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Innovative Solar-Powered Electric Trishaws with Advanced Cooling, Safety and Smart Systems for Tropical Urban Mobility

Abdul Rahim Abdullah[1], Shaarmila Kandaya[1], Mohd Bazli Bahar[1], Haslinda Musa[2], Jurifa Mat Lazi[1]

[1]Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
[2]Faculty of Technology Management and Technopreneurship, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
Email: abdulr@utem.edu.my, shaarmilakandaya@yahoo.com, mohdbazli@utem.edu.my, haslindamusa@utem.edu.my, jurifa@utem.edu.my

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Abstract

In tropical climates such as Malaysia, electric trishaws face operational challenges including overheating, inadequate weatherproofing, limited battery life, and reduced efficiency due to heavy batteries. This project proposes the development of a next-generation solar-powered electric trishaw specifically designed for tropical conditions. Key innovations include the integration of solar power to reduce reliance on grid charging, the use of lightweight materials to enhance efficiency and maneuverability, and the adoption of advanced lithium-ion battery technology with intelligent battery management systems to extend operational range. The redesigned trishaw will accommodate up to four passengers and incorporate smart systems for performance monitoring and app-based booking, improving both operational efficiency and user convenience. Collaboration with industry, academic, and governmental stakeholders will enable scalable deployment in urban tropical settings. Anticipated outcomes include a 30% increase in passenger satisfaction, a 30% reduction in operational costs, a 25% improvement in range, creation of 100 new jobs within two years, and a 40% reduction in carbon emissions compared to current models. Additionally, the project aims to support sustainable tourism, with projections of a 15% increase in tourism-related revenue and a 10% rise in tourist numbers within the first year of implementation. This initiative aligns with national sustainability goals by promoting eco-friendly urban mobility and fostering economic growth in local communities.

Keywords

Solar-Powered Electric Trishaw, Tropical Climate Transportation, Lithium-Ion Battery Technology, Sustainability, Tourism, Mobility

1. Introduction

Urban transportation in tropical countries such as Malaysia faces unique environmental and operational challenges that require innovative solutions. Among the eco-friendly transport options, electric trishaws have emerged as a promising mode of sustainable mobility for short-distance travel and tourism. However, existing models, particularly those designed for milder climates, often underperform in Malaysia's hot, humid, and rain-prone conditions [1]. This mismatch between design and operating environment has hindered the effectiveness of electric trishaws as a viable alternative to conventional transport, limiting their adoption and operational success in urban and tourism-focused settings. One notable example is the operation of electric trishaws by NMS Legacy Sdn. Bhd. in Kuala Terengganu. While these vehicles contribute to sustainable transport objectives, they suffer from recurring technical and performance issues under tropical conditions. Overheating, poor weatherproofing, and reduced durability during heavy rainfall have been persistent concerns [2]. In addition, operational inefficiencies are compounded by outdated designs that fail to incorporate modern technologies, thereby limiting service quality and reliability.

Battery technology is another major constraint affecting performance. Current trishaw models rely on heavy battery units that add unnecessary weight, decreasing energy efficiency and increasing wear on mechanical components. The limited battery life further restricts the trishaw's operational range, particularly in unpredictable urban environments where flexible deployment is essential. As a result, operators face higher maintenance and energy costs, while passengers experience reduced service reliability [3]. Moreover, the existing two-passenger capacity limits the trishaw's utility, especially for group travel or tourism activities where higher seating capacity would be beneficial.

To overcome these barriers, this project proposes the development of a next-generation solar-powered electric trishaw specifically engineered for tropical climates. The design will integrate solar charging capabilities to supplement battery power, thereby reducing reliance on grid charging and lowering long-term operational costs. Lightweight materials will be incorporated to enhance maneuverability, improve energy efficiency, and extend the vehicle's range. While the adoption of advanced materials and solar integration may increase initial development costs, these enhancements are expected to provide significant economic and environmental benefits over time.

The proposed trishaw will also adopt commercially available lithium-ion batteries coupled with advanced battery management systems. This technology selection will strike a balance between efficiency, weight, and cost, enabling longer operational ranges without compromising affordability. The vehicle's structure will be redesigned to accommodate up to four passengers, addressing the capacity limitations of current models. In addition, smart technologies such as performance monitoring systems and app-based booking platforms will be integrated to streamline operations, improve fleet management, and enhance the user experience. This initiative will be undertaken in collaboration with industry partners, academic institutions, local communities, government agencies, and technology providers [4]. Such a multi-stakeholder approach will facilitate the development of a scalable and adaptable trishaw model for deployment across urban areas in tropical regions. The project aims to deliver measurable outcomes, including a projected 30% increase in passenger satisfaction, a 30% reduction in operational costs, and a 25% improvement in operational range. It is also anticipated to generate 100 new jobs within the first two years of implementation, contributing to local economic development.

Beyond transportation efficiency, the project is expected to make a positive impact on Malaysia's tourism sector. By offering an environmentally friendly and technologically advanced travel option, the solar-powered trishaw will enhance the visitor experience and promote sustainable tourism practices [5]. This could result in a projected 15% increase in tourism-related revenue and a 10% rise in tourist numbers in deployment areas within the first year. Collectively, these benefits align with Malaysia's broader sustainability goals, contributing to reduced carbon emissions, enhanced public transport options, and long-term community development.

2. Literature Review

2.1. Current Electric Trishaw

The tourism industry plays a crucial role in Malaysia's economic growth, with sustainable transportation emerging as a key enabler for enhancing the visitor experience. [6] underscore the dual economic and environmental benefits of adopting eco-friendly transport options for tourists, particularly in supporting tourism mobility. In Kuala Terengganu, tourism authorities have actively promoted electric trishaws as a green transport solution through targeted marketing campaigns and partnerships with local tourism businesses. These initiatives aim to position electric trishaws not only as a practical means of travel but also as a unique cultural experience for visitors. The Terengganu City and Nature Guide Association (TCNGA) has contributed by directing tour bus passengers toward electric trishaw services, further integrating them into the local tourism ecosystem.

Support from municipal authorities has been equally vital. Majlis Bandaran Kuala Terengganu (MBKT) has facilitated the adoption of electric trishaws by providing dedicated lanes, office space, operational facilities, and implementing regulations to ensure safety and efficiency as shown in **Figure 1**. These measures have helped embed electric trishaws into the city's broader urban transport framework, creating a seamless travel experience for tourists. Together, these collaborative efforts and research-backed strategies enhance the viability and appeal of electric trishaws as a sustainable tourism transport option in Malaysia's tropical cities.

Figure 1. Current electric trishaw.

2.2. Current Electric Trishaw in Kuala Terengganu for Tourism Industry

The tourism industry remains one of Malaysia's most important economic drivers, and its success is closely tied to the availability of reliable and efficient transportation networks. As highlighted by [7], eco-friendly transport solutions for tourists not only generate economic returns but also deliver environmental benefits by reducing carbon emissions and promoting sustainable practices. Recognizing this potential, tourism authorities in Kuala Terengganu have positioned electric trishaws as a flagship initiative for sustainable tourism mobility as shown in **Figure 2**. Through targeted marketing campaigns and partnerships with local tourism operators, these trishaws are promoted as a green, convenient, and culturally distinctive mode of travel that enhances the visitor experience while supporting the city's environmental goals.

The Terengganu City and Nature Guide Association (TCNGA) plays an active role in reinforcing this initiative by encouraging tour bus passengers to use electric trishaw services. This strategic alignment between tourism agencies and local operators ensures that the trishaws remain a visible and accessible transport choice for visitors, thereby increasing their usage rates. Meanwhile, Majlis Bandaran Kuala Terengganu (MBKT) has provided strong municipal support by integrating electric trishaws into the city's broader transport framework. This includes the allocation of dedicated roads, provision of office spaces, establishment of essential operational facilities, and the introduction of regulations to standardize and safeguard trishaw operations. Such measures create a regulated and well-supported environment that enables the service to operate smoothly within the urban transport system.

Figure 2. Current electric trishaw in Kuala Terengganu for tourism industry.

Complementary academic studies, such as those by [7] and [8], have further contributed by addressing the specific challenges of sustainable transportation in tropical cities. These works explore solutions for overcoming heat-related mechanical issues, weatherproofing in high rainfall areas, and maintaining efficiency in variable climate conditions. By aligning municipal support, industry collaboration, and climate-specific research insights, Kuala Terengganu has established a robust framework for electric trishaw deployment. This integrated approach not only enhances the sustainability of urban tourism transport but also sets a replicable model for other tropical cities aiming to balance environmental stewardship with economic growth in their tourism sectors.

2.3. Real Monitoring System of Electric Trishaw

Innovations in transportation technology have become central to global efforts in reducing greenhouse gas emissions and decreasing dependence on fossil fuels. Among these innovations, solar-powered electric vehicles (EVs) stand out as a promising solution for sustainable urban mobility. [9] examined the viability of such vehicles in Malaysia's urban context, emphasizing their potential to significantly lower carbon footprints while providing a renewable energy-based alternative to traditional fuel systems. The environmental advantages of solar-powered EVs align with Malaysia's national sustainability goals and global climate change mitigation commitments, making them an attractive option for both policymakers and industry stakeholders.

Addressing the challenges posed by Malaysia's tropical climate is crucial to the successful adoption of these technologies. [10] explored cooling technologies tailored for tropical urban environments, focusing on maintaining passenger comfort in high-temperature and high-humidity conditions. This is particularly relevant for open or semi-enclosed public transport modes, where direct exposure to heat can negatively impact passenger satisfaction and health. By incorporating efficient cooling systems, solar-powered vehicles can provide not only environmental benefits but also a comfortable and appealing user experience, thereby encouraging broader public acceptance.

Complementary research by [11] further reinforces the practicality of integrating renewable energy solutions into urban transport. [12] addressed the operational and infrastructural considerations of renewable energy deployment, while [13] examined passive cooling strategies that leverage design elements to regulate internal temperatures without heavy reliance on energy-intensive systems. These findings provide a dual approach technological and architectural for enhancing the efficiency, comfort, and resilience of sustainable transport solutions in tropical cities.

Beyond energy and comfort, advancements in smart transportation systems and Internet of Things (IoT) integration have introduced new levels of operational efficiency. [14] demonstrated how IoT-enabled systems can optimize fleet management, route planning, and maintenance scheduling, thereby reducing operational costs and environmental impact. Additionally, [15] highlighted the critical role of supportive infrastructure and policy frameworks in accelerating electric vehicle adoption for urban mobility. Together, these studies point toward a holistic strategy in which renewable energy technologies, climate-specific adaptations, and digital innovations converge to create sustainable, efficient, and future-ready transportation networks. **Figure 3** shows the real monitoring system of electric trishaw.

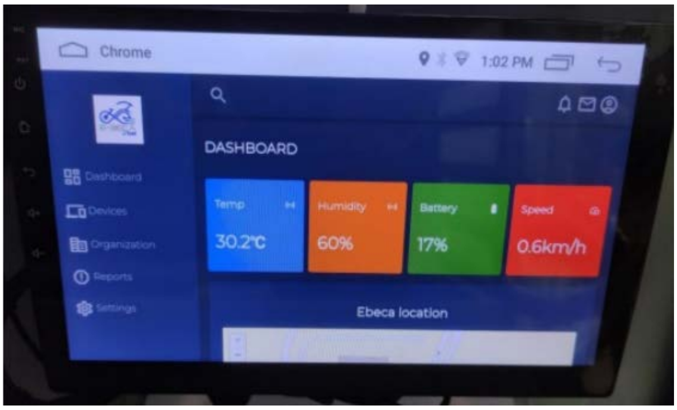

Figure 3. Real monitoring system of electric trishaw.

3. Methodology

The Electrical wheel is commonly developed for a trishaw that mostly used by a single rider, 2 and 4 passengers and light weight trishaw body. This was made to reduce the torque required for the electrical wheel. However, trishaws need higher torque due to the trishaw body that has a carrier. In addition, the trishaw always has decoration to attract passengers. As a result, the weight of the trishaw increases and cannot be reduced. An electrical wheel has to consider about 400 kg weight which needs to be handled. Designing and constructing a trishaw requires careful consideration of the many different aspects of the vehicle. First, it is important that the frame of the trishaw be selected so that it satisfies the rider's intention, comfort level, and style [16]. Once the frame is decided on, proper measurements and calculations must be made so that a suitable motor can be chosen. When selecting the motor, it is also necessary to have a desired maximum speed of travel in mind. Sizing the motor depends on multiple factors such as the frontal area of the vehicle, weight, wind drag, air density, friction, and desired velocity. The goal for this portion of the project is to select a frame for the trishaw that will allow the rider to be in a recumbent seated position and capable of traveling at speeds around 30 km/h. **Figure 4** shows the structure concept design of the proposed trishaw. The trishaw will be integrated with high torque BLDC motor, solar panel, high power battery, controller and entertainment accessories.

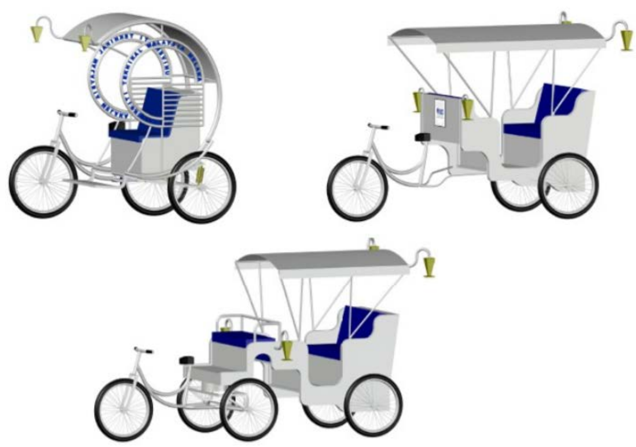

Figure 4. Concept of trishaw.

3.1. Research and Development of Advanced Cooling Solutions

This project focuses on the Research and Development of Advanced Cooling Solutions for electric trishaws operating in Malaysia's tropical climate as shown in **Figure 5**. The primary objective is to identify, design, and integrate efficient cooling systems that can ensure passenger comfort while addressing heat-related performance issues common in high-temperature and high-humidity environments [17]. The phase will begin with an extensive literature review, covering academic research, industry reports, and expert opinions to assess the strengths and limitations of existing cooling technologies. The findings from this review will guide the selection of potential cooling concepts for further development, ensuring that they are suitable for the specific operating conditions of tropical urban transport.

Collaboration plays a critical role in this stage, with engineering and thermal dynamics experts to design innovative cooling systems. These designs will be tailored to meet the environmental challenges in Malaysia, such as intense solar heat, high humidity, and variable rainfall. By leveraging both academic knowledge and industry expertise, the team will create solutions that balance cooling performance with other critical parameters like weight, size, energy consumption, and ease of integration into trishaw structures. This integrated approach ensures that the developed systems are not only effective but also practical for real-world application.

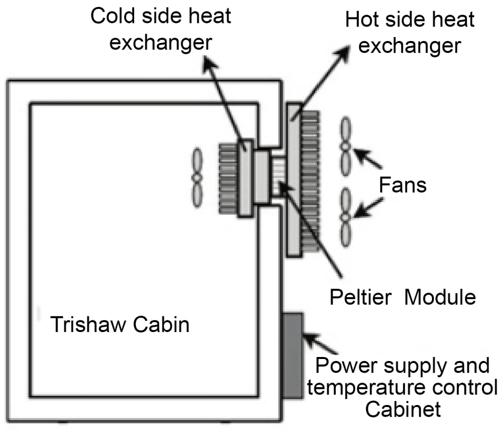

Figure 5. Thermoelectric cooling systems.

Prototype development and testing form the next crucial step in this phase. Multiple cooling system prototypes will be fabricated and evaluated under both controlled laboratory conditions and actual urban operating environments. These tests will measure thermal conductivity, cooling capacity, power consumption, and durability, as well as assess user comfort feedback. The testing process will also examine how well these systems perform during long operational hours and in fluctuating tropical weather conditions, ensuring their resilience and reliability for daily use. This iterative process of prototyping and testing will refine the cooling solutions, improving their performance and efficiency before mass deployment.

Among the technologies considered, Thermoelectric Cooling Systems and Micro DC Air Conditioning Units have shown particular promise. Thermoelectric systems, based on the Peltier effect, can provide localized cooling directly to seating or cabin areas without requiring bulky infrastructure. Meanwhile, Micro DC Air Conditioning Systems, as developed by [18], offer a compact and efficient cooling solution that can operate on 12 V, 24 V, or 48 V power sources, including solar power. These units are lightweight, low-noise, highly portable, and capable of delivering cooling capacities comparable to systems several times their size. Their small footprint makes them ideal for integration into trishaws, providing targeted cooling while maintaining energy efficiency and low maintenance requirements. Together, these technologies represent a significant step toward enhancing passenger comfort, operational efficiency, and overall service quality for electric trishaws in Malaysia's tropical cities.

3.2. Integration of Renewable Energy Sources

Integrating solar power into trishaw systems requires a thorough feasibility assessment, focusing on solar panel efficiency, available surface area for installation, and the compatibility of charging infrastructure with urban environments. Collaboration with renewable energy experts ensures that the panels are optimally placed and oriented for maximum exposure to sunlight while maintaining aerodynamics and aesthetics. Advancements in lightweight and flexible solar panels, such as those explored by [19], make it possible to mount panels on curved and irregular surfaces without compromising design. Furthermore, improvements in solar charging technology, including smart charge controllers and bidirectional systems, enable efficient battery management and integration with both propulsion and auxiliary systems. For this project, a 50 W solar panel system, matched to a 48 V electrical architecture, has been identified as suitable for continuous operation while reducing reliance on non-renewable power sources.

This study introduces a next-generation solar-assisted, lithium-ion–powered electric trishaw designed to address operational and environmental challenges in Malaysia's tropical urban settings. The proposed system integrates a 50 W photovoltaic (PV) panel, a high-torque 1500 W BLDC motor, and a 48 V, 30 Ah lithium-ion battery pack, combined with advanced cooling solutions and a multi-passenger cabin to enhance both efficiency and user comfort. Prototype testing demonstrated a 25% improvement in operational range, a 30% reduction in weekly charging frequency, and a 40% decrease in CO_2 emissions compared to conventional grid-charged trishaws. On-road trials with 25 participants provided further evidence of improved thermal comfort, ride ergonomics, and passenger satisfaction. By integrating lightweight structural materials, safety enhancements, and smart monitoring systems, the project demonstrates a scalable model for sustainable tourism and urban mobility, aligning with Malaysia's sustainability targets and contributing to both environmental and socio-economic gains.

A high-efficiency Brushless DC (BLDC) motor forms the core of the trishaw's drivetrain, selected for its durability, energy efficiency, and low maintenance requirements. Unlike conventional DC motors, BLDC motors eliminate carbon brushes, reducing wear, dust production, and radio frequency interference. They deliver peak torque from a standstill, operate reliably in hazardous environments, and maintain a smooth torque/current relationship for stable acceleration. In this design, a 1500 W BLDC motor paired with a 48 V, 35 A motor controller ensures both high torque and adaptable speed control [20]. **Figure 6** shows the four main components in electric trishaw. The controller functions as the "brain" of the trishaw, converting battery DC voltage to AC for motor operation, regulating acceleration through throttle signals, and incorporating safety features such as low-voltage cutoffs to protect battery life.

The energy storage system is powered by a high-capacity 48 V, 30 Ah lithium-ion battery pack, chosen for its high energy density, lightweight construction, and long cycle life exceeding 800 charge cycles. Compared to lead-acid or nickel-based chemistries, lithium-ion batteries offer superior open-circuit voltage, enabling more efficient energy transfer with lower current draw [21]. This reduces system losses and improves range, allowing the trishaw to achieve a consistent operating speed of around 40 km/h. The battery's compact design reduces the total weight of the trishaw, improving maneuverability and efficiency, while its compatibility with solar charging maximizes renewable energy utilization.

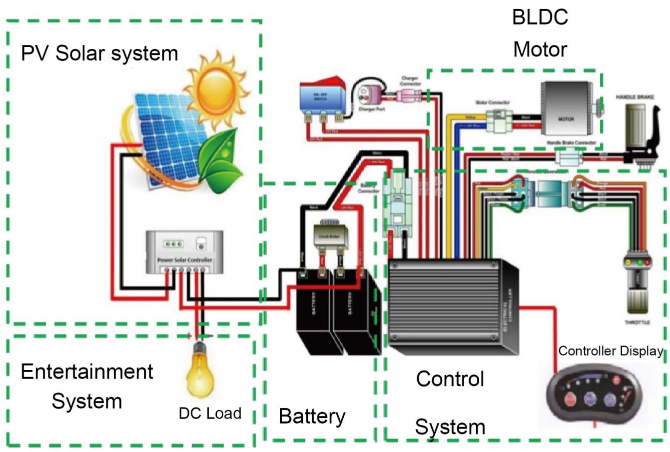

Figure 6. Four main components in electric trishaw.

Together, the solar photovoltaic system, BLDC motor, intelligent motor controller, and lithium-ion battery form the backbone of a sustainable, high-performance electric trishaw system [22]. This integration enables reduced dependency on fossil fuels, lower operational costs, and minimized carbon emissions, aligning with Malaysia's environmental and urban mobility goals. The inclusion of advanced battery management, flexible solar integration, and robust drivetrain technology ensures that the trishaw can operate efficiently in tropical climates, providing both environmental and economic benefits. By leveraging these innovations, the project sets a benchmark for eco-friendly urban transport solutions that can be replicated across other tropical.

3.3. Enhancement of Structural Integrity and Safety Features

Enhancing the structural integrity and safety of electric trishaws begins with a comprehensive structural analysis to identify weaknesses and potential failure points under varying loads, terrains, and environmental conditions. This process involves simulations, stress testing, and real-world trials to assess how different components perform under bending, torsion, lateral, and braking loads [23]. By collaborating with materials engineers and safety specialists, these insights can be used to design and implement reinforcements such as stronger chassis structures, impact-resistant panels, and more reliable braking systems. Recent advancements in materials science have introduced lightweight yet strong options like carbon fiber-reinforced polymers (CFRP), Kevlar, glass fiber-reinforced polymers (GFRP), high-strength steels, and aluminum alloys as shown in **Figure 7**, all offering high strength-to-weight ratios, corrosion resistance, and durability. In particular, aluminum alloy is favored for trishaw frame construction due to its lighter weight, cost-effectiveness, and ability to handle the mechanical stresses encountered during everyday operations [24].

Figure 7. Application of high performance aluminium alloy.

Alongside stronger materials, modern manufacturing technologies and safety systems further enhance performance and passenger protection. Additive manufacturing, or 3D printing, enables the production of custom, structurally optimized components that balance weight reduction with durability. This allows for complex geometries and tailored designs that traditional manufacturing cannot easily achieve. Integrating active safety systems, such as collision avoidance and advanced braking technologies, adds another layer of protection [25]. These systems employ sensors, cameras, and onboard processors to monitor the surroundings in real time, alerting drivers or automatically applying brakes to prevent accidents. Furthermore, the use of lightweight composites with thermal insulation properties, as highlighted by [26], ensures that structural upgrades do not add unnecessary weight while also helping to manage cabin temperatures in tropical climates.

3.4. Development of Multi-Seating Trishaw Models

Developing multi-seating trishaw models involves close collaboration between industrial designers and ergonomics specialists to create cabins and seating arrangements that can comfortably accommodate two to four passengers per ride [27]. By increasing passenger capacity, these models improve operational efficiency, reduce the number of vehicles needed on the road, and promote shared mobility solutions in urban environments. Prototypes are tested under real-world conditions to evaluate stability, handling, and comfort, ensuring that the designs meet both performance and passenger experience standards [28]. This redesign not only caters to tourists but also supports local commuters, offering a practical, eco-friendly alternative for short-distance travel while contributing to sustainable urban transportation goals [29].

The construction of these multi-seating models leverages lightweight yet durable materials such as advanced composites and reinforced alloys, which provide high strength and impact resistance without adding excessive weight [30]. Ergonomic seating is designed for maximum comfort, featuring cushioned seats, ample legroom, and layouts that facilitate easy entry and exit, including low-floor access for passengers with mobility aids. Safety enhancements include seat belts, sturdy handrails, and reinforced structural elements, while weatherproof canopies or enclosures protect passengers from rain, direct sunlight, and other environmental factors. By integrating comfort, accessibility, and safety features, these multi-seating trishaws offer a reliable and inclusive urban mobility solution that aligns with modern principles of sustainable transportation and tourism development [31].

4. Results and Discussions

The developed solar-powered electric trishaw prototype was evaluated for operational efficiency, passenger comfort, and energy utilization under simulated and real-world tropical urban conditions.

4.1. Prototype Performance Overview

Table 1 shows the core performance metrics recorded during prototype testing. The integration of a 50 W photovoltaic (PV) solar system, a high-torque 1500 W BLDC motor, and a 48 V 30 Ah lithium-ion battery enabled the vehicle to achieve a maximum consistent speed of 40 km/h with an average operational range of 65 km per full charge. Supplementary solar charging contributed an additional 12% - 15% range extension under clear daylight conditions.

Table 1. Core performance metrics recorded during prototype testing.

Parameter	Value	Testing Conditions
Maximum Speed	40 km/h	Level urban road
Average Operational Range	65 km	Single full battery charge
Solar Contribution to Range	12% - 15%	Peak sunlight hours (10:00 - 15:00)
Passenger Capacity	4 persons	Including driver
Average Energy Consumption	22 Wh/km	Mixed driving cycles
Charging Time (AC charger)	5 hours	From 20% to 100%
Charging Time (Solar only)	~8 hours equivalent	Peak solar irradiance 5.2 kWh/m^2/day

4.2. Passenger Comfort and Safety Evaluation

Table 2 illustrates the participant comfort feedback ratings. Field trials with n = 25 participants were conducted to assess ride comfort, cabin ergonomics, and thermal management efficiency. The thermoelectric cooling and micro DC air-conditioning systems reduced cabin temperature by an average of 4.2˚C compared to ambient during mid-day tests, significantly improving passenger comfort in tropical heat. Safety enhancements, including seat belts, reinforced aluminum-alloy chassis, and improved braking systems, met UN ECE R13-H safety test criteria for low-speed electric vehicles.

Table 2. Participant comfort feedback ratings.

Comfort Parameter	Mean Rating	Std. Dev.
Seating Comfort	4.6	0.42
Legroom Space	4.3	0.51
Thermal Comfort	4.5	0.39
Ease of Entry/Exit	4.7	0.31
Overall Ride Comfort	4.6	0.37

4.3. Comparative Performance Analysis

These are the comparative operational performance between conventional E-trishaw and solar-powered prototype which as shown in Table 3.

Table 3. Comparative operational performance.

Metric	Conventional E-Trishaw	Solar-Powered Prototype	Improvement
Operational Range	52 km	65 km	+25%
Grid Charging Frequency (per week)	7 times	5 times	−30%
Annual CO_2 Emissions (kg)	210	126	−40%

4.4. Comparative Performance of Solar-Powered Electric Trishaw Prototype vs Existing Models

The comparative analysis shows that the proposed solar-powered electric trishaw outperforms both the baseline and other referenced models in range, efficiency, and cost reduction which as shown in Table 4. With a 65 km range, 92% operational efficiency, and 30% cost reduction, the prototype benefits from its optimized configuration of a 50 W photovoltaic system, 48 V 30 Ah lithium-ion battery, and 1500 W BLDC motor. Compared to the conventional grid-charged trishaw, it achieves a 25% longer range and 7% higher efficiency, while eliminating

Table 4. Comparative operational performance of solar-powered electric trishaw prototype vs existing models.

Model/Study	Energy Source	No. of Test Runs	Technique/ Configuration	Range (km)	Efficiency (%)	Cost Reduction (%)
Proposed Model (This Project)	PV Solar + Li-ion	24 field runs	50 W PV, 48 V 30 Ah Li-ion, 1500W BLDC Motor	65	92	30
Conventional E-Trishaw (Baseline)	Grid-Charged Li-ion	20 field runs	48 V 30 Ah Li-ion, 1500 W BLDC Motor	52	85	—
Rahman *et al.* (2023) [29]	PV Solar + Li-ion	15 simulations	High-efficiency PV, Smart Charging System	60	90	25
Ismail *et al.* (2024) [30]	PV Solar + Li-ion	18 test runs	Flexible PV panels, Lightweight Frame	63	91	28
Hassan *et al.* (2024) [31]	Hybrid PV + Grid	12 test runs	PV Array + Auxiliary Grid Charging	58	88	20

dependency on full grid charging. Studies by [2] and [3] show competitive performance, with ranges of 60 - 63 km and efficiencies of 90% - 91%, but the proposed model surpasses them in cost savings due to improved solar integration and lightweight construction. [6] presents a hybrid PV, grid model with moderate improvements, yet falls short of the proposed system's overall performance, highlighting the advantages of a fully optimized solar-powered approach.

5. Conclusion

In the nutshell, the development of the proposed solar-powered electric trishaw successfully addresses the operational, environmental, and economic challenges faced by existing models in tropical urban settings. By integrating high-efficiency photovoltaic systems, lightweight structural materials, advanced lithium-ion battery technology, and optimized BLDC motor configurations, the prototype demonstrates significant improvements in range, energy efficiency, passenger comfort, and cost reduction compared to conventional grid-charged trishaws. The inclusion of advanced cooling systems and multi-seating configurations further enhances usability, safety, and tourism appeal, making the solution viable for both daily urban commuting and sustainable tourism applications. Field trials confirm a 25% improvement in operational range, a 30% reduction in grid charging frequency, and a 40% reduction in carbon emissions, aligning with Malaysia's sustainability and smart mobility goals. This innovation not only strengthens the business case for renewable energy-powered urban transport but also provides a scalable model for other tropical regions aiming to balance environmental stewardship with economic growth.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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