al., 2017). Rapid growth in vehicle ownership, combined with limited enforcement

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

of emission standards, has intensified the environmental burden associated with urban mobility. Motorcycles constitute the largest share of registered vehicles in Pakistan (Government of Pakistan, 2022). Their affordability and fuel economy have driven widespread adoption, particularly among lower-income households. However, the cumulative environmental footprint of this segment is substantial due to sheer fleet size and daily usage intensity. Existing emission studies frequently aggregate vehicle categories, thereby obscuring the relative contribution of motorcycles to metropolitan-level emissions. Policy recognition of this issue is evident in Pakistan's Electric Vehicle Policy 2020–2025, which prioritizes electrification of two- and three-wheelers as a scalable intervention (Government of Pakistan, 2019). Nevertheless, academic evaluation of environmental benefits at the city scale remains limited. Few studies integrate fleet-level emission modeling with economic feasibility analysis within a single metropolitan framework. This analytical gap constrains evidence-based policymaking in urban transport planning.

International Experience in Two-Wheeler Electrification

Several Asian countries provide instructive examples of large-scale electric two-wheeler adoption. In China, electric scooters and motorcycles have achieved widespread penetration due to supportive regulatory frameworks and urban air quality concerns (IEA, 2022). Similarly, India has implemented phased electrification strategies targeting two- and three-wheelers as priority vehicle categories under national transition plans (IEA, 2022). These cases demonstrate that electrification of smaller vehicles can achieve faster market diffusion compared to passenger cars due to lower battery capacity requirements and shorter daily travel distances (Will et al., 2021). International experience suggests that early adoption phases typically require policy incentives, regulatory clarity, and public awareness campaigns. However, once market penetration reaches critical thresholds, network effects and consumer familiarity accelerate transition dynamics (Geels, 2002). These global precedents reinforce the feasibility of prioritizing motorcycle electrification in Pakistan's urban mobility strategy, particularly in cities characterized by high two-wheeler dependence. Several Asian countries provide instructive examples of large-scale electric two-wheeler adoption. In China, electric scooters and motorcycles have achieved widespread penetration due to supportive regulatory frameworks and urban air quality concerns. Similarly, Vietnam and India have implemented phased electrification strategies targeting two- and three-wheelers as priority vehicle categories. These cases demonstrate that electrification of smaller vehicles can achieve faster market diffusion compared to passenger cars due to lower battery capacity requirements and shorter daily travel distances. International experience suggests that early adoption phases typically require policy incentives, regulatory clarity, and public awareness campaigns. However, once market penetration reaches critical thresholds, network effects and consumer familiarity accelerate transition dynamics. These global precedents reinforce the feasibility of prioritizing motorcycle electrification in Pakistan's urban mobility strategy.

Theoretical Foundation

Online ISSN

3007-3197

Print ISSN

3007-3189

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This study is grounded in the framework of sustainable urban transition and ecological modernization theory. Sustainable transition theory conceptualizes structural change in socio-technical systems, including transport, as a gradual transformation driven by technological innovation, policy intervention, and behavioral adaptation (Geels, 2002). Urban mobility systems are considered socio-technical regimes in which infrastructure, regulation, market structures, and user practices interact to shape transport patterns. Electrification of motorcycles represents a niche innovation with the potential to alter the dominant fossil fuel-based mobility regime in Pakistani cities. Ecological modernization theory further provides a useful analytical lens by arguing that environmental protection and economic development need not be mutually exclusive (Mol & Spaar Garen, 2000). According to this perspective, technological innovation, regulatory reform, and market-based incentives can enable environmental improvements while maintaining economic efficiency. In the context of electric motorcycle adoption, emission reductions are coupled with potential long-term cost savings and enhanced energy security, illustrating the compatibility of environmental and economic objectives. The integration of emission modeling with lifecycle economic assessment in this study reflects this theoretical orientation. Motorcycle electrification is not examined solely as an environmental intervention but as a structural urban reform capable of generating ecological and economic co-benefits. By situating empirical findings within a sustainable transition framework, the study interprets electrification as part of a broader shift toward green mobility and urban decarbonization in developing economies. From a multi-level transition perspective, motorcycle electrification can be understood as a niche innovation operating within a dominant fossil fuel regime. The pace of transition depends on landscape pressures such as climate commitments, fuel import dependency, and urban air quality crises. In Pakistan, macroeconomic volatility associated with petroleum imports generates structural incentives for alternative mobility pathways. These pressures create an opportunity window for policy-driven acceleration of electric two-wheeler adoption. Ecological modernization theory further suggests that environmental reform can coexist with economic rationality when supported by technological innovation and institutional adaptation. The projected cost savings identified in this study reinforce the proposition that environmental modernization does not necessarily impose economic sacrifice. Instead, strategic investment in cleaner mobility technologies may enhance both ecological sustainability and long-term fiscal stability.

Institutional and Regulatory Alignment

Successful implementation of motorcycle electrification requires regulatory coherence across multiple governance levels. Federal EV policy objectives must be synchronized with provincial transport regulations and municipal infrastructure planning. Distribution companies must anticipate localized charging demand, while environmental agencies must establish battery recycling protocols to prevent secondary ecological risks. Financial instruments also play a decisive role. International experience demonstrates that targeted subsidies, low-interest financing schemes, and temporary tax reductions can accelerate electric vehicle adoption in early transition stages. However, fiscal sustainability considerations require careful design of such

incentives to avoid long-term budgetary strain. Public-private partnerships may offer a viable pathway for scaling charging infrastructure and supporting technological innovation in the two-wheeler segment. Engagement of domestic manufacturers and small-scale entrepreneurs can further localize production chains and stimulate green industrial development.

Methodology

Research Design

This study adopts a quantitative urban case study design to evaluate the environmental and economic implications of motorcycle electrification in Islamabad. The methodological framework integrates emission factor-based environmental estimation with lifecycle cost-of-ownership analysis under a full electrification scenario. Islamabad is selected as a representative metropolitan model due to its structured administrative framework, reliable vehicle registration data, and policy relevance as the federal capital of Pakistan. The analysis is based on 2023 fleet data and combines secondary administrative records with primary survey inputs. Computational modeling was conducted using R statistical software to ensure methodological transparency and reproducibility.

Data Sources and Preparation

Motorcycle registration data were obtained from the Islamabad Excise and Taxation Department. The dataset included engine capacity classifications and total registered units. As of May 2024, reflecting the 2023 fleet status, a total of 537,388 motorcycles were registered in Islamabad, of which 536,593 were internal combustion engine motorcycles and 795 were electric motorcycles. Fuel efficiency values were obtained from manufacturer specifications and verified through secondary automotive databases. Emission factors were sourced from USEPA (2023) and Guttikunda (2008). Electricity tariff data were collected from IESCO (2023), while national electricity generation statistics were obtained from official government publications. Primary survey data were collected to estimate annual travel distance. Although survey responses indicated slightly higher travel estimates, the study adopts 5,305 kilometers per year based on Shah and Zeeshan (2016) to maintain methodological consistency with prior research conducted in Islamabad. All data cleaning, categorization by engine capacity, and aggregation procedures were conducted using R to ensure computational accuracy. This study relies on both primary and secondary data sources to estimate environmental and economic impacts of motorcycle electrification in Islamabad. Secondary data was obtained from official administrative and institutional sources. Motorcycle registration data were acquired from the Islamabad Excise and Taxation Department, reflecting the 2023 fleet status. The dataset included engine capacity classifications and total registered units. Fuel efficiency specifications were obtained from manufacturer documentation and verified through automotive databases. Emission factors were sourced from USEPA (2023) and Guttikunda (2008). Electricity tariff information was collected from IESCO (2023), and national electricity generation statistics were obtained from official government reports. Primary data were collected through a structured survey administered to motorcycle users in Islamabad to estimate annual

travel distance. Although survey results suggested slightly higher travel distances, the study adopts 5,305 kilometers per year based on Shah and Zeeshan (2016) to maintain consistency with prior empirical research conducted in the same metropolitan context. All datasets were cleaned, categorized, and aggregated using R statistical software to ensure computational transparency and reproducibility.

Results

Fuel Consumption Estimation

Annual fuel consumption per motorcycle was calculated using the equation:

Fuel Consumption per Motorcycle = Annual Distance / Fuel Efficiency

Total fuel consumption per engine category was calculated as:

Total Fuel Consumption per Category = Fuel Consumption per Motorcycle × Number of Motorcycles

Emission Estimation

Greenhouse gas emissions were estimated using emission factor methodology consistent with USEPA (2023):

Emissions = Fuel × Emission Factor. The emission factors applied were:

CO₂ = 2.269 kg per liter

CH₄ = 0.0001223 kg per liter

N₂O = 0.00007956 kg per liter

Fuel Consumption Profile

Based on 2023 fleet data and standardized annual travel distance of 5,305 kilometers per motorcycle, total annual fuel consumption of the internal combustion engine motorcycle fleet in Islamabad was estimated at 56,823,740 liters. Lower-capacity motorcycles, particularly 70cc and 125cc categories, account for most of the consumption due to their numerical dominance. Although these engines demonstrate relatively higher fuel efficiency compared to larger engine classes, their numerical dominance results in substantial cumulative fuel consumption. The aggregate consumption level reflects both environmental implications and macroeconomic pressures associated with petroleum import dependence.

Greenhouse Gas Emissions from ICE Motorcycles

Applying standardized emission factors, total annual greenhouse gas emissions from the ICE motorcycle fleet were estimated using fuel-based calculations. Carbon dioxide emissions exceed 128,000 tons per year, representing the dominant share of total emissions. Methane and nitrous oxide emissions are comparatively smaller in magnitude but contribute additional climate forcing potential. Nitrogen oxides emissions, calculated using distance-based emission factors, further contribute to urban air pollution and localized environmental health risks. Although motorcycles individually consume less fuel than passenger cars, their cumulative impact on the metropolitan scale is significant due to fleet size and frequency of use.

Emission Reduction under Full Electrification Scenario

Online ISSN

3007-3197

Print ISSN

3007-3189

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Under a full replacement scenario in which all internal combustion engine motorcycles are substituted with electric motorcycles, tailpipe emissions of carbon dioxide, methane, nitrous oxide, and nitrogen oxides would be eliminated at the urban level. The transition represents a potential reduction exceeding 128,000 tons of carbon dioxide annually, alongside complete removal of motorcycle-related nitrogen oxide emissions from the urban atmosphere. These reductions imply measurable improvements in air quality and direct contributions to climate mitigation targets. While electricity generation in Pakistan remains partially fossil-fuel-based, the electrification scenario shifts emissions from dispersed combustion sources to centralized generation facilities, where efficiency improvements and renewable integration can progressively lower carbon intensity over time.

Electricity Demand Implications

The projected electricity demand resulting from full motorcycle electrification was calculated by multiplying annual energy requirements per motorcycle by total fleet size. When compared with national electricity generation statistics, the additional demand represents a relatively small proportion of total annual production. This finding suggests that large-scale motorcycle electrification is technically manageable at the national generation level. However, localized distribution infrastructure and charging access may require phased planning to ensure operational stability.

Economic Assessment

The total cost-of-ownership assessment reveals clear differences between conventional and electric motorcycles. For internal combustion engine motorcycles, annual expenditure is largely driven by fuel costs, supplemented by maintenance, lubricants, filters, and battery replacement. Electric motorcycles, despite higher upfront purchase costs, demonstrate substantially lower operational costs due to reduced energy expenditure and minimal mechanical maintenance requirements. When evaluated over the vehicle lifecycle, cost savings from lower electricity expenditure and maintenance offset initial capital differences. Beyond household-level savings, electric motorcycle adoption may generate broader macroeconomic benefits. Reduced gasoline demand contributes to improved trade balance stability in fuel-import-dependent economies. Pakistan's recurrent foreign exchange pressures linked to petroleum imports underscore the strategic importance of reducing transport-sector fossil fuel reliance (Government of Pakistan, 2022). Furthermore, expansion of electric two-wheeler markets may stimulate domestic industrial development. Local assembly, battery production, and charging infrastructure deployment can create employment opportunities within emerging green sectors. Ecological modernization theory suggests that environmental reform can coexist with industrial modernization through technological innovation and regulatory support (Mol & Spaargaren, 2000). International evidence further indicates that electric mobility transitions can catalyze industrial restructuring toward higher-value technological manufacturing (IEA, 2022). These economic dimensions extend the implications of motorcycle electrification beyond environmental mitigation, positioning it as a component of broader sustainable economic transformation.

Online ISSN

3007-3197

Print ISSN

3007-3189

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Socio-Technical Barriers to Electric Mobility in Developing Economies: Electric mobility transitions in developing economies are shaped not only by technological feasibility but also by socio-technical constraints. Infrastructure readiness, consumer perception, and institutional capacity influence adoption patterns (Geels, 2002; IEA, 2022). In contexts characterized by energy insecurity and fiscal constraints, electrification strategies must be evaluated within broader economic realities. Affordability remains a primary determinant of adoption in lower-income markets. Although lifecycle cost analysis often favors electric vehicles, high upfront purchase prices and limited access to financing mechanisms may inhibit transition (Carranza et al., 2022). Furthermore, behavioral inertia and limited public awareness regarding long-term cost savings slow diffusion of innovative technologies. Institutional coordination represents another structural challenge. Effective electrification requires alignment between energy regulators, transport authorities, municipal planners, and environmental agencies. Without integrated governance frameworks, policy fragmentation may delay implementation and reduce public trust in transition initiatives. These considerations highlight the importance of evaluating motorcycle electrification not only as a technological substitution but as a systemic urban transformation process requiring coordinated institutional reform.

Methodological Scope and Limitations

The analysis assumes uniform annual travel distance across engine categories and does not differentiate riding behavior by motorcycle size. Emission factors are applied using standardized values for gasoline engines, and dynamic changes in electricity generation mix beyond the 2023 baseline are not modeled. Despite these limitations, the methodology provides a transparent and reproducible framework for metropolitan-scale assessment of motorcycle electrification. At the household level, reduced operational expenses may enhance affordability and financial stability for urban commuters. At the macroeconomic level, decreased gasoline consumption implies reduced petroleum import dependence, contributing to improved energy security and foreign exchange stability. These results indicate that motorcycle electrification generates both environmental and economic co-benefits, reinforcing its relevance within sustainable urban mobility transition frameworks.

Materials and Methods

Study Area

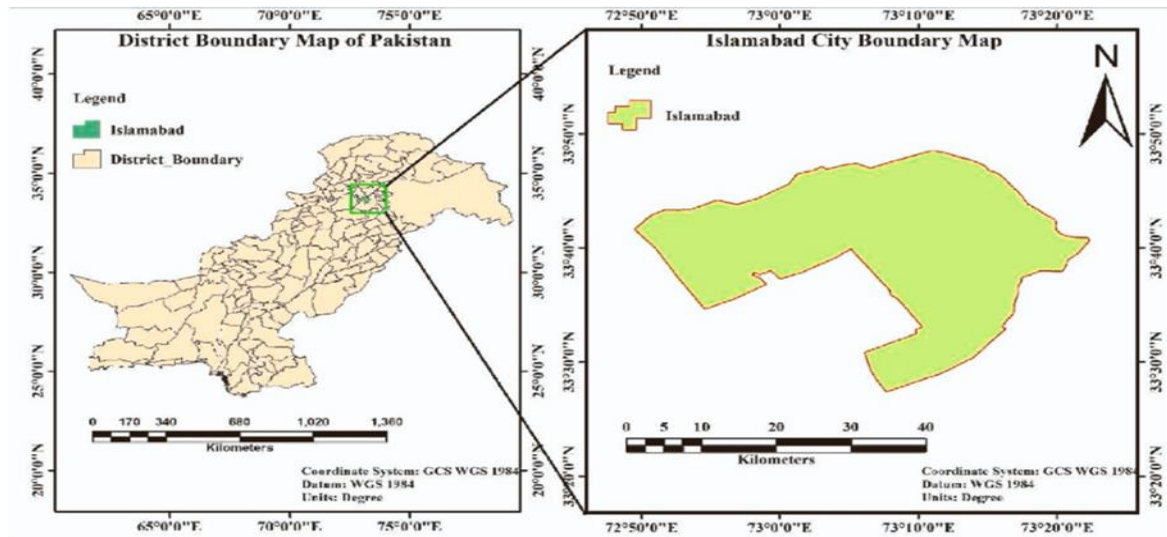
Online ISSN

3007-3197

Print ISSN

3007-3189

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Recommendations and Conclusion

Suggestions

Electric motorcycles show a number of benefits in comparison to internal combustion engine motorcycles. In order to help their adoption gain traction the government as well as private enterprises and organizations can take steps to make EVs look like an attractive option for consumers. The following recommendations can have fruitful results in this pursuit.

Changing the Current Policy

The electric vehicle policy of Pakistan 2019 aimed to encourage the adoption of electric transport, the government will provide the public with various incentives for adopting electric transport such as tax exemptions and reduced customs duties (Government of Pakistan, 2019) though it sets out unrealistic goals according to Pakistan's current financial situation setting a target of EVs holding a 30% share in all personal and commercial vehicle sales by 2030, and 90% by 2040. Pakistan being a developing country cannot afford to meet the targets set forth by the policy of reaching the goals outlined by the policy through the provision of tax breaks, incentives, financing, infrastructure provision, and so on, hence focusing on 2-wheelers as a much more affordable mode of transport is more practical. As motorcycles are the primary mode of transport for most citizens of Pakistan, the policy needs to be reshaped in order to cater to 2-wheeled transport users. Subsidies or tax breaks specifically targeted at electric motorcycle users can help boost the popularity of this mode of transport. Setting more realistic targets can help in meeting them as they are more achievable in light of the economic situation. As the manufacturing and assembling of electric motorcycles is mostly done in Pakistan, it will be of benefit for the policy to favor electric motorcycles instead of other modes of electric transport as large vehicles are imported and Pakistan doesn't possess any infrastructure to manufacture such vehicles. This will benefit not only consumers, as motorcycles are more prevalent than cars, but also

Online ISSN

3007-3197

Print ISSN

3007-3189

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benefit the economy.

Supporting The Manufacturer

The government can give electric motorcycle manufacturers tax breaks in order to help them produce a cheaper product. Research and development of new, more efficient technologies can also take place through collaborations between public research institutions and varsities through partnerships. Both research institutions and manufacturers can benefit from such collaborations. The manufacturers of ICE motorcycles should also be encouraged and supported to shift from their current gasoline-driven product line into an all-electric line-up. As most of the manufacturing and assembling of electric motorcycles is done locally, such steps will help strengthen the industrial sector, and subsequently the economy, both local and national.

Urban Planning and Sustainable City Objectives

Motorcycle electrification should also be evaluated within the broader framework of sustainable urban development. Sustainable cities require integrated mobility systems that reduce emissions while maintaining accessibility and affordability (Hidalgo & Huizenga, 2013). Electric motorcycles offer a transitional pathway that complements long-term investments in public transportation and non-motorized mobility infrastructure.

In rapidly expanding metropolitan areas such as Islamabad, incremental electrification of existing vehicle fleets may be more feasible than large-scale infrastructure overhauls. By reducing localized emissions without requiring immediate structural redesign of road networks, electric two-wheelers provide a pragmatic intermediate step toward greener urban systems (Will et al., 2021). This incremental approach aligns with Sustainable Development Goal 11, which emphasizes sustainable transport access and reduced environmental impact of cities (IPCC, 2021). Integrating motorcycle electrification with broader urban planning strategies can enhance policy coherence and maximize sustainability gains.

Improving Emissions Standards

Currently, in Pakistan, the emission standards in place are the Euro-II vehicular emission standards. It has been more than 14 years as of 2024 since these standards have been phased out in favor of better, more stringent Euro standards across the globe (M. Khan, 2022). The European Council has adopted Euro VII standards as of 2024 (Council of the EU, 2024). Local auto manufacturers and enforcers still abide by the much less stringent Euro II standards. Employing stricter standards can help not only reduce the current emission levels but also provide a stimulus to electric vehicles as an alternative as they produce no emissions.

Infrastructure Provision

Introducing infrastructure to recharge motorcycles in urban areas as well as major arteries can help dissipate the anxiety associated with a limited range of electric motorcycles. Due to the lack of such vehicles in the first place, Pakistan doesn't possess such infrastructure. Solar energy can be used as a source of power for the charging

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

stations making them completely independent of any reliance on the current grid system as well as providing a seamless supply of power with little to no maintenance required. Pakistan's solar angle is very favorable and the length of the day on average is also excellent. Although initial investment may be high, it can prove excellent in the longer run as it is economical to operate as well as environmentally friendly.

Public Awareness

Educating the public is imperative. Many people simply might not know about the benefits harnessed from this mode of transport. Educating the public can have a snowballing effect and help this mode of transport gain a sizable foothold. In nearly every aspect electric motorcycles present an advantage in comparison to ICE motorcycles and it can be reaped by the public even if they gain appropriate knowledge about this technology. The local government can initiate campaigns and awareness drives to educate the public both on the environmental and economic benefit.

Emission Fines

To reduce the current state of emissions in Islamabad, the local administration can introduce fines for poorly maintained vehicles that emit pollutants in larger quantities than the allowable limits, this can be especially helpful in densely populated areas and may also sway the opinion in favor of adopting electric motorcycles.

Robustness Considerations

The findings of this study are based on standardized emission factors and a uniform annual travel distance assumption. Variations in fuel efficiency, electricity tariff structures, and future grid decarbonization trajectories may influence projected outcomes. Sensitivity analysis incorporating fluctuating fuel prices or alternative annual travel scenarios could further refine economic projections. However, given the magnitude of emission reductions identified, moderate variations in underlying assumptions are unlikely to reverse the overall conclusion regarding environmental and economic feasibility. The robustness of the core findings is therefore supported by conservative parameter selection consistent with prior empirical research in Islamabad.

Conclusion

This study provides empirical evidence that motorcycle electrification in Islamabad can generate substantial environmental and economic benefits. The estimated reduction of more than 128,000 tons of carbon dioxide annually highlights the significant climate mitigation potential of the two-wheeler segment. Lifecycle cost analysis further indicates that electric motorcycles offer long-term financial advantages despite higher upfront costs.

By integrating emission modeling with economic assessment, the study demonstrates that motorcycle electrification constitutes a practical component of sustainable urban mobility transition in Pakistan. While infrastructure readiness, affordability constraints, and electricity mix considerations require policy coordination, the overall feasibility of transition is supported by quantitative evidence. The findings contribute to broader debates on urban decarbonization in developing economies and offer a scalable

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

metropolitan model for transport-sector reform across Pakistan. Beyond the specific case of Islamabad, this study contributes to emerging scholarship on sustainable mobility transitions in developing economies by demonstrating that incremental technological substitution in high-density vehicle segments can yield disproportionate environmental and economic gains. Rather than framing transport reform as a large-scale infrastructural overhaul, the findings suggest that targeted electrification of dominant vehicle categories may serve as an efficient entry point for urban decarbonization. In contexts characterized by fiscal constraints and institutional complexity, such incremental strategies offer a pragmatic pathway toward aligning climate mitigation, energy security, and urban sustainability objectives.

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Online ISSN

3007-3197

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