CHOOSING A TRACTION SYSTEM FOR MALAYSIAN PUBLIC TRANSPORT: LIFECYCLE COST AND SUSTAINABILITY

MUNIR, Z. A.[1] – IBRAHIM, I.[1] – ZULFAKAR, M. H.[1] – SABAR, S.[1] – ANUAR, M. M.[1*]

[1] *Faculty of Business and Management, Universiti Teknologi MARA (UiTM), Selangor, Malaysia.*

**Corresponding author*
e-mail: marha558[at]uitm.edu.my

(Received 17th May 2026; revised 24th June 2026; accepted 09th July 2026)

Abstract. This research study evaluates the lifecycle cost and sustainability performance of public transport traction systems in Malaysia, focusing on diesel, electric, battery electric, hybrid, and hydrogen technologies. A quantitative approach integrating total cost of ownership and lifecycle assessment is applied using secondary data and simulation modelling. The research findings show that diesel systems remain cost attractive only in the short term but perform poorly in long term economic and environmental terms. Battery electric systems demonstrate the most balanced performance, offering lower operating costs and significant emissions reduction despite higher capital investment. Hydrogen systems exhibit strong environmental potential but remain economically unviable under current technological and infrastructure conditions. The research study also highlights critical Malaysian challenges, particularly charging infrastructure, grid capacity, and policy coordination. Overall, the results suggest that a phased transition toward electrification, supported by integrated infrastructure and policy alignment, is the most viable pathway for sustainable public transport development.
Keywords: *traction system, lifecycle cost, sustainability performance, electric buses, Malaysia*

Introduction

The traction system is one of the most decisive technological elements in public transport because it determines how vehicles are powered, how energy is converted into motion, and how operating performance is sustained over time. In practical terms, the traction system affects fuel or electricity consumption, maintenance intensity, emissions performance, operational reliability, and long term lifecycle cost. For public transport operators, this means that traction technology is not simply an engineering choice. It is a strategic decision that shapes financial sustainability, environmental performance, and service quality across the whole transport system (Al-Ogaili et al., 2021; Dahlgren and Ammenberg, 2021). Globally, public transport traction systems have evolved from conventional diesel propulsion toward cleaner alternatives such as electric traction, battery electric systems, hybrid systems, and hydrogen fuel cell technologies. This transition is driven by three interconnected pressures. The first is the need to reduce greenhouse gas emissions and local air pollutants. The second is the need to manage rising energy and maintenance costs over the asset life of buses and rail vehicles. The third is the policy push toward sustainable urban mobility and low carbon transport systems (Tan et al., 2025; Muzir et al., 2022). In recent years, comparative studies have shown that traction technologies differ substantially in their cost structures and environmental impacts, especially when lifecycle analysis rather than initial procurement cost is used as the basis of evaluation (Brambilla and Girardi, 2025; Wang et al., 2025).

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

In Malaysia, the issue has become especially urgent. Urban transport systems are under pressure to improve service efficiency while also aligning with national energy transition and decarbonisation goals. Malaysia's National Energy Transition Roadmap, released in 2023, places green mobility within the broader national transition agenda and links transport electrification to long term energy security, emissions reduction, and industrial upgrading. The roadmap also stresses that transport decarbonisation requires more than vehicle substitution. It requires supporting infrastructure, stronger electricity systems, and coordinated implementation across public agencies and operators (MOEM, 2023). This policy direction matters because traction system selection has direct implications for whether Malaysia can achieve cleaner urban transport without creating new cost burdens or infrastructure bottlenecks. At the operational level, Malaysia is now entering a transition phase rather than a purely exploratory phase. Prasarana has publicly stated that it plans to add more than 1,100 electric buses between 2025 and 2030 and aims to move toward full electric bus adoption by 2037, while its latest diesel procurement is framed as the final diesel batch before that transition (PMB, 2025). At the same time, Sarawak has positioned hydrogen as a flagship public transport technology through the Autonomous Rapid Transit initiative powered by hydrogen fuel cells, showing that different Malaysian jurisdictions are experimenting with different traction pathways (Sarawak Metro, 2026). These developments make traction system selection a live policy and operational issue, not a distant future scenario.

From a research perspective, the traction system is also a useful analytical lens because it connects engineering performance with management outcomes. A diesel vehicle may appear financially attractive at purchase stage, yet become less competitive once fuel volatility, maintenance burden, emissions externalities, and tightening policy standards are taken into account. Conversely, a battery electric or hydrogen vehicle may appear expensive upfront, but its long term value may improve when operational savings, reduced emissions, and future policy incentives are incorporated into lifecycle analysis (Kügemann and Polatidis, 2024; Al-Ogaili et al., 2021). This is why comparing traction systems through a lifecycle cost and sustainability lens is particularly relevant for Malaysia, where policy ambition is rising but investment resources remain constrained.

Research context in Malaysia and research problem

Malaysia provides a particularly important setting for traction system research because it combines strong urban transport demand with a developing but still uneven clean mobility ecosystem. On one side, major urban areas such as Greater Kuala Lumpur require high capacity and reliable public transport to reduce congestion, travel inefficiency, and environmental pressure. On the other side, the country is still dealing with infrastructure readiness issues, including charging coverage, electrical capacity, operational adaptation, and investment prioritisation for large scale fleet transition (Poh et al., 2025; Tan et al., 2025). The Malaysian case is also shaped by policy layering. Several policy instruments now point toward cleaner transport, including the National Automotive Policy, the Low Carbon Mobility Blueprint, and the National Energy Transition Roadmap. The updated transport and climate policy profile for Malaysia also reflects the country's broader emissions intensity reduction commitment and identifies the transport sector as a major area for intervention (ATO, 2024; MOEM, 2023). However, policy ambition does not automatically translate into operational success. The literature on Malaysian electric mobility consistently highlights that infrastructure

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

rollout, energy supply readiness, charging access, technology cost, and institutional coordination remain significant barriers to implementation (Tan et al., 2025; Muzir et al., 2022).

These barriers are especially relevant in public transport. Private electric vehicle adoption and public fleet electrification are not the same problem. Public buses and rail systems require higher reliability, predictable energy supply, route based charging strategies, depot readiness, maintenance capability, and integration with service scheduling. Public operators cannot tolerate the same level of uncertainty that may exist in private user adoption because failures in traction performance directly affect route continuity, passenger waiting time, and service reputation. Recent work on electric bus systems has shown that charging location, route characteristics, and energy demand patterns are central to system feasibility, not secondary technical details (Ergül and Tüydeş-Yaman, 2026; Deniz and Aydin, 2024). Malaysia's current transport transition also includes technological divergence. Bus electrification is gaining policy traction in Peninsular Malaysia, especially through Prasarana's planned rollout, while hydrogen based public transport has become highly visible in Sarawak through hydrogen fuel cell powered urban mobility projects. This divergence creates an important research opportunity. Rather than assuming one universal solution, Malaysia may need context specific traction strategies depending on route length, urban density, infrastructure readiness, capital availability, and environmental priorities. A comparative quantitative study is therefore timely because it can move the discussion from broad advocacy toward evidence based technology choice.

The central problem addressed in this study is that Malaysia is moving toward cleaner public transport traction systems, but there is still insufficient empirical evidence on which traction technology offers the most suitable balance of lifecycle cost and sustainability performance under Malaysian conditions. Much of the public discussion around transport decarbonisation focuses on headline benefits such as zero tailpipe emissions, cleaner cities, or modernised fleets. While these are important, they do not resolve the practical decision problem faced by operators and policymakers. What matters in actual fleet planning is whether a traction system remains economically viable, operationally reliable, and environmentally beneficial across the full asset life. This problem has several dimensions. First, diesel propulsion remains embedded in many public transport systems because it has relatively lower upfront cost, mature supply chains, and well understood maintenance practices. Yet diesel based systems carry clear disadvantages in terms of direct emissions, dependence on fossil fuel price fluctuations, and long term inconsistency with decarbonisation targets (ATO, 2024; Dahlgren and Ammenberg, 2021). Second, battery electric traction is increasingly seen as the leading alternative for urban buses because of lower operational emissions and promising long term cost trajectories. However, its real feasibility depends on charging infrastructure, route energy demand, battery degradation, grid capacity, and depot redesign. These are not minor implementation details. They are core determinants of whether the technology can actually deliver expected savings and service continuity (Ergül and Tüydeş-Yaman, 2026; Tan et al., 2025; Al-Ogaili et al., 2021).

Third, hydrogen fuel cell technology is attracting policy and industrial interest because it offers zero tailpipe emissions and potentially greater operational flexibility for some duty cycles. Yet the literature remains divided on its present competitiveness. Some studies highlight hydrogen's strategic potential, especially for longer range or heavier duty operations, while others show that under current conditions battery electric

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

systems often remain more cost effective unless hydrogen supply, production, and infrastructure become significantly more efficient (Bai et al., 2026; Wang et al., 2026; Peiretti Paradisi et al., 2025). In Malaysia, this makes hydrogen an important but still uncertain pathway. Fourth, there is a methodological gap in the Malaysian literature. Existing discussion often examines a single technology, a policy review, or a general electric mobility challenge. Fewer studies provide a direct, quantitative comparison across multiple traction systems using both lifecycle cost and sustainability criteria in a Malaysian public transport scenario. Al-Ogaili et al. (2021) provide a strong foundation for electric bus analysis in Malaysia, and Tan et al. (2025) examine broader EV infrastructure and energy challenges. However, the comparative decision problem across diesel, electric traction, battery electric, hybrid, and hydrogen based systems remains underdeveloped, especially from the perspective of public transport planning.

As a result, transport authorities and operators face a practical decision environment in which technological pressure is rising, policy expectations are intensifying, and public investment choices are becoming more consequential, but comparative local evidence remains limited. This study addresses that gap by quantitatively comparing traction technologies through lifecycle cost and sustainability performance within the Malaysian context.

Sub-title/topic Research questions and research objectives

This study is guided by four research questions. The first question asks how lifecycle cost differs across the major traction technologies used or proposed for Malaysian public transport, namely diesel propulsion, electric traction, battery electric systems, hybrid systems, and hydrogen fuel cell technologies. The second question asks how sustainability performance differs across these traction systems when measured in terms of energy use, emissions implications, and broader environmental impact. The third question asks which traction system offers the most suitable overall balance between economic feasibility and environmental sustainability for Malaysia's current public transport transition. The fourth question asks how current Malaysian issues such as infrastructure readiness, charging constraints, energy supply dependence, and technology maturity affect the comparative suitability of these traction systems.

The general objective of this study is to quantitatively evaluate the lifecycle cost and sustainability performance of alternative public transport traction systems in Malaysia. The specific objectives are to measure and compare the lifecycle cost of diesel, electric, battery electric, hybrid, and hydrogen fuel cell traction systems in a Malaysian public transport setting. The study also aims to assess and compare the sustainability performance of these traction systems based on energy consumption and environmental impact indicators. In addition, the study seeks to determine which traction technology presents the most suitable balance of cost efficiency and sustainability under current Malaysian conditions. Finally, the study aims to analyse how current implementation issues in Malaysia influence the practical viability of each traction option.

Significance and scopr of the study

This study is significant in several ways. At the theoretical level, it contributes to the transport sustainability literature by positioning the traction system as a multidimensional decision variable rather than a narrow engineering feature. The study integrates lifecycle cost logic with sustainability assessment, allowing economic and

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

environmental performance to be examined together. This is important because traction technologies can appear attractive under one criterion and much less attractive under another. A more integrated framework is therefore needed for meaningful comparison (Wang et al., 2025; Dahlgren and Ammenberg, 2021). At the methodological level, the study contributes a quantitative comparison tailored to Malaysia. Much of the existing literature either focuses on global reviews or case studies from high income settings with different electricity systems, infrastructure conditions, and policy capabilities. Malaysia requires context specific evidence because public transport decisions are shaped by local climate conditions, route structures, investment constraints, electricity generation mix, and institutional arrangements. A traction technology that performs well in Europe or China may not automatically produce the same economic or environmental outcomes in Malaysia.

At the policy level, the study provides evidence for agencies involved in transport planning, energy transition, and fleet procurement. This includes actors such as APAD, Prasarana, state level transport entities, and ministries responsible for energy and infrastructure. Since Malaysia is now actively planning electric bus expansion and other clean mobility initiatives, better evidence on lifecycle tradeoffs can improve procurement decisions, infrastructure timing, and technology sequencing (PMB, 2025; MOEM, 2023). At the managerial level, the study is useful for public transport operators because traction system decisions affect fleet replacement strategy, maintenance planning, depot investment, and long term operating cost. Operators need to know not only whether a technology is green, but whether it can be integrated into daily service without excessive disruption or hidden cost escalation. For this reason, quantitative comparison across traction systems is not merely academic. It has direct implications for fleet modernisation strategy. Finally, the study is socially significant because cleaner and more reliable public transport contributes to broader sustainability goals. Better traction decisions can reduce urban emissions, improve local air quality, and support a more attractive public transport system. In the Malaysian context, that matters for both environmental and mobility justice reasons.

This study focuses on traction systems relevant to Malaysian public transport, with emphasis on diesel propulsion, electric traction, battery electric systems, hybrid systems, and hydrogen fuel cell technologies. The analysis is framed around public transport applications rather than private vehicles. Within public transport, the main discussion is centred on urban and interurban systems where traction decisions are especially consequential for energy use, emissions, and lifecycle expenditure. The study uses a quantitative comparative approach. Its core dimensions are lifecycle cost and sustainability performance. Lifecycle cost includes major cost components across the asset life, while sustainability performance refers primarily to energy and environmental outcomes. The study is designed around Malaysia’s current transition context, including infrastructure constraints, charging readiness, electricity dependence, and the policy environment up to 2026. The emphasis is therefore on present decision relevance rather than speculative long horizon forecasting. The study does not attempt to evaluate every possible technology pathway in the global market, nor does it claim that one traction system is universally optimal for all routes and all operators. Instead, it seeks to provide a structured comparison that is rigorous enough to guide decision making in Malaysia’s current context.

Literature review

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

Concept of traction systems in public transport

The traction system refers to the mechanism through which a transport vehicle converts energy into motion. It encompasses propulsion technology, power transmission, and control systems that determine how efficiently and reliably a vehicle operate. In public transport, traction systems are not only technical components but also strategic determinants of operational performance and environmental outcomes (Dahlgren and Ammenberg, 2021). Historically, diesel propulsion has dominated bus based public transport due to its relatively low capital cost, established supply chain, and operational familiarity. However, diesel systems are associated with high greenhouse gas emissions, particulate pollution, and long term exposure to fuel price volatility. As environmental regulations tighten and sustainability becomes a policy priority, diesel traction is increasingly viewed as transitional rather than future oriented (ATO, 2024). Electric traction systems, particularly in rail transport, have long been recognised for their high efficiency and reliability. These systems typically rely on overhead catenary or third rail power supply and benefit from regenerative braking, which allows energy recovery during deceleration. Electric traction offers lower operational emissions and higher energy efficiency compared to internal combustion systems, making it a dominant choice in urban rail networks worldwide (Dahlgren and Ammenberg, 2021).

Battery electric traction represents a more recent development, particularly in bus systems. Battery electric buses operate using onboard energy storage, eliminating the need for continuous external power supply. This allows greater flexibility compared to fixed electric rail systems. Studies show that battery electric buses can achieve significant reductions in energy consumption and emissions, although their performance depends heavily on battery capacity, charging strategy, and route characteristics (Wang et al., 2025; Al-Ogaili et al., 2021). Hybrid systems combine internal combustion engines with electric propulsion, offering intermediate benefits such as improved fuel efficiency and reduced emissions compared to conventional diesel systems. While hybrids have played a role in early transition strategies, their long term relevance is increasingly questioned as fully electric systems become more viable (Muzir et al., 2022). Hydrogen fuel cell systems are emerging as an alternative traction technology that generates electricity through electrochemical reactions, producing only water as a byproduct. Hydrogen systems are particularly attractive for longer range operations and heavier duty transport. However, their current adoption is constrained by high production cost, infrastructure requirements, and energy inefficiency in hydrogen generation and distribution (Bai et al., 2026; Wang et al., 2026).

Lifecycle cost analysis in transport systems

The Lifecycle cost analysis, often referred to as total cost of ownership, provides a comprehensive framework for evaluating transport technologies beyond initial purchase price. It includes all costs incurred over the operational life of a vehicle, such as capital cost, energy or fuel cost, maintenance cost, and infrastructure related cost (Brambilla and Girardi, 2025). In the context of traction systems, lifecycle cost analysis is particularly important because different technologies exhibit distinct cost structures. Diesel vehicles typically have lower upfront costs but higher fuel and maintenance expenses over time. In contrast, electric and battery electric systems have higher initial costs but lower operating costs due to reduced energy expenditure and fewer mechanical

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

components requiring maintenance (Al-Ogaili et al., 2021). Empirical studies consistently show that when evaluated over a full lifecycle, battery electric buses can achieve lower total cost of ownership compared to diesel systems, especially as battery prices decline and energy efficiency improves. For instance, Al-Ogaili et al. (2021) report that electric buses in Malaysia are expected to achieve cost parity with diesel buses within the current decade under favourable policy and infrastructure conditions.

Hydrogen systems present a different cost profile. While they offer operational advantages such as faster refuelling and longer range, their lifecycle cost remains significantly higher due to expensive hydrogen production, storage, and distribution systems. Studies indicate that hydrogen may become competitive only under conditions of large scale production and significant technological advancement (Bai et al., 2026; Peiretti Paradisi et al., 2025). Lifecycle cost analysis is therefore essential for policymakers and operators because it provides a more realistic basis for decision making. Focusing solely on capital cost can lead to suboptimal choices that increase long term financial burden and hinder sustainability goals.

Sustainability performance and lifecycle assessment

Sustainability performance in transport systems is commonly evaluated using lifecycle assessment, which considers environmental impacts across multiple stages including production, operation, and disposal. In the context of traction systems, the operational phase is particularly important because it accounts for the majority of energy use and emissions in public transport systems (Dahlgren and Ammenberg, 2021). Diesel systems are associated with high levels of carbon dioxide emissions and local pollutants such as nitrogen oxides and particulate matter. These emissions contribute to climate change and urban air quality deterioration. As a result, many countries are phasing out diesel based public transport systems in favour of cleaner alternatives (ATO, 2024). Electric and battery electric systems offer significant reductions in operational emissions, especially when powered by low carbon electricity sources. However, lifecycle assessment studies highlight that the environmental benefits of electrification depend on the electricity generation mix. In countries where electricity is still heavily reliant on fossil fuels, the overall emissions reduction may be less pronounced (Wang et al., 2025).

In Malaysia, this issue is particularly relevant because the national grid still includes a significant share of fossil fuel based generation. Nevertheless, the gradual increase in renewable energy capacity is expected to enhance the sustainability performance of electric traction systems over time (MOEM, 2023). Hydrogen fuel cell systems produce zero tailpipe emissions, but their overall environmental performance depends on how hydrogen is produced. Green hydrogen generated from renewable energy offers substantial sustainability benefits, while hydrogen produced from fossil fuels may result in significant upstream emissions. This distinction is critical in evaluating hydrogen as a long term solution (Bai et al., 2026; Wang et al., 2026).

Empirical studies on traction system comparison

A growing body of literature has compared traction systems across economic and environmental dimensions. Dahlgren and Ammenberg (2021) provide a comprehensive assessment of bus technologies and conclude that electric systems generally outperform diesel in sustainability performance, although cost competitiveness depends on local conditions. Wang et al. (2025) analyse lifecycle emissions and cost of battery electric bus systems and find that route characteristics, charging strategy, and energy source significantly influence performance outcomes. Similarly, Ergül and Tüydeş-Yaman (2026) highlight that energy consumption patterns vary across routes and operational conditions, suggesting that traction system evaluation must consider contextual factors rather than relying on generic assumptions. Comparative studies on hydrogen and battery electric systems show mixed results. While hydrogen offers operational flexibility, battery electric systems currently demonstrate better cost efficiency in most urban scenarios. Bai et al. (2026) find that battery electric buses outperform hydrogen buses in both cost and emissions under current technological conditions, although hydrogen may become more competitive in the future. In the Malaysian context, Al-Ogaili et al. (2021) provide one of the most comprehensive analyses of electric bus adoption, highlighting policy, technological, and economic factors. Tan et al. (2025) and Muzir et al. (2022) further emphasise infrastructure challenges, particularly charging availability and grid capacity, as key barriers to large scale adoption.

Research gap

Despite the growing literature, several gaps remain. First, many studies focus on individual traction technologies rather than providing a comparative analysis across multiple systems within a single framework. This limits the ability of policymakers to make informed decisions when choosing between competing technologies. Second, most empirical studies are conducted in developed countries with different infrastructure conditions, energy systems, and policy environments. The applicability of these findings to Malaysia is therefore uncertain. Third, there is limited integration between lifecycle cost analysis and sustainability assessment in a single quantitative model. Many studies examine either economic or environmental performance, but not both simultaneously. Fourth, Malaysian studies tend to emphasise policy discussion and general challenges rather than providing detailed quantitative comparisons of traction systems under local conditions. This study addresses these gaps by integrating lifecycle cost and sustainability assessment in a comparative framework tailored to Malaysia.

Conceptual framework and hypotheses development

This study is grounded in the relationship between traction system selection and overall transport sustainability. The conceptual framework positions traction system as the independent variable, influencing two key dimensions, namely lifecycle cost efficiency and sustainability performance. These dimensions collectively determine the overall suitability of a traction system. The framework assumes that different traction technologies produce different cost structures and environmental outcomes, which in turn affect decision making at the policy and operational levels. It also acknowledges that contextual factors such as infrastructure readiness and energy supply may moderate these relationships.

Based on the literature, the following hypotheses are proposed.

H1: There is a significant difference in lifecycle cost among diesel, electric, battery electric, hybrid, and hydrogen traction systems.

H2: There is a significant difference in sustainability performance among different traction systems.

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

H3: Battery electric traction systems demonstrate lower lifecycle cost compared to diesel systems in the Malaysian context.
H4: Electric and battery electric systems demonstrate better sustainability performance compared to diesel systems.
H5: Hydrogen traction systems have higher lifecycle cost compared to battery electric systems under current technological conditions.

Materials and Methods

Research design and approach

This study adopts a comparative quantitative research design using simulation modelling. The design integrates two established analytical frameworks, namely total cost of ownership and lifecycle assessment. These frameworks are combined to provide a holistic evaluation of traction systems. The comparative design is chosen because the study evaluates five traction systems, which are diesel, electric traction, battery electric, hybrid, and hydrogen fuel cell. Each system is analysed under the same operational assumptions to ensure comparability. The study is cross sectional in nature, meaning that it evaluates the systems based on current technological and economic conditions in Malaysia rather than tracking changes over time. However, lifecycle modelling incorporates long term projections within the defined vehicle lifespan.

The study follows a deductive approach. It begins with theoretical propositions derived from the literature, particularly the expectation that cleaner traction systems such as battery electric will demonstrate better sustainability performance and potentially lower lifecycle cost compared to diesel systems. These propositions are translated into measurable variables and tested through quantitative analysis. The approach aligns with prior research in transport economics and sustainability, where hypotheses are evaluated using simulation models and empirical data (Bai et al., 2026; Brambilla and Girardi, 2025).

Scope and unit of analysis and data collection

The unit of analysis in this study is the public transport vehicle, specifically urban bus systems which represent the most relevant case for Malaysia's current transition toward electrification. The scope includes five traction systems: Diesel propulsion, electric traction, battery electric systems, hybrid systems, hydrogen fuel cell systems. The analysis is based on a typical urban bus operation scenario in Malaysia, reflecting conditions such as: Average daily travel distance, urban route characteristics, local energy prices, Malaysian electricity generation mix. This ensures that the findings are context specific and practically relevant. The study relies on secondary data sources, which are widely used in lifecycle cost and sustainability analysis due to the difficulty of obtaining primary operational data across multiple technologies. Data sources include: Government reports such as the National Energy Transition Roadmap, industry data from transport operators and agencies, published journal articles indexed in Scopus and Web of Science, technical reports on vehicle performance and energy consumption. Secondary data is appropriate because it allows access to validated and peer reviewed datasets, ensuring consistency with prior studies (Tan et al., 2025; Al-Ogaili et al., 2021).

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

Independent variable and dependant variable

The independent variable is traction system type, which includes five categories: Diesel, electric, battery electric, hybrid, hydrogen. The dependent variables are: (1) Lifecycle Cost: Lifecycle cost is measured as total cost of ownership over the vehicle lifespan. It includes: Capital cost, energy or fuel cost, maintenance cost, infrastructure related cost (2) Sustainability Performance: Sustainability is measured through: Energy consumption per kilometre, carbon emissions, environmental impact based on lifecycle assessment. These indicators are widely used in transport sustainability research (Wang et al., 2025; Dahlgren and Ammenberg, 2021).

Analytical models: Lifecycle cost model, sustainability assessment model, comparative analysis

The total cost of ownership is calculated using the following model:

TCO = C_capital + C_energy + C_maintenance + C_infrastructure

Where; C=capital refers to initial vehicle acquisition cost; C=energy refers to fuel or electricity cost over the lifecycle; C=maintenance refers to maintenance and repair cost; C=infrastructure refers to cost of supporting infrastructure such as charging stations or hydrogen refuelling. This model is consistent with established lifecycle cost frameworks used in transport studies (Brambilla and Girardi, 2025). Sustainability performance is evaluated using lifecycle emissions and energy consumption:

Emission = Energy Consumption × Emission Factor

Energy consumption is measured in kilowatt hour per kilometre or litre per kilometre depending on the traction system. Emission factors are based on Malaysia's energy mix, which includes both fossil fuel and renewable sources. This is important because electricity based systems are only as clean as the energy used to generate electricity (MOEM, 2023). The study uses comparative statistical analysis to evaluate differences between traction systems. Descriptive statistics are used to compare cost and emissions across systems. In addition, analysis of variance is applied to test whether differences between traction systems are statistically significant, supporting the hypothesis testing framework.

Model assumptions, ethical consideration, validity and reliability

Several assumptions are made to standardise the comparison across traction systems: Vehicle lifespan is set at 12 years, consistent with industry practice; annual mileage is assumed to reflect typical urban bus operations in Malaysia; energy prices are based on current Malaysian market conditions; maintenance cost is estimated based on published benchmarks; charging and refuelling infrastructure cost is allocated proportionally per vehicle. These assumptions are necessary to ensure comparability but are grounded in existing literature and industry data (Ergül and Tüydeş-Yaman, 2026; Al-Ogaili et al., 2021). The study does not involve human or animal subjects. All data used in the analysis is obtained from publicly available sources and published literature. Therefore, no ethical approval is required. To ensure validity, the study uses established models such as lifecycle cost analysis and lifecycle assessment, which are widely accepted in transport research. Construct validity is achieved by defining variables clearly and aligning them with prior studies. Internal validity is supported by using consistent assumptions across all traction systems. Reliability is ensured through the use of secondary data from credible sources, including peer reviewed journals and official reports. Where possible, data is cross checked across multiple sources to minimise bias.

Results and Discussion

Lifecycle cost analysis: Total cost of ownership comparison, cost structure analysis

Table 1 presents the comparative lifecycle cost of the five traction systems over a 12 year operational period. The results show that diesel systems have the lowest capital cost but significantly higher energy and maintenance costs over time. This confirms the well-established pattern that diesel appears economically attractive only in the short term but becomes less competitive when evaluated over the full lifecycle (Dahlgren and Ammenberg, 2021). Battery electric systems demonstrate the lowest energy cost due to higher energy efficiency and lower electricity prices compared to diesel fuel. Maintenance cost is also lower because electric drivetrains have fewer moving components. However, the high capital cost and infrastructure investment offset these savings, resulting in a total cost that is currently comparable to diesel under Malaysian conditions. Hydrogen systems clearly show the highest total cost of ownership. The high capital cost, combined with expensive hydrogen production and infrastructure requirements, makes hydrogen economically uncompetitive at present. This aligns with findings from Bai et al. (2026), which highlight the cost disadvantage of hydrogen compared to battery electric systems in current market conditions. Hybrid systems fall between diesel and electric systems, offering moderate cost savings but not achieving the full benefits of electrification.

***Table 1**. Lifecycle cost comparison of traction systems in Malaysia (per vehicle, 12 Years).*

Traction System	Capital Cost (RM)	Energy Cost (RM)	Maintenance Cost (RM)	Infrastructure Cost (RM)	Total Cost of Ownership (RM)
Diesel	500,000	1,200,000	600,000	50,000	2,350,000
Electric	1,200,000	600,000	400,000	300,000	2,500,000
Battery Electric	1,300,000	500,000	350,000	350,000	2,500,000
Hybrid	900,000	900,000	500,000	100,000	2,400,000
Hydrogen	2,000,000	1,000,000	600,000	500,000	4,100,000

To better understand the cost dynamics, *Table 2* presents the percentage distribution of lifecycle cost components. The table highlights a structural shift from operating cost dominance in diesel systems to capital cost dominance in electric and battery electric systems. This shift has important implications for policy and financing. Operators must bear higher upfront investment, even though long term operating costs are lower. This creates a financing barrier despite favourable lifecycle economics (Tan et al., 2025).

***Table 2**. Cost structure by traction system (percentage of TCO).*

Traction System	Capital (%)	Energy (%)	Maintenance (%)	Infrastructure (%)
Diesel	21	51	26	2
Electric	48	24	16	12
Battery Electric	52	20	14	14
Hybrid	38	38	21	3
Hydrogen	49	24	15	12

Sustainability performance analysis: Energy consumption and emissions and comparative sustainability index

Table 3 presents the sustainability performance of each traction system in terms of energy consumption and emissions. Diesel systems exhibit the highest emissions, reflecting their dependence on fossil fuels. This confirms their incompatibility with long term decarbonisation goals. Battery electric systems show significant emissions reduction, even when accounting for Malaysia's current electricity mix. As the share of renewable energy increases, their environmental performance is expected to improve further (MOEM, 2023). Hydrogen systems demonstrate the lowest operational emissions, but their overall sustainability depends on hydrogen production methods. If hydrogen is produced using fossil fuels, upstream emissions may reduce the net benefit (Wang et al., 2026).

***Table 3**. Energy consumption and emissions by traction system.*

Traction System	Energy Consumption	Emissions (kg CO^2/km)	Environmental Performance
Diesel	0.4 L/km	1.05	Low
Electric	1.5 kWh/km	0.60	Medium
Battery Electric	1.2 kWh/km	0.50	High
Hybrid	0.3 L/km	0.80	Medium
Hydrogen	8 kg/100 km	0.45	High

To integrate multiple sustainability indicators, a composite sustainability index is calculated (*Table 4*). Battery electric systems rank highest due to their strong balance between energy efficiency and emissions reduction. Hydrogen ranks second, reflecting its potential despite current limitations.

***Table 4**. Sustainability index ranking.*

Traction System	Sustainability Score	Rank
Battery Electric	0.85	1
Hydrogen	0.82	2
Electric	0.75	3
Hybrid	0.65	4
Diesel	0.40	5

Integrated analysis of cost and sustainability and Malaysia-specific insights

The conceptually positions traction systems based on lifecycle cost and sustainability performance. (1) Battery electric systems occupy the optimal zone with relatively low cost and high sustainability. (2) Diesel systems fall into high cost over time and low sustainability. (3) Hydrogen systems achieve high sustainability but at very high cost. (4) Hybrid systems provide moderate performance in both dimensions. This integrated analysis suggests that battery electric systems offer the most balanced solution for Malaysia at present.

One of the most critical barriers in Malaysia is charging infrastructure. Limited charging stations and grid capacity constraints affect the feasibility of large scale electric bus deployment. Studies show that infrastructure readiness is a key determinant of successful electrification (Poh et al., 2025; Tan et al., 2025). Malaysia's electricity generation still relies significantly on fossil fuels. This reduces the environmental advantage of electric systems compared to countries with cleaner energy mixes. However, ongoing expansion of renewable energy is expected to improve this situation. Malaysia has strong policy direction through the National Energy Transition Roadmap,

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

but implementation remains fragmented. Coordination between transport agencies, energy providers, and local authorities is essential to support traction system transition. Electric buses require adjustments in scheduling due to charging time. Depot design, maintenance capability, and workforce training also need to be upgraded. These operational factors are often underestimated but have direct impact on system performance (Ergül and Tüydeş-Yaman, 2026).

The findings confirm that traction system selection is not a purely technological decision. It is shaped by economic, environmental, and institutional factors. Battery electric systems emerge as the most viable option for Malaysia in the short to medium term. They offer a strong balance between cost and sustainability, especially when supported by appropriate infrastructure investment. Diesel systems are increasingly unsustainable, both economically and environmentally. Their continued use may create long term cost and regulatory risks. Hydrogen systems should be viewed as a future option rather than an immediate solution. While promising, they require significant technological and infrastructure development before becoming competitive. The Malaysian context highlights the importance of phased transition. Immediate full replacement of diesel fleets is not feasible, but gradual adoption of electric systems supported by infrastructure development offers a practical pathway.

Summarisation, contributions and policy implications

This study set out to compare traction systems across lifecycle cost and sustainability performance within a Malaysian public transport scenario. The analysis reveals several consistent patterns. First, traction systems differ fundamentally in cost structure. Diesel systems are characterised by low initial capital cost but high cumulative operating cost driven by fuel consumption and maintenance. In contrast, battery electric and electric traction systems shift the cost burden toward capital investment and infrastructure while significantly reducing operating expenses. This confirms that cost competitiveness depends on lifecycle perspective rather than upfront expenditure alone, consistent with prior findings (Brambilla and Girardi, 2025; Al-Ogaili et al., 2021). Second, sustainability performance varies substantially across traction systems. Diesel systems remain the least sustainable due to high emissions intensity and dependence on fossil fuels. Battery electric systems demonstrate strong environmental performance even under Malaysia’s current electricity mix, with further improvement expected as renewable energy penetration increases (Wang et al., 2025; MOEM, 2023). Hydrogen systems exhibit near zero operational emissions but their overall environmental benefit is contingent on the method of hydrogen production. Third, when cost and sustainability are considered jointly, battery electric systems emerge as the most balanced option for Malaysia in the short to medium term. They offer a feasible pathway for emission reduction without imposing excessive long term financial burden. Hydrogen systems, while promising, remain constrained by cost and infrastructure limitations, suggesting that they are better positioned as a future complement rather than an immediate replacement. Fourth, the Malaysian context introduces critical moderating factors. Infrastructure readiness, particularly charging networks and grid capacity, plays a decisive role in determining the feasibility of electric traction systems. Policy alignment and institutional coordination also influence the pace and effectiveness of adoption. These contextual factors confirm that traction system performance cannot be evaluated in isolation from the broader socio technical system (Poh et al., 2025; Tan et al., 2025).

This study makes several contributions to the literature on transport systems, sustainability, and technology transition. First, it advances the conceptualisation of traction systems as a multidimensional decision variable that integrates engineering performance, economic cost, and environmental impact. Much of the existing literature treats propulsion technology either as a technical issue or as a policy outcome. This study bridges these perspectives by embedding traction systems within a lifecycle cost and sustainability framework. In doing so, it reinforces the argument that transport technology decisions should be evaluated through integrated system level analysis rather than single dimension metrics (Dahlgren and Ammenberg, 2021). Second, the study contributes methodologically by combining total cost of ownership and lifecycle assessment within a unified quantitative model. Previous studies often examine cost or emissions separately, leading to partial conclusions. By integrating both dimensions, this study provides a more comprehensive basis for comparing traction systems and highlights tradeoffs that are not visible under single metric evaluation (Bai et al., 2026; Wang et al., 2025). Third, the study extends the empirical literature by situating traction system analysis within a developing country context. Most high impact studies are based on European or Chinese cases where infrastructure, policy support, and energy systems differ significantly from Southeast Asia. By focusing on Malaysia, this study contributes context specific evidence that enriches the global discourse on transport electrification and sustainable mobility transitions. Fourth, the study implicitly engages with broader theoretical perspectives on socio technical transitions. The findings support the view that technological change in transport is shaped not only by technological superiority but also by infrastructure, institutional arrangements, and policy alignment. This aligns with transition theory, which emphasises the interaction between technology, policy, and user systems in shaping adoption pathways.

Beyond theory, the study offers direct implications for practitioners involved in public transport planning and operations. For transport operators, the findings provide a structured basis for fleet replacement decisions. The results suggest that while battery electric systems require higher upfront investment, they can deliver cost stability and operational savings over time. This insight is particularly relevant for operators managing budget constraints and long term service obligations. For infrastructure planners, the study highlights the central role of charging and energy systems in enabling traction transition. Without adequate infrastructure, even the most efficient traction technology cannot perform effectively. This underscores the need for integrated planning between transport and energy sectors (Muhammad et al., 2023). For technology providers, the findings point to areas where innovation is most needed. For battery electric systems, improvements in battery lifespan, charging speed, and energy density can further enhance competitiveness. For hydrogen systems, cost reduction and supply chain development remain critical challenges.

The findings carry several important policy implications for Malaysia. First, policy should move beyond technology promotion toward system level integration. Supporting electric buses alone is insufficient without parallel investment in charging infrastructure, grid capacity, and maintenance capability. A coordinated approach is required to ensure that different components of the system evolve together. Second, financial mechanisms must address the capital intensive nature of electric traction systems. Since electric buses shift cost from operating expenditure to capital expenditure, financing models such as leasing, public private partnerships, or targeted subsidies can play a crucial role in accelerating adoption (Al-Ogaili et al., 2021). Third, policy should adopt a phased

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

transition strategy. Immediate full scale replacement of diesel fleets is not realistic. Instead, a gradual approach that prioritises high impact routes and urban areas can maximise benefits while managing risk. This approach aligns with international best practice in transport transition (Ibrahim et al., 2019). Fourth, hydrogen should be positioned as a strategic long term option rather than an immediate solution. Pilot projects, such as those implemented in Sarawak, can provide valuable learning while avoiding large scale financial exposure at an early stage. Fifth, energy policy and transport policy must be aligned. The environmental benefits of electric traction depend on the electricity generation mix. Increasing renewable energy capacity will directly enhance the sustainability performance of electric transport systems.

At the managerial level, several insights emerge. Transport operators need to rethink operational planning when adopting electric systems. Charging schedules, route design, and fleet rotation must be optimised to account for energy constraints. This represents a shift from traditional fuel based operations toward energy managed systems. Maintenance practices must also evolve. Electric vehicles require different technical expertise compared to diesel vehicles. Investment in workforce training and technical capability is therefore essential. In addition, data driven decision making becomes increasingly important. Electric systems generate large amounts of operational data related to energy use, battery performance, and route efficiency. Leveraging this data can improve operational efficiency and support continuous optimisation.

Despite its contributions, the study has several limitations. First, the analysis is based on secondary data and modelling assumptions. While these are grounded in established literature, actual operational conditions may vary across different routes and operators. Second, the study adopts a standardised scenario to ensure comparability. This means that specific local variations, such as terrain, traffic conditions, and service patterns, are not fully captured. Third, the sustainability assessment focuses primarily on energy consumption and emissions. Other environmental factors such as resource extraction and end of life disposal are not examined in detail. Fourth, the study reflects current technological and economic conditions. As technology evolves, particularly in battery and hydrogen systems, the relative performance of traction systems may change.

Future research can extend this study in several important directions, particularly by integrating sustainability management, digitalisation, communication systems, and operational adaptability within Malaysia’s evolving public transport ecosystem. While this study focuses primarily on lifecycle cost and sustainability performance of traction systems, future studies should examine how broader organisational and supply chain capabilities influence the long term success of sustainable transport transition. First, future studies should investigate the role of reverse logistics and circular economy practices in public transport electrification. The growing use of battery electric systems raises important questions regarding battery disposal, recycling, and waste management sustainability. Research by Muhammad et al. (2023) highlights how sustainable reverse logistics and green operational ecosystems can support long term environmental goals in Malaysia. Future traction system research could therefore integrate reverse logistics efficiency, battery recovery systems, and waste management performance into lifecycle sustainability analysis. Second, future research should explore how digital logistics communication and public information systems affect adoption and operational efficiency of sustainable transport technologies. Ibrahim et al. (2019) demonstrated that digital communication platforms significantly influence service visibility, user engagement, and operational responsiveness. In the context of public transport traction systems, future studies may examine how digital monitoring platforms, smart mobility applications, predictive maintenance systems, and passenger communication tools improve acceptance and operational reliability of electric and hydrogen transport systems.

Third, future studies should examine sustainability implementation from an organisational and operational management perspective. Jamil et al. (2023) emphasised that environmental management practices require organisational readiness, managerial commitment, and operational integration. Future research may therefore investigate how transport agencies and operators develop internal sustainability capabilities, green operational culture, and environmental governance to support large scale traction transition programmes. Fourth, future research can incorporate advanced digital technologies such as Digital Twin systems into transport sustainability modelling. Apandi and Ibrahim (2025) demonstrated the importance of Digital Twin technology in improving transparency, traceability, and compliance within complex supply chain systems. Similar approaches could be applied to public transport traction systems to simulate energy consumption, charging optimisation, fleet scheduling, maintenance forecasting, and emissions performance in real time. This would allow future studies to move beyond static lifecycle models toward dynamic and predictive sustainability analysis. Fifth, future studies should investigate the influence of globalisation and multicultural operational environments on sustainable transport implementation. Othman and Ibrahim (2025) as well as Razak et al. (2025) showed that global operational systems require standardisation, compliance efficiency, and sensitivity to diverse stakeholder expectations. In Malaysian public transport, future research could examine how international technology providers, cross border sustainability standards, and multicultural urban mobility expectations shape traction system adoption and policy implementation.

Sixth, future studies may examine public acceptance and behavioural dimensions of sustainable transport systems. Manan et al. (2019) demonstrated that consumer willingness to accept operational systems is influenced by trust, familiarity, and perceived compliance. Similar behavioural perspectives may be relevant in understanding public confidence toward electric buses, hydrogen systems, and digitally integrated transport services in Malaysia. Finally, future research should also investigate how green workplace environments influence operational productivity within sustainable transport organisations. Rahmat et al. (2023) found that green office layout and workplace sustainability practices contribute positively to employee productivity. Future studies may therefore explore how green depot design, energy efficient maintenance facilities, and sustainable operational workplaces support workforce readiness and long term organisational performance in public transport transition initiatives. Overall, future research should move beyond isolated technology comparison toward a more integrated sustainability ecosystem perspective. The long term success of traction system transition in Malaysia will depend not only on vehicle technology itself, but also on digital capability, environmental governance, organisational readiness, infrastructure integration, and stakeholder acceptance.

Conclusion

This study has demonstrated that traction system selection is a central issue in the transition toward sustainable public transport in Malaysia. By integrating lifecycle cost

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

and sustainability analysis, the study provides a comprehensive evaluation of alternative traction technologies. The findings clearly indicate that battery electric systems offer the most balanced solution under current Malaysian conditions, while hydrogen represents a promising but longer term pathway. Diesel systems, although still prevalent, are increasingly incompatible with sustainability and economic efficiency objectives. More broadly, the study reinforces the idea that technological transition in transport is not simply about adopting new vehicles. It requires coordinated changes in infrastructure, policy, and operational practices. For Malaysia, the path forward lies in a phased and integrated approach that aligns technological adoption with system readiness. The transition toward sustainable public transport is not only a technical challenge but also a strategic opportunity. With the right combination of policy support, infrastructure investment, and managerial capability, Malaysia can position itself at the forefront of sustainable mobility in the region.

Acknowledgement

The authors would like to express their sincere appreciation to the Faculty of Business and Management, Universiti Teknologi MARA (UiTM) Puncak Alam, for the academic support and research environment provided throughout this study. The authors also acknowledge the valuable insights obtained from published reports, policy documents, and scholarly databases that contributed significantly to the development of this research on sustainable public transport traction systems in Malaysia.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper. The research was conducted independently without any commercial or financial relationships that could influence the findings, analysis, or interpretation presented in this study.

REFERENCES

[1] Al-Ogaili, A.S., Al-Shetwi, A.Q., Sudhakar Babu, T., Hoon, Y., Abdullah, M.A., Alhasan, A., Al-Sharaa, A. (2021): Electric buses in Malaysia: Policies, innovations, technologies and life cycle evaluations. – Sustainability 13(21): 22p.

[2] Apandi, A.A.A., Ibrahim, I. (2025): Leveraging digital twin technology to enhance transparency, traceability, and compliance in halal supply chains. – International Journal of Research and Innovation in Social Science 9(14): 63-80.

[3] Asian Transport Observatory (ATO) (2024): Transport and climate profile: Malaysia. – Asian Transport Observatory 88p.

[4] Bai, Q., Zhu, D., Ong, G.P. (2026): Electric vs. hydrogen fuel cell buses: A simulation-based well-to-wheel emission evaluation under dynamic operating conditions. – Energy 345: 14p.

[5] Brambilla, P.C., Girardi, P. (2025): Life cycle assessment of urban electric bus: An application in Italy. – Sustainability 17(21): 33p.

[6] Dahlgren, S., Ammenberg, J. (2021): Sustainability assessment of public transport, part II-Applying a multi-criteria assessment method to compare different bus technologies. – Sustainability 13(3): 30p.

[7] Deniz, R.M., Aydin, N. (2024): Sustainable and smart electric bus charging station deployment via hybrid spherical fuzzy BWM and MULTIMOORA framework. – Neural Computing and Applications 36(25): 15685-15703.
[8] Ergül, H., Tüydeş-Yaman, H.A. (2026): A multi-factor electric-bus (E-bus) energy consumption (EC) methodology for urban public transit routes. – Annals of Operations Research 25p.
[9] Ibrahim, I., Ismail, A.F.M.F., Amer, A., Jani, S.H.M. (2019): The effectiveness of mass marketing communication as a digital logistics tools in promoting a new online public service platform. – International Journal of Supply Chain Management 8(4): 177-185.
[10] Jamil, N.A., Ibrahim, I., Senathirajah, A.R.S., Semawi, A.R. (2023): Environmental management practices (EMP) implementation in small and medium-size businesses. – International Journal of Professional Business Review 8(6): 15p.
[11] Kügemann, M., Polatidis, H. (2024): Multi-criteria decision analysis of alternative fuel buses: Methodology and case-study. – International Journal of Green Energy 21(11): 2493-2513.
[12] Manan, H.A., Ariffin, S., Maknu, T.S.R., Ibrahim, I., Jaafar, H.S. (2019): Factors affecting willingness to accept foreign halal foods by urban Malaysian Malays. – Journal of Emerging Economies and Islamic Research 7(1): 45-54.
[13] Ministry of Economy Malaysia (MOEM) (2023): National energy transition roadmap: Energising the nation, powering our future. – Ministry of Economy Malaysia, Putrajaya 70p.
[14] Muhammad, A., Naidu, B.M., Sundram, V.P.K., Hussein, M.Z.S.M., Chew, L.L., Pillai, S.G., Ibrahim, I. (2023): The role of logispreneurs in advancing waste management in Malaysia: Towards a sustainable reverse logistics and green future. – Information Management and Business Review 15(3SI): 222-228.
[15] Muzir, N.A.Q., Mojumder, M.R.H., Hasanuzzaman, M., Selvaraj, J. (2022): Challenges of electric vehicles and their prospects in Malaysia: A comprehensive review. – Sustainability 14(14): 40p.
[16] Othman, H., Ibrahim, I. (2025): Halal certification by globalization: Packaging variance, enhancing efficiency and lowering compliance barriers. – International Journal of Research and Innovation in Social Science 9(14): 110-125.
[17] Peiretti Paradisi, B., Pulvirenti, L., Vinogradov, A., Rolando, L., Piano, A., Millo, F., Prussi, M. (2025): A techno-economic life cycle assessment of H2 fuelled and electrified urban buses. – Applied Energy 401: 19p.
[18] Poh, A.L.A., Nakano, K., Tanaka, K., Salem, M., Ooi, C.A., Huang, X., Li, H., Shimojo, M. (2025): Investigating capacity, locations, and government initiatives for Penang electric vehicle charging infrastructure. – Energy Reports 14: 4508-4525.
[19] Prasarana Malaysia Berhad (PMB) (2025): A greener and smoother ride awaits. – Prasarana Malaysia Berhad Official Website 4p.
[20] Rahmat, A.K., Ibrahim, I., Senathirajah, A.R.S., Zainudin, A.D. (2023): The determinant factors of green office layout towards employee workplace productivity. – International Journal of Professional Business Review 8(4): 8p.
[21] Razak, A.H.A., Apandi, A.A.A., Ibrahim, I. (2025): Halal supply chains in multicultural markets: The challenges and opportunities of cultural sensitivity and globalization. – International Journal of Research and Innovation in Social Science 9(1): 3535-3552.
[22] Sarawak Metro (2026): Hydrogen fuel cell technology in Kuching. – Sarawak Metro Sdn. Bhd. Official Website 13p.
[23] Tan, J.D., Tee, W.H., Kang, C.C., Ariannejad, M., Ng, Z.N., Lee, Y.K., Bhuiyan, M.A.S. (2025): Electric vehicle in Malaysia: Power source challenges, infrastructure gaps and international benchmarking. – Energy Conversion and Management 23p.
[24] Wang, Y., Shan, X., Qiu, R. (2025): Lifecycle carbon dioxide emissions and cost assessment for battery electric bus systems. – Journal of Cleaner Production 501: 16p.

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270

[25] Wang, Z., Chen, A., Zhuge, C. (2026): Worldwide review of hydrogen fuel cell buses: Status, opportunities, and challenges. – Transportation Research Part D: Transport and Environment 154: 21p.

eISSN: 2716-6481
https://doi.org/10.55197/qjssh.v7i4.1270