Automatic rickshaw transport and environmental sustainability in developing cities: The moderating role of energy transition

Grace Aminieli Mmari

gracemmariz2@gmail.com

National Institute of Transport, Tanzania

https://doi.org/10.51867/ajernet.7.3.15

ABSTRACT

This study examined the relationship between auto-rickshaw transport and environmental sustainability in developing cities, with particular emphasis on the moderating role of energy transition. The Multi-Level Perspective (MLP) Theory of Sustainability Transitions, which describes how institutional, technological, and energy-system changes affect sustainable transport transitions, served as the study's compass. The study adopted a systematic desk review research design based on secondary data analysis of empirical studies, policy documents, and institutional reports from Tanzania, Africa, Asia, and other developing regions. Results showed that the use of autorickshaws is vital for low-cost urban transportation and for the last-mile connectivity but fossil-fuel use, an outdated fleet, congestion and poor regulation are major factors in pollution and environmental degradation. The study also revealed that energy transition via electrification, battery innovation, renewable charging systems, and policy reform can significantly enhance environmental sustainability, but electrification alone is not enough at fossil-fuel dependent electricity systems. Based on the study, it can be concluded that the key factor moderating the path of the auto-rickshaw transport is energy transition and in what way it will develop soon depends on how sustainable the energy supply is. The study suggests integrated transport-energy policy frameworks to support the transformation of autorickshaws in developing cities sustainably, including actions on electrification, renewable energy, charging infrastructure and policy changes.

Keywords: Auto-Rickshaw Transport, Developing Cities, Energy Transition, Environmental Sustainability, Renewable Energy, Sustainable Urban Mobility

I. INTRODUCTION

Across the developing world, nations experiencing rapid urbanization, a lack of adequate public transportation systems, and a growing demand for short-distance, cost-effective transportation have resulted in a reliance on informal and intermediate modes of transportation, such as auto-rickshaws, including tuk-tuks, bajajis, and electric three-wheelers (Sobhani et al., 2020). These are important in the first and last mile connectivity, job creation, and accessibility in densely populated urban areas where traditional modes of public transport, such as buses or rail, may not be available or adequate (Cervero, 2000). Their flexibility in operation, reduced capital requirements, and presence on roads with limited traffic infrastructure usage make them a crucial mobility solution for millions in developing cities (Nyachieo et al., 2025).

Globally, the three-wheeler market grew by 13% in 2023 to 4.5 million sales, with electric models accounting for 21% of total sales, up from 18% in 2022, while nearly 1 million electric three-wheelers were sold worldwide, reflecting 30% annual growth (International Energy Agency [IEA], 2024). Even in this scenario, traditional fossil-fuel-based autorickshaws remain a major source of urban pollution, emitting Carbon Monoxide (CO), Hydrocarbons (HC), Nitrogen Oxides (Nox), Particulate Matter (PM), and Greenhouse Gases (GHGs). This environmental burden is particularly high in developing countries, with 99% of the global population exposed to poor air quality in 2019 and 89% of air pollution-related premature deaths taking place in Low- and Middle-Income Countries (LMC) countries (World Health Organization [WHO], 2024). The trends suggest that in the future, auto-rickshaws will still be a vital mode of transportation for people in urban areas, but their environmental sustainability will heavily rely on clean energy transition, fuel systems, and regulation.

Policy and technological pathways show that the sustainability impacts of the energy transition of autorickshaws can significantly change in developing countries outside mainstream Western economies. This was due to strong incentives and policy support for EVs, which led to over 580,000 electric three-wheelers being sold in India in 2023, the country's largest electric three-wheeler market (IEA, 2024). Electric rickshaws are promoting urban mobility access in Bangladesh but also triggering power grid pressure from unmanaged charging and fossil-based electricity sources, as it limits the entire environmental benefits (Al-Amin & Sahabuddin, 2023). The strategies for urban small-vehicle electrification are increasingly focused on decarbonizing informal mobility in Indonesia, but the lack of charging infrastructure, financing and policy coherence are significant challenges. It demonstrates that energy transition can provide environmental opportunities but is subject to moderation by infrastructure, governance and electricity sources in those cases.

In Africa, the introduction of autorickshaws is growing in the face of transport deficits, unemployment, and rapid urbanization, yet the lack of energy transition facilities and dependence on fossil fuels puts environmental sustainability at risk. In Tanzania, the researchers Gerutu et al. (2021) discovered that petrol-based bajajis are an important source of urban pollution and CNG alternatives might help lower emissions and running expenses. Electric three-wheelers have shown promise for reducing urban transport emissions in Kenya, but challenges remain with regards to weak charging infrastructure and financing constraints, as noted by Ayetor et al. (2023). Electric mobility strategies that combine battery-swapping and renewables in Rwanda have opened the door for cleaner three-wheelers, but the potential for their expansion is conditioned by the readiness of institution and infrastructure (Nnene et al., 2026). Such experiences suggest that the sustainability path of Africa's autorickshaws are increasingly linked to the effectiveness of energy transition.

In Tanzania, auto-rickshaws are a fundamental component of urban transport, which also serves as a key transport mode for the cities of Tanzania, such as Dar es Salaam, but their growing reliance on petrol-powered fleets, the ageing of engines, lack of maintenance, and increased congestion have a significant impact on urban emissions and environmental risks. Gerutu et al. (2021) found that conventional bajajis make a significant contribution to pollution and Goletz et al. (2021) demonstrated that electric three-wheelers are technically possible but limited by batteries, infrastructure and funding. While Tanzania has embraced the concept of sustainable development, the policies for its implementation have been weak and have failed to significantly impact the reliance on fossil fuels, thus significantly reducing the potential for energy transition to increase environmental sustainability. However, although providing socio-economic benefits, Tanzania's auto-rickshaw systems can further contribute to environmental degradation unless more robust e-mobility policies and measures are implemented (Goletz et al., 2021; Ayetor et al., 2023).

Despite an increase in research on transport emissions, vehicle electrification, and renewable energy systems, there has been little systematic study of how energy transition modifies the link between auto-rickshaw transportation and environmental sustainability in developing cities (Emodi et al., 2022). Existing research frequently focuses on emissions, electrification, or infrastructure independently, without fully understanding how fuel transitions, renewable integration, and policy systems interact to determine sustainability outcomes (Harikumar et al., 2020). This disparity is particularly pronounced in developing nations, where autorickshaws are crucial for urban transportation but their environmental effect is unknown due to inadequate energy and policy integration (Pkhikidze et al., 2026). As Kanuri et al. (2023) point out, without a thorough knowledge of this moderating role, auto-rickshaws may continue to provide mobility while contributing to environmental damage. Therefore, this study addresses this gap by examining the relationship between auto-rickshaw transport and environmental sustainability, assessing the influence of energy transition, and analyzing how energy transition shapes sustainability outcomes in developing cities.

1.1 Research Objectives

i. To evaluate the relationship between auto-rickshaw transport and environmental sustainability in developing cities.
ii. To assess the influence of energy transition on auto-rickshaw transport systems in developing cities.
iii. To analyze the moderating role of energy transition in the relationship between auto-rickshaw transport and environmental sustainability in developing cities.

II. LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 Theory of Multi-Level Perspective (MLP)

This study is based on the theory of Multi-Level Perspective (MLP) on Sustainability Transitions (Geels, 2011), which is a theory explaining the socio-technical interactions that lead to the shift from an unsustainable to a sustainable socio-technical system configuration, involving niche innovations, dominant socio-technical regimes, and broader socio-technical landscapes. In this context, the conventional fossil-fuel based auto-rickshaws in developing cities are the dominant system, that is locked into a specific technology, poorly regulated and heavily dependent on fossil fuels, and the system outcome is environmental sustainability. Energy transition electrification, battery innovation, renewable charging systems and policy reform serves as niche innovation which disrupts or reconfigures this regime (Tanveer et al., 2025). One strength of MLP in this study is its ability to transcend technological adoption viewpoints and understand how infrastructure, governance, policy incentives, fuel systems and environmental pressures influence the evolution of auto-rickshaw systems to either sustainability or a continuation of negative environmental outcomes (Geels, 2002; Geels, 2011). This renders MLP an apt approach as it directly elucidates the interaction among the study's key variables, namely auto-rickshaw transport, environmental sustainability, and the moderating role of energy transition.

2.2 Empirical Review

2.2.1 Auto-Rickshaw Transport and Environmental Sustainability

The empirical literature reveals that the connection between auto-rickshaw transport and environmental sustainability in developing cities is complex and much depends on the technology of the vehicles, fuel systems, and fleet and operating conditions. In Dar es Salaam, the switch from petrol-powered auto-rickshaws to compressed natural gas (CNG) resulted in substantial reductions in particulate matter (PM2.5) emissions, alongside cost savings for the vehicles, highlighting the potential for operational costs and emissions to be lowered by alternative forms of fuel. In a similar study, Choudhary et al. (2020) found that urban traffic conditions such as congestion, stop and go traffic, lengthened travel time and vehicle age have significant impact on carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NOx) emissions from auto-rickshaws. In line with these findings, Reynolds et al. (2011) found that the older the vehicle and the presence of a two-stroke engine in the vehicle resulted in higher particulate matter and carbon dioxide emissions compared to the newer four-stroke engine models. These studies collectively indicate that the environmental sustainability of the auto-rickshaw transport is not just about the low cost of auto-rickshaw services in cities, but about the synergy between the fuel technology, vehicle state and urban operating environments.

Other studies in the literature also show that fuel selection and the technological upgrade of the auto-rickshaw transport system is a key determinant of the environmental consequences. Harikumar et al. (2020) determined that replacing petrol and LPG fueled auto-rickshaws, as is commonly done in the cities, with electric-powered auto-rickshaws would result in a significant decrease in the level of certain local pollutants such as CO, HC, NOx, and PM, while the reduction of GHGs would be limited by the current electricity generation mix. Similarly, Martin et al. (2024) found that electric three-wheelers in Dar es Salaam can contribute to sustainable urban mobility and have the potential of significantly cutting down on greenhouse gas emissions. Kumar, et al. (2022) also emphasized the significance of e-rickshaws in enhancing the last-mile connectivity and accessibility for urban transport. Although these contributions are made, the existing literature is fragmented. Research on emissions is mainly concentrated on vehicle performance and fuel systems, while the research on electrification and last mile mobility is mainly focussed on technology and operation benefits, and less on the wider environmental context, like the electricity generation sources, energy infrastructure and the wider sustainability context. However, little is known about how different aspects of the auto-rickshaw transportation service collectively affects environmental sustainability in developing cities. This disconnect highlights the importance of a more holistic view and understanding that considers the socio-technical nature of auto-rickshaw transport, and the need to understand the ambient effect of the various aspects of the transport system (technologies, fuel shifts, fleet composition and urban development) as a whole.

2.2.2 Influence of Energy Transition on Auto-Rickshaw Transport Systems

The empirical literature reveals that energy transition is rapidly transforming auto-rickshaw transport systems in developing cities, through the electrification of fleets and the technological innovation, as well as through transport governance change. Goletz et al. (2021) concluded that small EVs, including electric three-wheelers, provide significant opportunities for sustainable urban transportation by reducing energy requirements, air pollutant emissions and land use efficiency. Likewise, Kanuri et al. (2023) concluded that the electrification of passenger auto-rickshaw fleets in Indian cities offers many environmental and socio-economic benefits, such as emissions reductions and cost savings. Both studies, however, highlight the challenges in the transition to electric mobility, noting a lack of charging infrastructure, financing options, institutional coordination and policy support. The results indicate that energy transition is not only a technological substitution process but a much more complex socio-technical transition, which needs to be supported by a suitable regulatory framework, investments in infrastructure, and cooperation among stakeholders. While the availability of the electric vehicle technologies is a necessary but not sufficient condition for the success of energy transition in auto-rickshaw systems, enabling environments for adoption and sustainability for long term use must also be created by governments and institutions.

The literature also shows that energy transition impacts not only on the electrification of auto-rickshaw but also on charging station, battery technology, integration of renewable energy and policy supports. Battery swapping and charging stations can be used both as transport infrastructure and distributed energy storage systems, as shown by Hasan (2020), which can help to integrate renewable energy sources like solar photovoltaic systems. Similarly, Al-Amin and Sahabuddin (2023) revealed that the adoption of electric Auto Rickshaws can impact the national electricity grid as a whole, however solar charging can decrease peak electricity demand and carbon intensity. On the other hand, Hossain et al. (2023) noted that technical issues, battery management problems, lack of charging infrastructure, and limited regulatory support hinder the sustainability advantages of this type of vehicle. These studies all recognise the transformative potential of the energy transition for auto-rickshaw transport systems, but most of these focus on a single aspect of the energy transition, like electrification, charging technologies, renewable energy or policy interventions. However, there is a lack of empirical synthesis so far to show how these inter-linked transition mechanisms work together to influence the development and performance of auto-rickshaw systems in developing cities. This gap signals the necessity for a more holistic approach to the understanding of energy transition as a multifaceted phenomenon affecting the processes of energy technology uptake, infrastructure development, operational efficiency, and institutional readiness in urban auto-rickshaw transport systems.

2.2.3 Moderating Role of Energy Transition between Auto-Rickshaw Transport and Environmental Sustainability

The empirical literature indicates that the environmental sustainability impacts of auto-rickshaw transportation are strongly shaped by the nature and quality of the energy transition processes, especially the source of electricity generation and the use of renewable energy. Koroma et al. (2022) showed that the environmental performance of BEVs is heavily sensitive to the composition of the electricity mix used for recharging the BEVs, with the cleaner the electricity, the greater the reductions in impacts on climate change. In the same vein, Podder et al. (2022) reported that the solar PVs and biogas technologies when combined in an EVs charging infrastructure is able to substantially mitigate greenhouse gas emissions and enhance the economic sustainability of charging stations. Looking further, Hassan et al. (2024) proposed that E3Ws can be deployed beyond their role in mobility operations as distributed energy storage assets to enable integration with renewable energy, grid stability and low carbon energy transitions in virtual power plant (VPP) systems. Together these studies cast doubt on the belief that merely electrifying powerlines will achieve environmental sustainability. Rather, it shows that the environmental advantages of electric auto-rickshaws depend on the presence of cleaner electricity supply systems, renewable energy-based charging stations and efficient energy management systems. Hence, energy plays a very critical role in moderating the outcomes of the use of electric auto-rickshaws in terms of creating real environmental sustainability.

The literature also suggests that the capacity of institutions, readiness of infrastructure and policy support are important factors that shape the effectiveness of energy transition as a moderating mechanism. Ayetor et al. (2023) revealed that although the environmental and economic benefits of e-TWs and e-T3Ws appear to be attractive, the lack of technical standards, charging infrastructure, battery management systems, and policy support are still major obstacles to their widespread adoption in Africa. Similarly, the study by Nnene et al. (2026) found that despite numerous African countries implementing policies for electric mobility, the implementation is scattered and unevenly distributed with critical gaps in the standards of charging infrastructure, training and capacity building of the workforce, grid readiness, and long-term regulatory frameworks. These results indicate that the environmental benefits of electric auto-rickshaw systems can be greatly undermined if the conditions of their energy transition are not adequate. Renewable energy integration, policy-making, electricity composition and infrastructure development have been noted as important factors by previous studies, but they tend to focus on one of these factors independently rather than as a moderating mechanism. Hence, the empirical knowledge of how energy transition not only affects the nature of the auto-rickshaw transport in the developing cities, but also its relationship with environmental sustainability is limited. This paper fills this gap by analyzing energy transition as a multidimensional moderating factor between the various features of the auto-rickshaw transportation system and the environmental sustainability outcomes, while using the concept of a sustainability transitions perspective.

III. METHODOLOGY

3.1 Research Design

The study adopted a systematic desk review design with secondary data analysis to explore auto rickshaw transport, environmental sustainability and energy transition as a moderating variable in developing cities. The study aimed to critically synthesize the existing empirical, theoretical and policy literature and therefore this design was appropriate. Systematic literature reviews work well when there is sparse and unorganized evidence that needs to be integrated in a systematic way to detect patterns, contradictions and gaps in the research (Snyder, 2019). The desk review design proved to be well suited for this study as the study examines interconnected transport, environmental and energy systems in multiple developing-country contexts, the broad comparative evidence is therefore more analytically valuable than field-based observations.

3.2 Study Area

This study focused on developing cities in Tanzania, Africa, Asia, and other developing regions where auto-rickshaw transport constitutes an important component of urban mobility systems. The study did not focus on any particular geographical area, but rather took a broader approach, looking at the wide variety of developing country experiences, challenges and opportunities related to auto-rickshaw transportation, environmental sustainability and energy transition. The review was based on evidence from Tanzania, India, Bangladesh, Kenya, Rwanda, and Ghana where the use of auto-rickshaws, electric three-wheelers and other intermediate modes of transport have been significant as a mode of providing affordable and accessible transportation, specifically for the first and last mile.

The chosen study area experiences fast urbanisation, rising transport demand, underdeveloped formal public transport network and rising environmental concerns, in addition to the development of transport electrification and renewable energy uptake initiatives. The common features outlined above make it clear that developing cities are the right context for the study of the linkage between auto-rickshaw transport and environmental sustainability, and the potential of energy transition to influence sustainability outcomes. The study brings together evidence from different development contexts to gain a more comprehensive understanding of the relationship between technology, infrastructure, institutions and energy system characteristics and the sustainability of auto-rickshaw transport systems in cities.

3.3 Data Sources, Search Strategy, and Selection Criteria

The peer-reviewed journals, institutional reports, policy documents and international databases were used to collect secondary data for ensuring credibility and academic rigor. The key sources used were Google Scholar, Scopus, Science Direct, SpringerLink, Taylor & Francis, World Bank, International Energy Agency (IEA), World Health Organization (WHO), and UN-Habitat. Only literature published from 2020 to 2026 is given priority to be current, and some theoretical works are included selectively if required. Using secondary data analysis as a method strengthens the efficiency of research and scholarship by providing a systematic method for utilizing credible existing evidence to draw out broader conclusions (von Spakovsky et al., 2000). Relevant studies were identified through a structured search strategy and keywords, including auto-rickshaw transport, three-wheelers, electric rickshaws, environmental sustainability, energy transition, developing cities, and renewable energy. The selection of studies for this review was based on the following inclusion criteria: the studies directly addressed at least one study variable, the studies were conducted in the context of developing countries, and the studies showed methodological credibility. To enhance the conceptual clarity and quality of review, publications that were weakly sourced, irrelevant and non-scholarly were excluded (Turnbull et al., 2023).

3.4 Data Presentation and Synthesis

In this study, data were presented in the form of descriptive synthesis of published quantitative evidence from the reviewed literature. The study did not perform any statistical analysis of its own, but it systematically compiled and categorized, from reliable published sources, numerical data in the form of percentages, estimates of emissions, levels of electrification, potential for fuel savings, trends in policy formulation and adoption, and environmental indicators. The results were presented in tabular, chart and graph form, and comparative summary tables to show patterns and relationships about auto-rickshaw transport, environmental sustainability and energy transition in developing cities. It was suitable because literature reviews can be used to synthesize and interpret existing evidence but not to produce primary statistical outputs (Snyder, 2019). The study showed and structured the already existing quantitative results in a comparative way, and was able to highlight the commonalities, contradictions and gaps in previous research in the field without losing their methodological value.

IV. FINDINGS & DISCUSSIONS

4.1 Auto-Rickshaw Transport and Environmental Sustainability

This section summarizes results of the first objective on evaluating the relationship between auto-rickshaw transport and environmental sustainability in developing cities. It investigates how the emissions, fuel types and the last mile mobility functions of the autorickshaw affect the environment and how they can be useful for urban mobility as well as be detrimental or beneficial to the environment depending on the conditions of their use and energy.

a) Auto-Rickshaw Emissions & Urban Air Pollution

The reviewed results clearly reveal that the use of autorickshaws offers low cost and flexibility to mobility in developing cities, while the traditional fossil fuel-based mobility fleet also contributes to environmental degradation in cities. In Dar es Salaam, petrol-powered rickshaws are seen to create significant pollution and higher operating costs, whereas the conversion to CNG resulted in a 99.20 Tsh/km operating cost, which dropped to 54.38 Tsh/km per km, with estimated annual savings of around Tsh 2.5 million per rickshaw and significant reductions in PM2.5 emissions, as reported by Gerutu et al. (2021). The findings show that these cleaner fuels in transition can also help to lower environmental and economic impacts (Table 1).

Table 1

Comparison of fuel saving between CNG 4-stroke and petrol rickshaws

Type of vehicle	**3-wheelers (rickshaws)**	
Fuel	**CNG**	**Petrol**
Measuring unit	**Kg**	**L**
Unit equivalence	Energy content: 13.3 kWh/kg	Energy content: 8.6 kWh/L
	~ 1.5 L of petrol per 1 kg CNG	1L
Fuel cost (Tsh per unit)	1,550a	1852b
Mileage (km/unit of fuel)	28.50	(28 km/1.5 L) = 18.67
Operating cost per km (Tsh/km)	54.38	99.20
Average vehicle running (km/day)	155.4c	155.4c
Annual vehicle running [DA] (km/year)	155.4 km/day × 30 days/mon× 12mon/year = 55,944 km/year	55,944 km/year
Operating cost/day (Tsh/day)	8,450	15,415
Saving cost of fuel per km [S] (Tsh/km)	99.20 - 54.38 = 44.82	
Saving cost of fuel per day (Tsh/day)	15,415 - 8,450 = 6,965	
Saving cost of fuel per month [SCF](Tsh/month)	44.82 × 30 days/mon × 155.4 km/ day = 208,950.84	
Saving cost of fuel per year (Tsh/year)	208,950.84 Tsh/mon × 12mon/year = 2,507,410	
Saving cost of all rickshaws per year (Tsh/year)	2,507,410 Tsh/year/rickshaw × 50,000d rickshaws = 125.370504 bil.	
Approximate conversion cost [CV] (Tsh)	800,000	
Payback distance [PD] (km)	CV / S= 800,000 Tsh / 44.82 km/ year = 17,849.2 km	
Payback period [PB] (months)	CV / SCF = 800,000 Tsh / 208,950.84 Tsh/mon = 3.8 ≈ 4 months[e]	
Fuel consumed per rickshaw per day (kg/day)	155.4 km/day × 28.5 km/kg = 5.45 kg/day	
Fuel consumed per rickshaw per year (ton/year)	5.45 kg/day × 366 days/year ≈ 2 Tonnes	
Fuel consumed for all rickshaws per year (ton/year)	2 tonnes/rickshaw/year × 50,000 rickshaws ≈ 100 million tonnes/ year	
CNG revenue for all rickshaws per year (Tsh/year)	100 million tonnes/year × 1,550 Tsh = 155 bil[f]	

Source: (Gerutu et al., 2021)

Likewise, Choudhary et al. (2020) have found that the emission impact of auto-rickshaws is high on traffic load, travel time and the age of the vehicles. They determined that CO and HC emissions increased significantly with congested traffic, low-speed driving and increased vehicle mileage, whereas NOx was related to high-speed driving conditions. The trend in both the studies suggests that environmental sustainability deteriorates in the case of fossil-fuel auto-rickshaw running with poor traffic systems, long traffic congestion and mechanical aging (Figure 1).

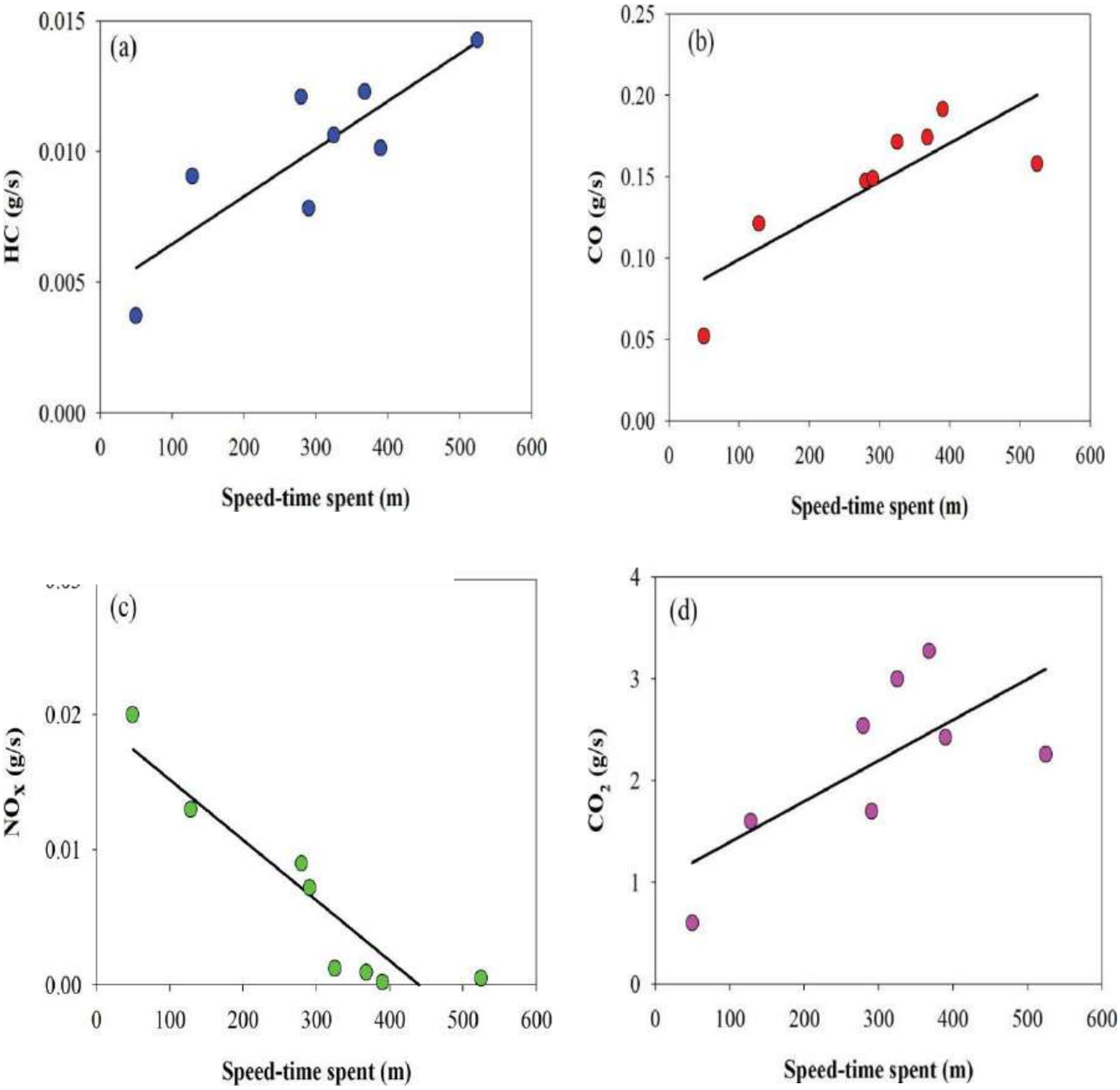

Figure 1
The Relationship between Speed and Time Spent with the Emission of Pollutants
Source: (Choudhary et al., 2020)

b) Type of Fuel and Environmental Implications

The reviewed studies reveal that the use of different fuels significantly influences the environmental sustainability of auto-rickshaw services. In Chennai, Harikumar et al. (2020) identified that the LPG and petrol-powered auto-rickshaws emit high number of pollutants such as 14.66 metric tons of carbon monoxide, 7.42 metric tons of hydrocarbons, 1.47 metric tons of NOx and 0.74 metric tons of particulate matter on a daily basis and are also a significant contributor to greenhouse gas emissions. These research results are evidence that fossil fuel emissions, even relatively clean ones like LPG, still cause environmental damage (Table 2).

Table 2
Estimated Current Emissions and Fuel Consumption from Auto-Rickshaws in Chennai

	Carbon Monoxide	Hydrocarbons	Nitrous Oxides	Particulate Matter
Total per day emissions in Metric Tons (MT)	14.66	7.42	1.47	0.74
		Fuel Consumed (in thousand Litres)		GHG Emissions (in MT)
LPG		339.52		556.81
Petrol		131.53		302.52

Source: (Harikumar et al., 2020)

Also, the authors (Harikumar et al., 2022) found that the fossil fuel dominated system is structurally anchored and Kochi had 8273 diesel, 6023 petrol, 2106 CNG and just 34 electric auto-rickshaws. This distribution illustrates that fossil-fuel technology still dominates urban three-wheelers even though cleaner technology alternatives exist, leading to continued high emissions. The overall trend indicates that environmental sustainability continues to increase from petrol/diesel to CNG and electric systems, albeit with a sluggish pace of transition in part because of the limited electrification.

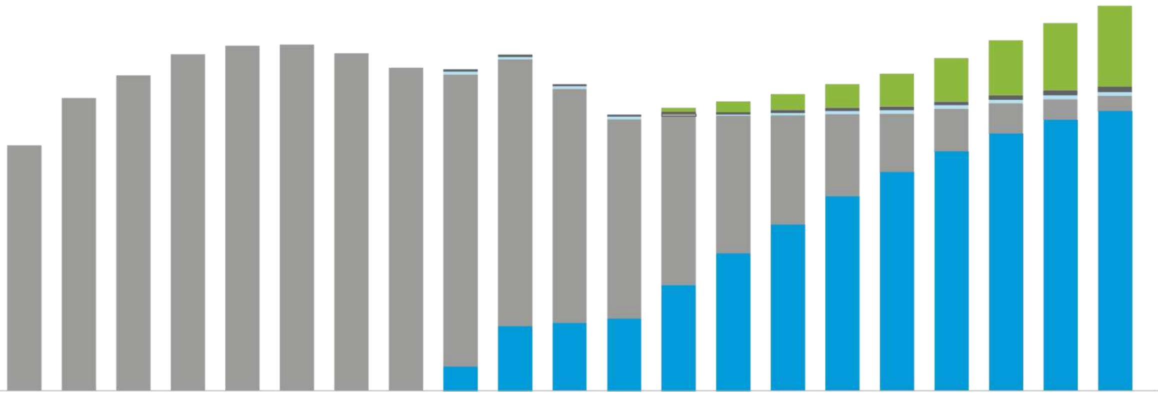

Figure 2
Distribution of Auto-Rickshaws by Fuel Type in Kochi
Source: (Harikumar et al., 2022)

c) Auto-rickshaws and sustainable last-mile mobility

The results also suggest that, if connected to sustainable urban mobility systems, the use of auto-rickshaws can have a positive impact on environmental sustainability. In Dar es Salaam, Martin et al. (2024) discovered that e3W were first deployed as feeder services for the Bus Rapid Transit (BRT) network to connect people to less accessible areas of the city and cut down the use of fossil fuel-based last-mile transport. This trend signals that electric ARs can contribute to low emission urban mobility when deployed in a strategic manner within the formal public transport system.

Plate 1
Electric three-wheelers for feeder services in Dar es Salaam
Source: (Martin et al., 2024)

In similar vein, Kumar et al. (2022) observed that, in Ranchi, India, e-rickshaws and cycle rickshaws have proven to be a critical asset for boosting last-mile mobility within the urban area, providing passengers with a low-cost and environmentally friendly means of getting to and from transport hubs. There was a high level of passenger acceptance of e-rickshaws, with the three key elements of financial, speed and environmental being highly emphasized. In all of these studies, the findings point to greater potential for the auto-rickshaw to evolve from an environmentally damaging transport method to a sustainable urban mobility asset if they are powered by cleaner energy and integrated into well-designed transport systems.

Table 3

Passengers' perception of cycle rickshaw and e-rickshaw for last-mile connectivity

Comparing Variables	Passengers Perception Cycle-rickshaw	E-Rickshaw	Policy Recommendations
Pollution	Non-polluting	Non-polluting	Shall be promoted and continued as a non-polluting communication option that supports achieving liveable and smart cities of the future. (Though, the e- rickshaws may contribute to e-waste)
Affordability	Affordable	Affordable	Both types of Rickshaws cater to the lower and middle class at affordable prices. Thus, it shall be continued and promoted as last-mile connectivity.
Charges/Fare	Flexible/negotiable	Fixed - INR 10/- for 2–5 KM	They are comfortable with charges as cycle rickshaw takes them to the desired dropping point compared to e-rickshaw.
Sitting capacity	2	4	It provides options depending upon the number of
Shared service	Mostly not shared with other passengers	Shared services	Passengers and travel places to book a rickshaw or e- rickshaw.
Power / Maintenance Connectivity to the	Manually pulled/ General repair and maintenance Enable the passengers, significantly	Pulled by an electric motor powered by battery /General repair and maintenance apart from Battery change after every 6–8 months Enable the passengers, significantly older	Both should be promoted, considering its distinct benefits and features. Both modes of transport employ poor and migrant workers. Cycle-rickshaws and E-rickshaw should be legally allowed
nearest bus transport hub- from home (Last-mile connectivity issue 1) Reach to suburbs where	older and children passengers to reach the nearest bus stop/ local transport hub Cycles rickshaws provide transport	and children passengers to reach the nearest bus stop/ local transport hub Only on fixed routes even to the suburbs	to act as a link- transport- last-mile connectivity to the main bus stops and transport hubs As both modes of transport cater to the different routes,
public transport is not available. (Last-mile connectivity issue 2)	access to the suburbs which are not connected to public transport		both should be promoted and incorporated as the last mile connectivity option.

Source: (Kumar et al., 2022).

4.2 Effect of Energy Transition on Auto-Rickshaw Transport Systems

The section presents results of second objective on assessing the influence of energy transition on auto-rickshaw transport systems in developing cities. It is based on electrification of auto-rickshaw fleets, charging facilities and battery technology, renewable energy and solar power for charging, and cost factors and government incentives.

a) Electrification of auto-rickshaw fleets

The results of the review indicate that the energy transition is changing the auto-rickshaw systems mainly through fleet electrification, but uptake is still low compared to conventional fuels. Electric Auto Rickshaws can considerably minimise emissions, enhance air quality in urban cities, and cut down the operating expenses, and boost the first and last mile connectivity, observed Kanuri et al. (2023). Fleet transition is rather slow, however, with electric passenger three-wheelers constituting 5% of all passenger three-wheel vehicles and CNG 66% advanced, diesel 14% and petrol 10%. This is a sign of the increasing sustainability potential in electrification but that fossil fuel still has a strong presence because of infrastructural, regulatory and financial hurdles.The overall picture indicates that energy transition has provided an opportunity to auto-rickshaw systems to pursue a viable low-emission pathway, however, electrification rates are still underdeveloped, and the sector requires better policy coordination, financing mechanisms, and infrastructure to make a large-scale impact.

b) Charging facilities and battery technology

The charging systems and battery technologies have been identified consistently as essential factors for the feasibility of the operation of the electric auto-rickshaw system. Hasan (2020) reported that in Bangladesh, electric rickshaws are mainly powered by lead-acid batteries ranging from 4.8-kWh to 6-kWh capacity and 8- to 10-hour charging time, which limit the efficiency of their operational capacity in a day. The results show that battery restrictions have a direct impact on the service reliability, service uptime and driver productivity.

.

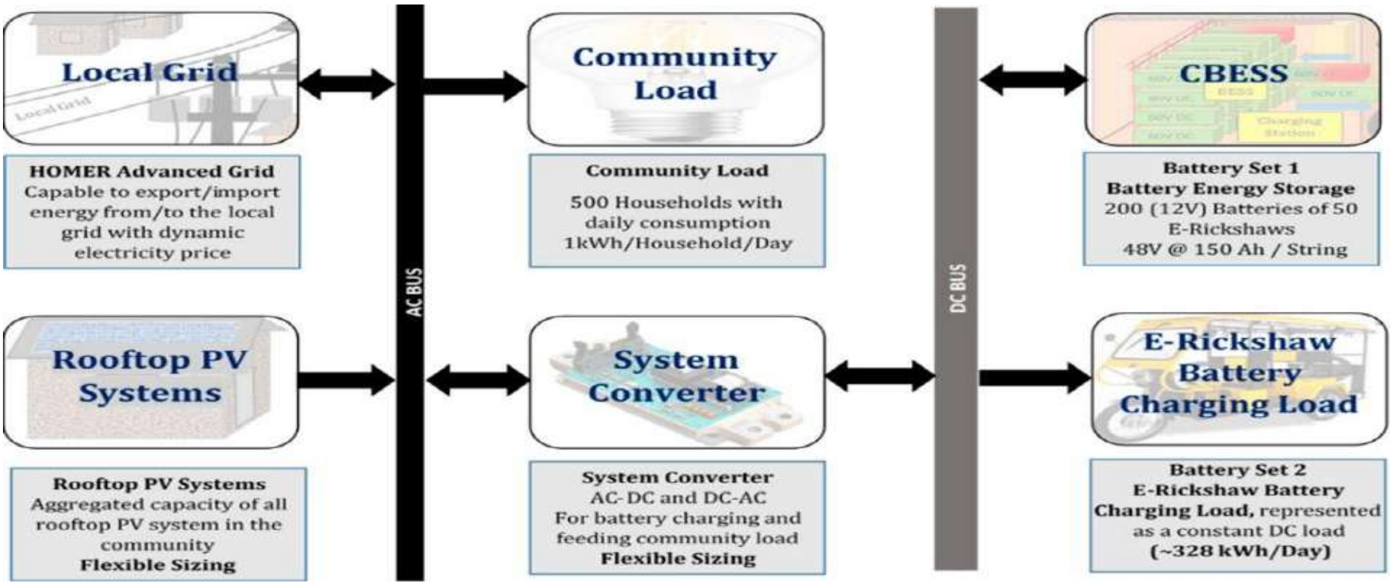

Figure 3
Architecture of battery swapping and charging station system for e-rickshaws
Source: (Hasan, 2020).

Solutions that minimized downtime and enhanced operational continuity were key technological solutions highlighted: Battery swapping and charging station systems. Hasan (2020) also proved the integrated Battery Swapping and Charging Stations (BSCS) can transform the charging infrastructure from charging points to a more comprehensive energy management system when connected with Solar PV, Community Battery Storage (CBS), and local electricity networks. The trend indicates that besides electrifying the vehicle, energy efficiency of the battery, charging availability, and integration of the energy infrastructure is important to ensure a successful energy transition in auto-rickshaw systems.

c) Renewable energy and solar power for charging

The reviewed studies indicate that integration of renewable energy sources to electric auto-rickshaws has a strong positive impact on the sustainability potential of such systems. Al-Amin and Sahabuddin (2023) determined that the consumption of an electric autorickshaw in Bangladesh is around 9.32 kWh per day per vehicle and if there are 500,000 electric autorickshaws, the total consumption is around 4,660 MWh per day most of which occurs during peak demand periods. This trend shows that electrification can further aggravate the energy-system pressure if it relies heavily on fossil-fuel-dominated national energy grids to charge.

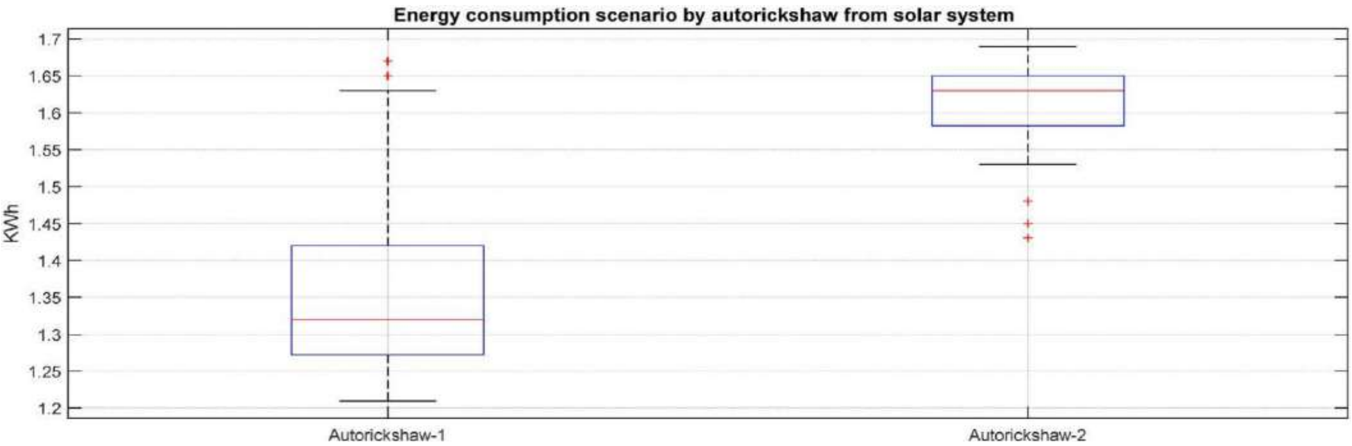

Figure 4
Solar Energy Contribution to Electric Autorickshaw Charging
Source:(Al-Amin & Sahabuddin, 2023)

Installing solar on the motorway provides a significant moderating opportunity. The study revealed that the solar autorickshaws can produce an average of about 46 kWh/month per car, which reduces the dependence on grid electricity, and solar power on a national level can save about 23,000 MWh/month. The results suggest that adopting renewable energy for integration into electric auto-rickshaw systems can significantly enhance the environmental and energy efficiency of these systems, but are limited by capital costs, technical barriers, and policy gaps.

d) Cost factors and Government incentives

The cost competitiveness aspect reflects economic evidence that demonstrates that cost competitiveness is a significant factor for energy transition in the auto-rickshaw system. According to Hossain et al. (2023), battery-powered electric three-wheelers (ET3W) in Bangladesh are found to be significantly less expensive in terms of retail cost, maintenance and daily operating costs as compared to CNG-operated auto-rickshaws. The retail price of the electric three-wheelers were also lower than that of CNG auto-rickshaws (USD 6,000–8,000), as was the cost of maintenance per month and daily operation. The trends suggest that energy transition can be pursued in ways which enhance economic access, in addition to meeting environmental goals (Table 7).

Table 4
Cost comparison between electric three-wheeler and CNG-operated auto-rickshaw

Factors	CNG Operated Auto Rickshaw	Battery Operated Electric Three-Wheeler
Maintenance Cost (Monthly)	60–80 USD	40–60 USD
Daily Income (Driver)	20–24 USD	14–16 USD
Daily Expenses (Driver)	4–5 USD	3–4 USD
Owner Daily Income	800 BDT (10 USD)	560 BDT (6.5 USD)
Retail Cost (With Assembly)	6000–8000 USD (from India), 6000–7000 USD (from China)	2375–2625 USD (from China)

Source:(Hossain et al., 2023)

Reviewed evidence also indicates that, however, there is not necessarily a direct link from affordability to transition. Hossain et al. (2023) highlighted the continued importance of government policies such as tax incentives, lower battery import taxes, battery manufacturing policies, charging infrastructure rules and battery recycling initiatives in driving adoption. Looking at the overall landscape, energy transition in auto-rickshaw systems is not only about technical feasibility but also about the economic structures and policy incentives reducing the barriers to their adoption.

4.3 Moderating Role of Energy Transition in Auto-Rickshaw Transport and Environmental Sustainability

The section presents results of third objective to analyze the moderating role of energy transition in the relationship between auto-rickshaw transport and environmental sustainability in developing cities.

a) Electricity composition as a moderating factor

The reviewed evidence reveals that energy transition plays a key role in the environmental sustainability of auto-rickshaw systems mostly by impacting the mix of electricity to which the rickshaws are connected. Electric auto-rickshaws have direct emission savings but the cumulative environmental impacts of using them rely significantly on the source of the electricity they use. The authors of Koroma et al. (2022) concluded that the environmental performance of the BEV life cycle was significantly enhanced by changes in electricity generation mix, such that a cleaner electricity mix reduced the impact of BEVs on global warming by 9.4%, on fine particulate matter by 2.1%, and on human carcinogenic toxicity by 2.3%. The results show that electrification is not enough to ensure sustainable outcomes, but the use of cleaner electricity systems significantly improves outcomes.

Table 8

Impact of electricity mix changes on life-cycle environmental impacts of battery electric vehicles

Indicators	Improvement strategies			Total reductions
	Recycling	LIB repurposing	Electricity mix changes	
Global warming	−8.3%	−0.8%	−9.4%	−18.4%
Fine particulate matter formation	−17.2%	−4.2%	−2.1%	−23.5%
Mineral resource scarcity	−25.2%	−2.9%	0.4%	−27.6%
Human carcinogenic toxicity	−14.3%	−1.0%	−2.3%	−17.6%
Human noncarcinogenic toxicity	−22.3%	−2.3%	−1.6%	−26.2%

Source:(Koroma et al., 2022)

The trend implies that energy acts as an important moderating factor because if the EARs really do reduce the total emissions, they do so by shifting emissions from the roads to the fossil-fuel based electricity generation systems. In other words, the sustainability connection between the use of auto-rickshaws and environmental impacts is much more positive when there is a more general shift towards renewable electricity in national energy systems.

b) Renewable energy integration as a sustainability amplifier

The findings also indicate that integration of renewable energy enhances the sustainability benefits of electric auto-rickshaws over vehicle electrification. Hassan et al. (2024) observed that VRPs are a viable option for integrating electric rickshaws as distributed energy storage systems in Bangladesh. Electric rickshaws, with roughly 4 million light electric vehicles (LEVs) that could provide 4 GW storage capacity, could be used to balance renewable energy, reduce peak loads, and stabilize the grid. This shows that energy-efficient systems using renewable energy make electric auto-rickshaws part of the larger sustainable energy landscape.

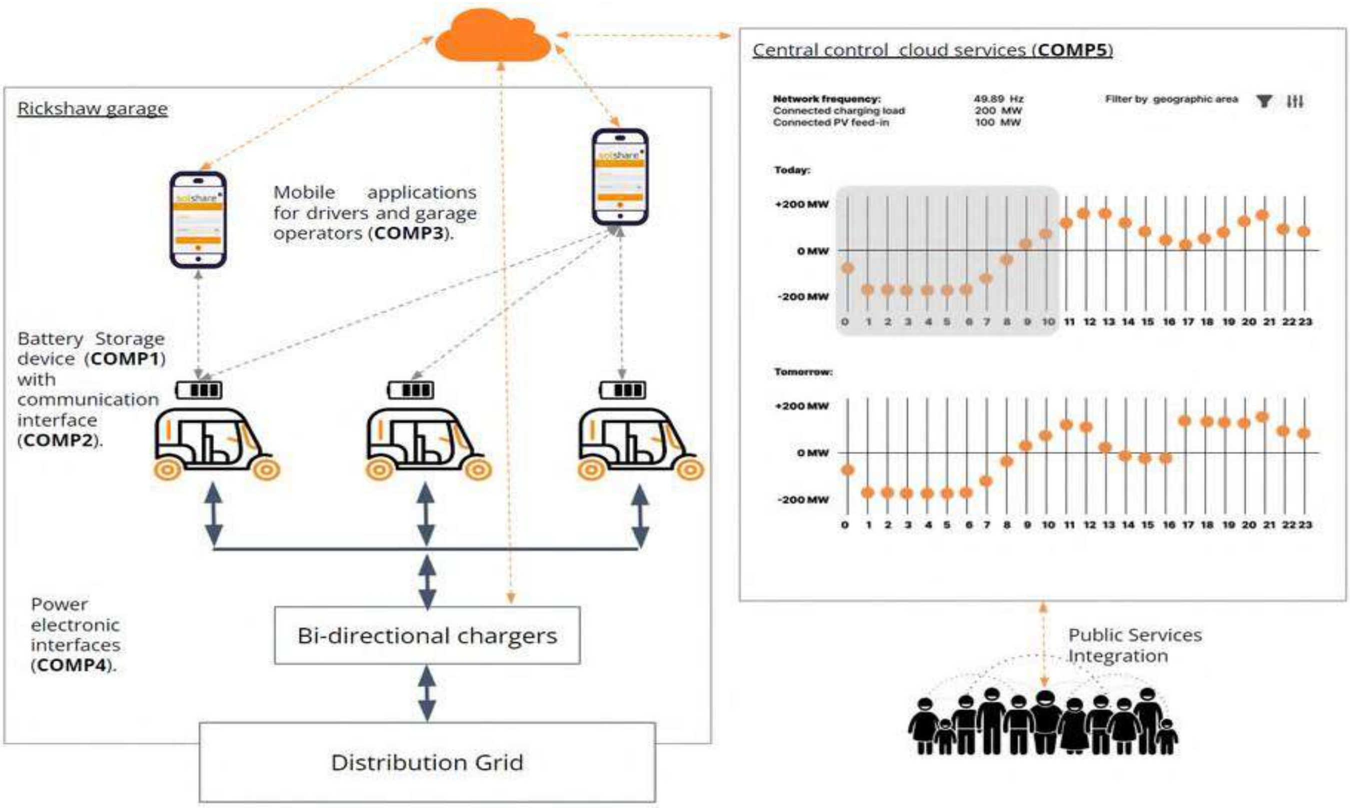

Figure 5
Critical technological components of the Rickshaw VPP deployment

The trend shows that renewable energy acts as a sustainability amplifier by enhancing the environmental impact of electric auto-rickshaws by integrating solar power, enabling bidirectional charging, and implementing battery storage systems. Hence, energy transition not only contributes to sustainability in the context of clean charging but also in terms of structuring the transport system about renewable energy resilience.

c) Inadequate energy transition as a limiting factor

Focusing on energy transition alone has been found to markedly undermine the environmental benefits of electric auto-rickshaws, as studies reviewed have consistently highlighted. While Bangladesh's electric three-wheelers are free from tailpipe emissions, Hossain et al. (2023) determined that about one million EVs are used daily, with a total daily electricity demand of about 11 GWh, or 6% of the nation's electricity generation. This is a large-scale electricity demand that can exacerbate fossil-fuel electricity generation when electricity generation is still carbon intensive, rather than eliminate it.

Table 10
Electric three-wheeler energy consumption comparison

Details (as of 2020)		**Energy in Giga Units (1 Unit = 1 kWh)**
Total Energy Generation in Bangladesh in one year		71,419
Total Energy Generation in Bangladesh in one day	365 days	195.66
Number of E3W approximated	1 million	
Average energy consumed by one E3W	11 units	
Number of average units consumed by all E3Ws		11

Source:(Hossain et al., 2023)

These results indicate a large-scale structural contradiction – electric autorickshaws can be seen as environmentally friendly at the vehicle level, but indirect environmental costs at the energy-system level if the charging infrastructure is still fossil fuel-based. It therefore indicates that the wider trend – namely, that electrifying vehicles first, and then reducing the carbon footprint of the grid by means of renewables or demand-side management – is hampering the full potential of electric auto-rickshaw systems for sustainability.

d) Government policy and infrastructure as transition enablers

It is also found that the success of energy transition in enhancing environmental sustainability is greatly moderated by policy systems and infrastructure. In this context, Hossain et al. (2023) revealed that the sustainability of electric mobility is significantly affected by charging regulations, battery recycling mechanisms, infrastructure standards, grid safety, and institutional governance. Much more than replacing vehicles is needed for sustainable outcomes, as emphasised by international charging standards like IEC and ISO frameworks, which point to regulated charging systems, safe infrastructure and energy governance.

Table 11

International standards for electric vehicle charging infrastructure

Schemes	Standard
Electrical Vehicle Conductive Charging System	IEC 61851-1:2017 [99], IEC 61851-23:2014 [100], IEC 61851-24:2014 [101]
Conductive Power Transfer	ISO 17409:2020 [102]
Over Current Protective Device	IEC 60947-2 [103], IEC 60947-6-2 [104], IEC 60269 [105]
Earthing	IEC 60364 [105]
Thundering Protection	IEC 62305 [106]
Insulation of Charging Equipment	IEC 61851-1 [99]
Charging Cable	IEC 62893-1 [107]
Charging Station Equipment Protection	IEC 60529 [108]

The overall pattern suggests that government action can be a structural enabler that can decide the coherency, safety, scalability and environmental effectiveness of energy transition. If there is no robust policy framework, no incentives for renewable integration, no battery management system and no regulation of charging infrastructure, electric auto-rickshaws may not perform well environmentally when they should. Hence, energy transition has a moderating effect between the use of auto-rickshaws and environmental sustainability by regulating the transition from being a partial technological shift to a sustainable solution through policy, infrastructure and governance.

4.4 Discussion

The results show that auto-rickshaw transport is not just a transport function but an auto-rickshaw mobility function, whose environmental impact is also not determined by the transport function alone, but by fuel systems, auto-rickshaw technological configuration and energy governance in the developing cities. While clearly enhancing urban accessibility and affordability and last-mile mobility, notably where formal mobility options are limited, the sustainability benefits of autorickshaws are reduced where fleets are not adequately powered with alternative fuels, where their engines are under-performing, and where they operate inefficiently within the congested urban transportation environment. It also reveals that energy transition is not just a technological upgrade but a structural condition of the vehicle that will be the key in shaping whether autorickshaws become a sustainable mobility asset or a burden for the environment in urban areas. This is not the issue of mobility of auto-rickshaws per se, but socio-technical conditions that auto-rickshaws operate in such as dependency on fuel, charging systems, electricity sources and institutional capacity.

The results are consistent with other prior research that found traditional auto-rickshaws based on conventional polluting fuels exacerbate pollution, and cleaner fuel and electrification approaches bolster sustainability impacts. As in Gerutu et al. (2021), the results also suggest that the usage of transitional fuels like CNG can lower operational costs and emissions and Choudhary et al. (2020) further validate that congestion, old fleet, and traffic conditions are significant factors that increase emissions irrespective of the transport utility. The findings also align with the study by Harikumar et al. (2020), who found that electrification has a large impact on the reduction of local pollutants, but can be less effective at maximising the climate benefits in fossil-based electricity systems. This work builds on previous research by considering not just fuel and/or emission impacts, but also the effect of energy transition on the transport-sustainability relationship. This more comprehensive synthesis complements the work done by Kanuri et al. (2023) and Ayetor et al. (2023) as it demonstrates that without the implementation of integrated infrastructure, renewable energy, and policy reform, electrification will only achieve partial sustainability.

Theory-wise, the results are very supportive of the Multi-Level Perspective (MLP) on Sustainability Transitions (Geels, 2011) The continued use of petrol and diesel and the continued dominance of the auto-rickshaw industry that is not well regulated indicates lock-in by the regime, where the fossil-fuel structure persists despite damage to the environment because of institutional, infrastructural and economic inertia. At the same time, several new technologies are niche innovations that have the potential to disrupt this regime, such as electrification, solar charging, battery swapping, and renewable integration. The results thus support MLP's thesis that transitions towards sustainability are not driven by technology choices but through a dynamic interplay of niche innovation, regime disruption, and landscape pressures, like urban pollution and climate issues. In this study, energy transition is the moderating factor between the sustainability or the continuation of the existing transport regime.

In the practice, the conclusions suggest that the sustainability of the auto-rickshaw is not just a transportation problem but needs integrated coordination of transport energy policies for policymaking in developing nations. The findings from Hasan (2020) and Al-Amin and Sahabuddin (2023) indicate that battery systems, solar charging, and grid connection are vital to achieving sustainability results, while Nnene et al. (2026) and Goletz et al. (2021) found that the fragmented policies, inadequate charging standards, and lack of incentives continue to be key obstacles. This is the time to go beyond merely encouraging vehicles to be electric and to focus on the provision of charging infrastructure that is powered by renewable energy, the governance of batteries, financing options, and regulatory coherence. Otherwise, developing cities can only move the emissions from roads onto the electricity grid, and leave the overall environmental impacts unchanged.

Overall, the results suggest a future of auto-rickshaw systems in developing cities that is not assured unless energy transition is not done on a symbolic rather than comprehensive basis. The study brings a more advanced view by not only showing that replacing engines is enough to make the environment more sustainable, but that it is necessary to change the broader socio-technical mobility environment. In this way, auto-rickshaws can serve as a strategic transition sector that could support sustainable urban development, if and only if there was a match in terms of renewable energy, infrastructure development and governance reform. Thus, this study highlights the critical nature of energy transition as the key moderating factor which transforms the auto-rickshaw transport from an informal mobility regime with high carbon emissions to a sustainable mobility opportunity in cities (Geels, 2002; Kanuri et al., 2023; Ayetor et al., 2023).

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

This study concludes that auto-rickshaw transport is both a mobility necessity and an environmental challenge in developing cities. Whilst providing a major boost to urban accessibility, affordability and last-mile connectivity, the current reliance on fossil-fuel powered auto-rickshaws, the use of increasingly aged vehicles, congestion and low standard of regulation, exacerbates emissions and environmental damage. The results show that the use of cleaner transitional fuels (CNG) is more effective in the short-term for achieving environmental benefits, while long-term energy transition needs to be achieved mainly by generalizing the energy transition, including electrification, integration of renewable energy, battery systems and policy reform. Therefore, the study concludes that transport alone is not a determinant of environmental sustainability but rather the interaction between transport and energy determines sustainability outcomes.

The investigation also finds that energy transition is the key moderating factor that can make the auto rickshaws from a polluting informal transport mechanism into a sustainable urban mobility system. This directly fulfills the aim of the study by demonstrating that the deployment of electrification without clean electricity, charging infrastructure, governance and enabling policy can only shift pollution from road to power system and fail to address the issue. The main contribution of knowledge is bridging the divide between studies of isolated transport, electrification and environmental sustainability in the field of auto-rickshaw systems by establishing that environmental sustainability in auto-rickshaw systems is indeed a socio-technical transition question. However, using secondary literature has reduced the opportunities for direct contextual testing and future empirical testing is needed in particular developing cities.

5.2 Recommendations

Cities should not approach auto-rickshaw sustainability as a transport issue alone but rather pursue an integrated transport-energy-policy approach, which encompasses fleet electrification, renewable energy powered charging, battery-swapping infrastructure, financing access and mandating regulatory standards. To avoid becoming a tokenistic measure, e-mobility should be integrated into national clean energy transitions, highly polluting fleets should be promptly phased out and electric and renewable infrastructure must be expanded. The future research should be directed towards primary level empirical studies at the city level to test the practical implementation of the effects of the infrastructure, governance and electricity composition on the realistic outcomes of environmental sustainability in the auto-rickshaw system

REFERENCES

Al-Amin Md, & Md Sahabuddin. (2023). High penetration of electric autorickshaw on national power system and barriers against the adoption of solar energy: A case study in Bangladesh. *Cleaner Engineering and Technology*, *14*(2023), 100637–100637. https://doi.org/10.1016/j.clet.2023.100637

Ayetor, G. K., Mbonigaba, I., & Mashele, J. (2023). Feasibility of electric two and three-wheelers in Africa. *Green Energy and Intelligent Transportation*, *2*(4), 100106. https://doi.org/10.1016/j.geits.2023.100106

Cervero, R. (2000). *Informal Transport in the Developing World.* United Nations Centre for Human Settlements (Habitat). https://unhabitat.org/sites/default/files/download-manager-files/Informal Transport in the Developing World.pdf

Choudhary, A., Kumar, P., Gaur, M., Prabhu, V., & Shukla, A. (2020). Real world driving dynamics characterization and identification of emission rate magnifying factors for auto-rickshaw. *Nature Environment and Pollution Technology, 19*(1), 93–101. https://neptjournal.com/upload-images/%288%29B-3605.pdf

Emodi, N. V., Okereke, C., Abam, F. I., Diemuodeke, O. E., Owebor, K., & Nnamani, U. A. (2022). Transport sector decarbonisation in the Global South: A systematic literature review. *Energy Strategy Reviews*, *43*(2022), 1–18. https://doi.org/10.1016/j.esr.2022.100925

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy, 31*(8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions, 1*(1), 24–40. https://doi.org/10.1016/j.eist.2011.02.002

Gerutu, G. B., Mohamed, C. H., Chombo, P. V., & Junction, B. T. R. (2021). Transition to compressed natural gas rickshaws for urban mobility: A case of Dar es Salaam City. *Journal of Logistics, Management and Engineering Sciences, 3*(2), 81–87. http://41.93.71.3:8080/xmlui/handle/123456789/145

Goletz, M., Ehebrecht, D., Wachter, C., Tolk, D., Lenz, B., Kühnel, M., Rinderknecht, F., & Hanke, B. (2021). Electrification of urban three-wheeler taxis in Tanzania: Combining the user's perspective and technical feasibility challenges. In A. Ewert, S. Schmid, M. Brost, H. Davies, & L. Vinckx (Eds.), *Small electric vehicles: An international view on light three- and four-wheelers* (pp. 97–112). Springer International Publishing. https://doi.org/10.1007/978-3-030-65843-4_8

Harikumar, A., Jain, H., & Phillip, S. (2022). *India's EV transition: Catalysing Kochi's electric 3-wheeler market through local policy* (August report, pp. 1–24). Council on Energy, Environment and Water. https://www.ceew.in/sites/default/files/ceew-research-on-electrification-of-3-wheeler-auto-rickshaw-market-through-local-policy-in-kochi.pdf

Harikumar, A., Thakur, P., & Pal, S. (2020). Assessing the Environmental Benefits from Switching Auto- rickshaws in Chennai to Electric. *The Energy and Resources Institute (TERI)*, *2009*(17), 8. https://www.teriin.org/sites/default/files/2020-06/assessing-environmental-research.pdf

Hasan, A. S. M. M. (2020). Electric rickshaw charging stations as distributed energy storages for integrating intermittent renewable energy sources: A case of Bangladesh. *Energies, 13*(22), Article 6119. https://doi.org/10.3390/en13226119

Hassan, A., Kirchhoff, H., Khan, M. A., & Groh, S. (2024). *The Rickshaw VPP: A discussion basis white paper for Bangladesh's light electric vehicle-based virtual power plant* (White Paper, May, pp. 1–28). SOLshare. https://solshare.com/wp-content/uploads/2024/09/SOLshare-Rickshaw-VPP-White-Paper_May-2024.pdf

Hossain, J. A., Hasan, Z., & Khan, Z. R. (2023). Affordable electric three-wheeler in Bangladesh: Prospects, challenges, and sustainable solutions. *Sustainability, 15*(1), Article 149. https://doi.org/10.3390/su15010149

International Energy Agency. (2024). *Global EV outlook 2024: Moving towards increased affordability*. International Energy Agency. https://www.iea.org/reports/global-ev-outlook-2024/trends-in-other-light-duty-electric-vehicles

Kanuri, C., Gounder, K., Sandhu, B. J. S., & Laroiya, A. (2023, October). Enabling the shift to electric auto-rickshaws: *A guidebook for electrification of auto-rickshaw fleets in Indian cities.* World Resources Institute India (WRI India) & National Institute of Urban Affairs (NIUA). https://wri-india.org/sites/default/files/E-auto-guidebook_WRI-India.pdf

Koroma, M. S., Costa, D., Philippot, M., Cardellini, G., Hosen, S., Coosemans, T., & Messagie, M. (2022). Life cycle assessment of battery electric vehicles: Implications of future electricity mix and different battery end-of-life management. *Science of the Total Environment, 831*, Article 154859. https://doi.org/10.1016/j.scitotenv.2022.154859

Kumar, A., Thomas, J., Wadhwa, S., Mishra, A., & Dasgupta, S. (2022). The last mile connectivity: Experience of passengers and drivers of e-rickshaws and cycle rickshaws in an Indian city. *Case Studies on Transport Policy, 10*(2), 978–989. https://doi.org/10.1016/j.cstp.2022.03.008

Martin, E., Berlin, A., Owigar, J., Mimano, C., & Shauri, J. (2024). *Scale-up concept note: Scaling sustainable and electric urban mobility solutions in Dar es Salaam* (SOLUTIONSplus Project Report No. 875041, pp. 1–278). SOLUTIONSplus. https://www.solutionsplus.eu/_files/ugd/de12cd_9d813239768e4f5cacf9ca625a993951.pdf

Nnene, O. A., Oyelohunnu, I. I., & Zuidgeest, M. H. P. (2025). Availability of electric mobility policy and its potential for adoption in Africa. *Transportation Research Part D: Transport and Environment*, *151*(2026), 1-23. https://doi.org/10.1016/j.trd.2025.105151

Nyachieo, G., Thindwa, T. N. C., Tasosa, A. B., Basil, P., Moseti, Y., & Jere, J. (2025). Transport and mobility governance: Uncovering barriers to walking infrastructure decision-making processes in urban areas in Kenya and Malawi. *Journal of Urban Mobility*, *8*(2025), 100138. https://doi.org/10.1016/j.urbmob.2025.100138

Pkhikidze, Nino; He, He. (2026). *PATH: A Model of Passenger Transport Emissions Pathways for Cities Across the Globe.* © World Bank. http://hdl.handle.net/10986/44701 License: CC BY-NC 3.0 IGO. https://doi.org/10.1596/44701

Podder, A. K., Supti, S. A., Islam, S., Malvoni, M., Jayakumar, A., Deb, S., & Kumar, N. M. (2022). Feasibility Assessment of Hybrid Solar Photovoltaic-Biogas Generator Based Charging Station: A Case of Easy Bike and Auto Rickshaw Scenario in a Developing Nation. *Sustainability*, *14*(1), 166. https://doi.org/10.3390/su14010166

Reynolds, C. C. O., Kandlikar, M., & Badami, M. G. (2011). Determinants of PM and GHG emissions from natural gas-fueled auto-rickshaws in Delhi. *Transportation Research Part D: Transport and Environment*, *16*(2), 160–165. https://doi.org/10.1016/j.trd.2010.10.004

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/https://doi.org/10.1016/j.jbusres.2019.07.039

Sobhani, Md. G., Imtiyaz, Md. N., Azam, Md. S., & Hossain, M. (2020). A framework for analyzing the competitiveness of unconventional modes of transportation in developing cities. *Transportation Research Part A: Policy and Practice*, *137*, 504–518. https://doi.org/10.1016/j.tra.2019.02.001

Tanveer, A., Song, H., Daud, A., Irfan, M., & Faheem, M. (2025). Identification and prioritization urban E-vehicles barriers toward sustainable cities: A spherical fuzzy decision-making approach. *Energy*, *315*, 134341. https://doi.org/10.1016/j.energy.2024.134341

Turnbull, D., Chugh, R., & Luck, J. (2023). Systematic-narrative hybrid literature review: A strategy for integrating a concise methodology into a manuscript. *Social Sciences & Humanities Open*, *7*(1), 100381. https://doi.org/https://doi.org/10.1016/j.ssaho.2022.100381

von Spakovsky, M., Nelson, D., Ellis, M., Olsommer, B., & Ogburn, M. (2000). A Multi– / Inter–Disciplinary Approach to Fuel Cell System Development: The U.S. DoE GATE Center for Automotive Fuel Cell Systems at Virginia Tech. *SAE Technical Papers*. https://doi.org/10.4271/2000-01-1555

World Health Organization. (2024). *Ambient (outdoor) air pollution*. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health