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Empowering Green Transportation: Strategies for Electric Vehicle Adoption and Charging Infrastructure in Malaysia

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ABSTRACT

An electric vehicle (EV) is a vehicle driven by an electric motor and a battery rather than a conventional internal combustion engine (ICE) that depends on petroleum or diesel fuel. The main objective of this paper is to provide a clear overview of the present EV market, particularly in Malaysia. There are several different types of EVs, such as hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEV), and fuel cell electric vehicles (FCEV). However, each of them has its strengths and weaknesses. This paper also discusses the technical specifications and general classifications of EVs. Malaysia follows MS IEC 61851 and SAE J1772 to outline the standards and procedures for conductive connection charging of electric vehicles. Mathematical modelling is often employed to forecast EV adoption among users. To enhance the EV adoption and alleviate transportation challenges, strategically placing Photovoltaic Electric Vehicle Charging Stations (PEVCS) in Malaysia is crucial. Lastly, this paper discusses the progress of EV developments in Malaysia and outlines the criteria required for the allocation of PEVCS.

1. Introduction

In recent years, global warming and other environmental issues have become a worldwide concern and require action to solve these issues. The growth of the electric vehicle (EV) industry is also increasing exponentially. Due to the superiorities of clean, environmentally green, and flexible operation, EVs have received more attention globally **Error! Reference source not found.**. Thus, the current scenarios of carbon emissions from the power and transportation sectors generate serious situations of a significant increase in air pollution **Error! Reference source not found.**. However, the rapid rise in the number of EVs which lead to the elimination of petroleum-based vehicles **Error!**

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Reference source not found.. It can be a solution to enhance the sustainability of growth, get better air quality, and cope with the effects of climate change **Error! Reference source not found.**. The EV has a lot of benefits which are environmentally friendly, more qualified, better security system, and noiseless **Error! Reference source not found.**.

Currently, oil prices are showing an upward trend. Hence, the electric vehicle (EV) is the best choice to shift from the internal combustion engine (ICE). Giménez-Gaydou *et al.,* **Error! Reference source not found.** mentioned that Battery Electric Vehicles (BEV) are most suitable, followed by Hybrid Electric Vehicles (HEV), Plug-in Hybrid Electric Vehicles (PHEV), and Fuel Cell Electric Vehicles (FCEV). Given concerns such as greenhouse gas (GHG) emissions, the scarceness of fossil fuel supplies, and the volatility of their prices, environmental protection has emerged as a foremost concern among several stakeholders, policymakers, and the scientific community **Error! Reference source not found.**. The development of EVs is increasing significantly due to the accessibility of charging stations (CSs), and it is essential to reduce range anxiety among EV drivers. The batteries in EVs need to be recharged after a specific driving range. As a result, creating a sustainable charging infrastructure is necessary for the widespread use of EVs.

The main contribution of this paper is to get a clear picture of the EV's current scenario, especially in Malaysia. The degree of adoption in Malaysia is still not promising, despite the surge in demand for EVs as an alternative form of green transportation on a global scale **Error! Reference source not found.**. Vodus Research **Error! Reference source not found.** stated that 38% of Malaysian survey respondents reported that the cost of buying an EV was expensive. Furthermore, from Berita Harian Online, Jim Lim Khai Xhiang, an RHB Investment Bank Analyst mentioned the EV prices are high due to the high battery cost, which accounts for about 30 to 40% of EV expenses and is predicted to continue rising by 2023 **Error! Reference source not found.**. Hence, it is seen that EV development is not rising significantly in Malaysia because of the high prices of EVs. This paper is organized as follows: Section 2 discusses the types of EVs as alternatives to an ICE vehicle. Section 3 is about the EV charging mode specification. Besides, Section 4 focuses on EV charging categories, and Section 5 mentioned the mathematical modelling of EV adoption. The discussion appears in Section 6. Finally, the authors conclude the paper in Section 7.

2. Types of Electric Vehicle

2.1 Hybrid Electric Vehicle (HEV)

According to Ajanovic **Error! Reference source not found.**, hybrid Electric Vehicles (HEV) use a hybrid of an internal combustion engine (ICE) and an electric motor. HEV has an ICE that utilizes gasoline and an EV to operate. Hence, the electric motor is limited to supplying power for the vehicle's initial acceleration and startup due to the battery's limited capacity **Error! Reference source not found.**. Moreover, HEVs cannot be recharged by plugging them into an electrical outlet. The electrical power produced by the braking system is used to charge the battery linked to the HEV system **Error! Reference source not found.**. Hence, HEV combines two different power sources since HEV cannot be charged directly from the electrical outlet.

Talari and Jatrothu **Error! Reference source not found.** mentioned HEV has four types that are series, parallel, series-parallel, and complex hybrids. In the series HEVs, the ICE power used by a generator to charge the batteries and electric motor can also be driven directly by the combination of ICE and generator without using or draining the battery **Error! Reference source not found.**,**Error! Reference source not found.**. The ICE and wheels are not linked mechanically in the series HEV **Error! Reference source not found.Error! Reference source not found.**. From the ICE, HEV produces the electricity to activate the electric motor and recharge the battery pack as shown in Figure 1. The benefits of series HEV include their compact design and ease of operation, while their drawbacks include their low overall efficiency and high motor-power requirements **Error! Reference source not found.**.

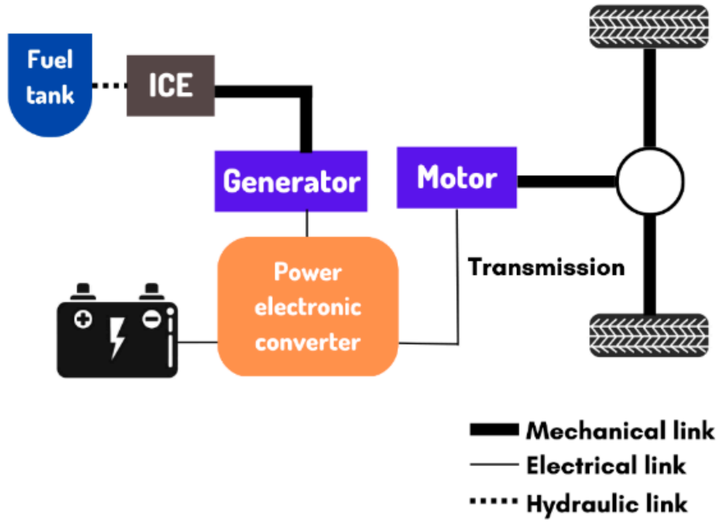

Fig. 1. Series HEV configuration. Adapted from **Error! Reference source not found.**

In parallel HEVs, the ICE is functional parallel to the electric motor and can operate separately or simultaneously to move the vehicle **Error! Reference source not found.**. In a parallel HEV layout, Parag Jose and Meikandasivam **Error! Reference source not found.** discussed both ICE and electric motor are connected to a gear system via the transmission system that has contact with the wheels, then the engine motor is powered by the battery. However, Qin *et al.,* **Error! Reference source not found.** mentioned the advantage of parallel HEV are minimal cost, fuel-efficient design, and high efficiency, while its shortcoming is low efficiency and a gearbox is needed. Hence, parallel HEV configuration is shown in Figure 2.

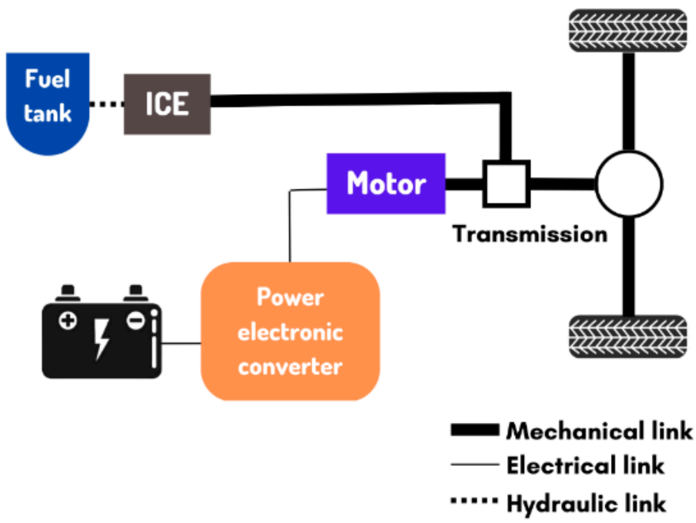

Fig. 2. Parallel HEV configuration. Adapted from **Error! Reference source not found.**

Parag Jose and Meikandasivam **Error! Reference source not found.** described the series-parallel HEV as a configuration that uses a power splitter to support both series and parallel operations. They also mentioned the series-parallel HEV has two portions: the first portion is the mechanical power from the ICE is transferred via the power split device to the generator and transformed into electrical energy, then fed to the engine motor through the inverter. Furthermore, the second portion comprises the mechanical power derived from the ICE and the engine motor drive system, which is connected to the gear system. Subsequently, the gear system transmits this power from the ICE and engine motor to the transmission and ultimately to the wheels. In addition, Qin *et al.,* **Error! Reference source not found.** also discussed the advantage of series-parallel HEV such as excellent performance and flexibility, while the flaw of this setup comes with higher development costs and complicated structures. Hence, the series-parallel configuration is illustrated in Figure 3.

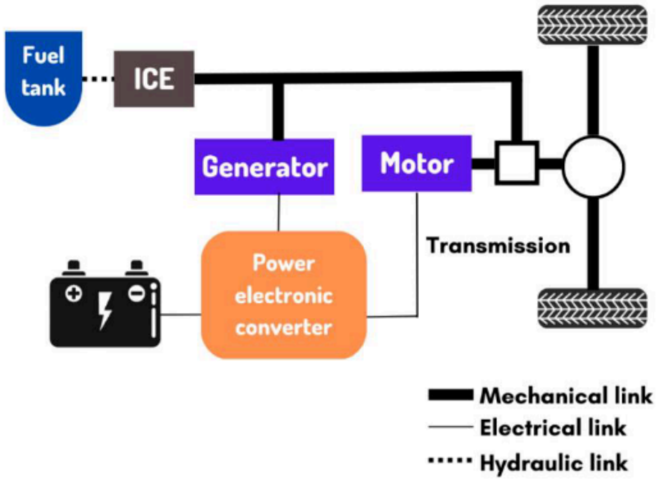

Fig. 3. Series-Parallel HEV configuration. Adapted from **Error! Reference source not found.**

According to Ehsani *et al.,* **Error! Reference source not found.** the complex HEV shares similarities with the series-parallel HEV configuration but the distinguish between the complex HEV and the series-parallel HEV is the incorporation of an extra bidirectional converter. The bidirectional converter enables two-way power flow in the electric motor. Its two-way power flow allows an array of operating modes, including the combination of an ICE and two electric motors. However, the complex configuration is portrayed in Figure 4.

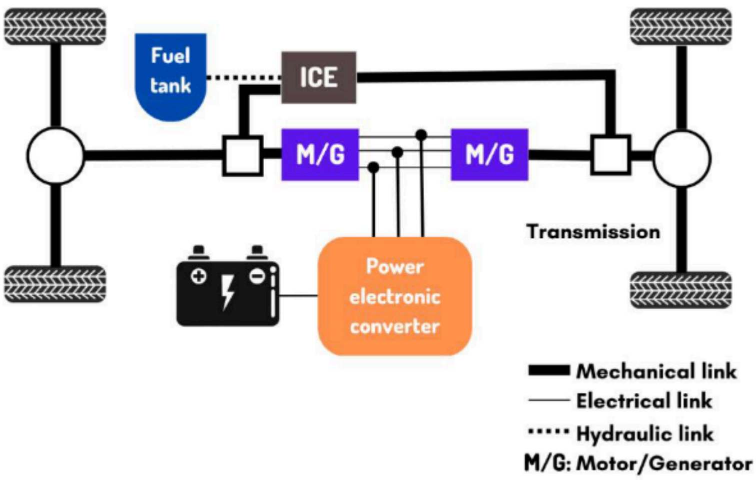

Fig. 4. Complex HEV configuration. Adapted from **Error! Reference source not found.**

2.2 Plug-In Hybrid Electric Vehicle (PHEV)

A Plug-in Hybrid Electric Vehicle (PHEV) is comparable to a typical HEV in terms of powertrain, but what distinguishes it is the capability to recharge from an external power source **Error! Reference source not found.**. PHEV may be operated by an ICE if their batteries run out and have limited pure-electric range, often between 50 and 100 km **Error! Reference source not found.**. Compared to HEVs, PHEVs typically feature huge batteries and more efficient electric motors **Error! Reference source not found.**. It is because PHEVs use electrochemical storage batteries to store this grid electricity within the vehicle **Error! Reference source not found.**. The PHEV configuration is presented in Figure 5. However, Liu *et al.,* **Error! Reference source not found.** discussed the ICE, a clutch of an electric motor with an automated mechanical gearbox (AMT), a final drive, and a battery that can be replenished from the power grid to compensate for the PHEV's hybrid powertrain. The PHEVs also have two types including extended range EV (EREV) and blended PHEV (BPHEV). The EREV also known as series PHEV and BPHEV is a parallel PHEV. According to Prajapati **Error! Reference source not found.**, the ICE is simply utilized to generate electricity and does not turn the wheels. Furthermore, EREV can operate entirely on electricity until the battery has to be recharged. While, BPHEV refers to the vehicle moving under normal driving situations by both the engine and the electric motor, which are attached mechanically to the wheels.

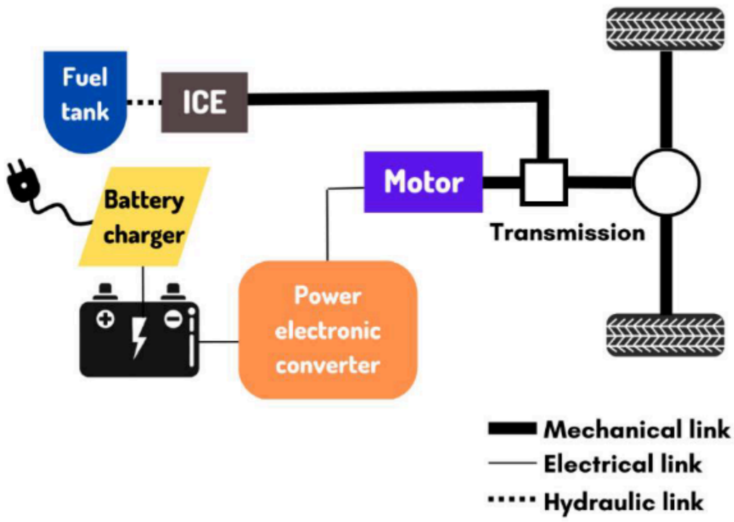

Fig. 5. PHEV configuration. Adapted from **Error! Reference source not found.**

2.3 Battery Electric Vehicle (BEV)

According to Mohammed and Jung **Error! Reference source not found.**, the increasing trends of global warming and air pollution issues encourage the demand for safer, more efficient, and cleaner vehicles which is the Battery Electric Vehicle (BEV). Without employing an ICE, BEV is powered by its batteries. Therefore, BEVs are extremely important for environmental protection and preventing climate change because BEVs do not emit any pollutants from electricity. Besides, they concurred that BEVs feature the most substantial battery capacity and offer an extensive range for purely electric driving in comparison to HEVs, PHEVs, and EREVs. Çağatay Bayindir *et al.,* **Error! Reference source not found.** mentioned BEVs have no emissions, are independent of crude oil, have high energy efficiency, and are readily available but have market high initial expense and have limited range. The BEV configuration is proposed in Figure 6.

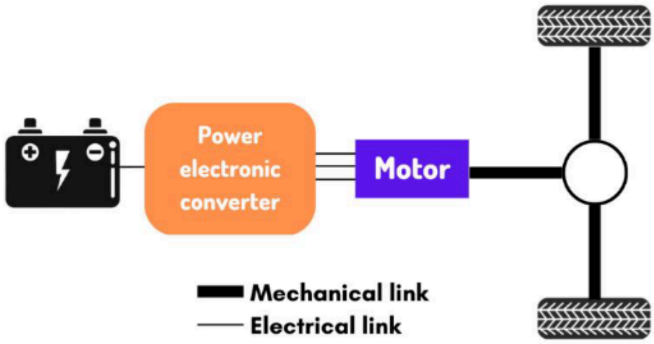

Fig. 6. BEV configuration. Adapted from **Error! Reference source not found.**

2.4 Fuel Cell Electric Vehicle (FCEV)

A Fuel Cell Electric Vehicle (FCEV) uses hydrogen as fuel and electrochemically generates heat and water **Error! Reference source not found.**. By storing energy as a form of hydrogen and employing it directly in fuel cells, the energy system can become highly sustainable and help integrate renewable energy sources (RESs) into the residential and commercial sectors **Error! Reference source not found.**. As a result, an FCEV is a form of electric vehicle in which the engine motor is powered by a fuel cell. From Thompson *et al.,* **Error! Reference source not found.**, hydrogen is a versatile energy resource that can be produced through processes such as electrolysis of water using electricity generated from RESs such as solar, wind, geothermal energy, and others, or via the conversion of fossil fuels or alternative carbon sources such as coal, natural gas, and biomass.

According to Muthukumar *et al.,* **Error! Reference source not found.**, the anode and cathode are the components where the chemical reaction occurs and make up a fuel cell. Fuels, specifically hydrogen and oxygen, are required to create electric energy with less pollution. Direct Current (D.C) is the type of current that the fuel cell generates. An inverter, a conversion device, is necessary if we need Alternative Current (A.C). The FCEVs are equipped with an energy storage device, a motor, driving, and control systems. Besides, Hong and Kim **Error! Reference source not found.** contended that FCEVs are suitable for long-driving ranges, limited time for recharge, and can decrease roadside pollution. Additionally, the majority of participants from Lipman *et al.,* **Error! Reference source not found.** agreed FCEVs are safer and easier to use than gasoline. FCEV has the potential as an emerging option to reduce environmental issues. The FCEV configuration is shown in Figure 7.

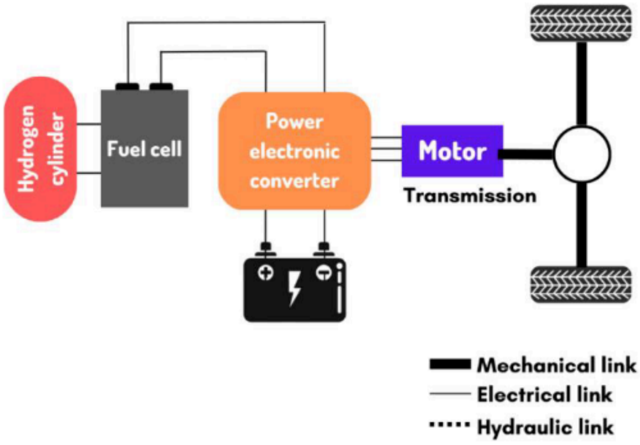

Fig. 7. FCEV configuration. Adapted from **Error! Reference source not found.**

3. Electric Vehicle Charging Mode Specification

The EV charging mode specification refers to technical specifications and defines how an EV is connected to CSs physically. In other words, the charging mode determines the communication protocol that the EV and CSs will use **Error! Reference source not found.**. Koh *et al.,* **Error! Reference source not found.** claimed that Alternating Current (AC) and Direct Current (DC) kinds are the two categories of EV battery chargers that are now in use. In addition, three major international organizations have established standards for EV battery charging including the International Electrotechnical Commission (IEC), the Society of Automotive Engineers (SAE), and CHArge de MOve (CHAdeMO). But, the three standards are not relevant to Tesla Motor's EVs, hence they have their own special charging standards.

According to Suruhanjaya Tenaga **Error! Reference source not found.**, Malaysian Standard (MS) IEC 61851 specifies four alternative modes of electric vehicle conductive charging in Malaysia. Mode 1 is connecting the EV to the main Alternate Current (A.C) supply network using a specified socket outlet. Besides, the charging cable assembly includes an in-cable control box for Mode 2 charging. Next, a specific electric vehicle charging station (EVCS) and charging cable assembly can be employed for Mode 3 charging. Then, using an off-board charger to transmit Direct Current (D.C) directly to the battery while bypassing the onboard charger is the principle underlying Mode 4 charging. Hence, Wang *et al.,* **Error! Reference source not found.**also described A.C. charging works in Mode 1, Mode 2, and Mode 3, whereas D.C charging operates in Mode 4, and fast charging is supported only by Mode 3 and Mode 4. The EV charging mode specification is summarized in Table 1 **Error! Reference source not found.**.

Table 1
Electric Vehicle Charging Mode Specification

	Mode 1	Mode 2	Mode 3	Mode 4
Connector	No	No	Yes	Yes
Type of charge	Slowly in A.C	Slowly in A.C	Slowly and accelerated	Fast in D.C
Type of connectors			IEC Type 2	CCS Type 2 CHAdeMO
Maximum voltage/ current	230 V/16 A (single-phase) 400 V/16 A (three phases)	32 A (single-phase)	230 V/32 A (single-phase) 400 V/32 A (three phases) 400 V/63 A (Three phase	CCS Type 2 (Up to 400 V / Up to 400 A) CHAdeMO (Up to 1000 V / Up to 400 A)
Special features	The use of a conventional socket outlet in the absence of communication and the presence of a residual current device (RCD)	The charging cable assembly includes an in-cable control box	Communication between the EVCS and the on-board charger of an EV is made possible via the control pilot cable of the charging cable assembly	Using the notion of bypassing the on-board charger and employing an off-board charger to supply a DC straight to the battery

4. Electric Vehicle Charging Categories

The EV charging category refers to a general classification, the charging power level, and the time required to charge EVs. According to Koh *et al.,* **Error! Reference source not found.**, the size of the battery, the station's power rating, and lastly the total number of EVs connected to the same charger at that same moment are the three key variables that affect how long it takes an EV to charge and three charging levels are available on EV battery chargers. LaMonaca and Ryan **Error! Reference source not found.** mentioned the electric vehicle charging categories such as Level 1, Level 2, and Level 3. Level 1 is the slowest charging method, and Level 2 is the standard charging for specialized private and public facilities. Thus, Level 3 charging is the fastest and employed for industries. Also, under the SAE J1772 standard, electric vehicle charging is categorized into three distinct levels. Levels 1 and 2 encompass slow charging methods utilizing AC on-board chargers, whereas Level 3 entails rapid charging via a DC off-board charger **Error! Reference source not found.**. The EV charging categories are summarized in Table 2 **Error! Reference source not found.Error! Reference source not found.**.

Table 2
Electric vehicle charging categories

	Level 1	Level 2	Level 3
Power	3.3 kW	7.4 – 22 kW	50 – 120 kW
Type of charge	A.C	A.C	D.C
Current	16 A	16 A	32 A
Voltage	120 V	240 V	415 V
Phase	Single-phase	Single – phase, Three – phase	Three phases
Mode	1 or 2	1,2 or 3	4
Time range	4 – 6 hours	1 – 4 hours	10 – 60 minutes
Recommend location	Wall box for the home or the office	Parking charging poles at private or public	Fast charging for public use

5. Mathematical Modelling of Electric Vehicles (EVs) Adoption

This section elaborates more on the mathematical modelling of EV adoption and how it is commonly used in this field. According to Maybury *et al.,* **Error! Reference source not found.**, mathematical modelling is essential to enable the formulation and solution of related issues in an organized and scientific manner that portrays the best practices and current findings. Javanmardi *et al.,* **Error! Reference source not found.** addressed the variables influencing the adoption of electric vehicles (EVs) using grey econometric and grey regression models. The study discovered that vehicle dimensions, battery warranty conditions, battery life, and charging facilities are significant in this context. As a way to provide more reliable results, Hafdaoui and Khallaayoun **Error! Reference source not found.** applied social assessment models that can be implemented in any region. Hence, technological, financial, and infrastructure perspectives are considered in evaluating the HEVs, BEVs, and FCEVs. The findings show HEVs have a better performance based on the score. The widespread EV adoption is dependent on the government providing more alternatives, lower purchasing costs, and enhanced secondary road infrastructure.

Besides, Li *et al.,* **Error! Reference source not found.** used a hybrid choice model (HCM) to determine the EVs adoption with combined effects of different factors such as market-oriented policy instruments and consumers' vehicle adoption decisions. So, the outcomes also provide policymakers with new insight into how to create the most advanced guidelines to encourage the adoption of EVs. In addition, the business model used by Huang and Qian **Error! Reference source not found.** indicates a favourable relationship between consumers' awareness of new EV business models and the tendency to purchase rented and shared EVs. Government policies, charging infrastructure, and resource limitation are the most remarkable barriers that affect the EVs adoption by using Interpretive structural modelling (ISM) - MICMAC (Matriced' Impacts Croise's Multiplication Applique' e a UN Classement) models **Error! Reference source not found.**.

Furthermore, Christensen and Salmon **Error! Reference source not found.** employed a decision-making surrogate model to resolve the effects of EV adoption and environmental events on air quality near highways. The results mentioned that future investments in public and private EVCSs should be considered to promote the adoption of EVs and achieve significant improvements in air quality under normal weather conditions and winter inversion situations. Khazaei and Tareq **Error! Reference source not found.** explored the factors affecting the adoption of BEVs by using structural equation modelling (SEM) and the outcomes found that social influence, facilitating conditions, environmental concern, and perceived enjoyment all had a favourable impact on the uptake of BEVs. Other than that, J. Li *et al.,* **Error! Reference source not found.** examined how economic and informational policies affect the pace of EV adoption by using a small world network and the adoption rate of EVs that are least impacted by the subsidy cut policy while charging at home is significantly impacted by collaboration in the execution of economic policies.

Moreover, the system dynamics (SD) model is good in determining the complex interactions among the mentioned influencing factors of EV adoption. According to the findings, consumers' unclear thoughts and the growth of trial EV projects are responsible for the slowdown in EV adoption **Error! Reference source not found.**. Prakash *et al.,* **Error! Reference source not found.** employed interpretive structural modelling (ISM) to evaluate the obstacles to broad adoption of EVs and it seems clear that point of time, government incentives, and consumer characteristics are the most ideal factors in EV adoption. Agent-based model is used to simulate the power demand from a given number of PHEVs and regarding the proportional volume of the power required and the diversity of the charging patterns, it is obvious that the adoption of PHEVs is becoming more widespread **Error! Reference source not found.**. Lastly, Javid and Nejat **Error! Reference source not found.** applied the discrete choice model to examine the possible factors that may be caused by purchasing PEVs and the findings revealed that a household's income, the maximum level of education in the household, the buyer's car sharing status, CSs density, and gas price in the country are the main influence on PEVs adoption.

6. Results and Discussion

The exposure and knowledge about EVs in Malaysia are still low compared to other countries. According to Muzir *et al.,* **Error! Reference source not found.**, EVs tend to be more expensive in Malaysia compared to traditional ICE. Consequently, Malaysians exhibit a preference for ICE vehicles due to the elevated costs associated with EVs. The price range for BEVs from Nissan is between RM70,000 – RM180,000. The PHEVs such as BMW, Mercedes Benz, and Volvo are around RM250,000 and above **Error! Reference source not found.**. A conventional vehicle such as Proton and Perodua is around RM40,000, which is cheaper than EVs. Hence, to motivate Malaysians to purchase EVs, the government should implement policies that give users incentives like affordable prices, reduced road taxes, and longer battery life guarantees **Error! Reference source not found.**. Table 3 shows the summary of the EVs model in Malaysia.

Table 3
Comparison of EVs model

Brand	Model	Price	Battery Capacity	Range	Types		
					BEV	HEV	PHEV

BYD	Atto 3	RM149,800	60.5 kWh	230 – 480 km	/		
Tesla	Model 3	RM260,000	82 kWh	614 km			/
BMW	X5	RM491,800	24 kWh	77 km			/
	X3	RM329,800	57.5 kWh	50 km			/
	XM	RM1,398,800	25.7 kWh	82 – 88 km			/
	740Le	RM642,800	7.4 kWh	46 km			/
	530e	RM360,800	12 kWh	82 – 88 km			/
	330e	RM298,800	7.6 kWh	56 km			/
	iX	RM403,800	105.2 kWh	630 km	/		
	i4 eDrive40	RM399,800	83.9 kWh	590 km	/		
	i4 M50	RM445,800	83.9 kWh	510 km	/		
	iX3	RM322,800	74 kWh	460 km	/		
Volvo	C40	RM288,888	69 kWh	438 km	/		
	XC40	RM278,888	69 kWh	425 km	/		
	XC90	RM432,888	18.8 kWh	68 km			/
	XC60	RM355,888	18.8 kWh	81 km			/
	S60	RM313,888	11.6 kWh	90 km			/
	S90	RM370,888	11.6 kWh	82 km			/
	V60	RM321,888	18.8 kWh	90 km			/
Hyundai	IONIQ 5	RM207,808	58 kWh	384 km	/		
	KONA electric	RM156,538	39.2 kWh	305 km	/		
Toyota	Corolla Cross	RM142,000	1.31 kWh / 6.5 Ahr	600 -650 km		/	
Nissan	Leaf	RM168,888	60 kWh	311	/		
	Serena	RM149,888	1.8 kWh	852 km		/	
Mercedes-Benz	EQA	RM296,888	66.5 kWh	458 – 496 km	/		
	EQB	RM333,888	66.5 kWh	423 km	/		
	EQC	RM393,888	80 kWh	423 km	/		
	EQE	RM419,888	90.6 kWh	669 km	/		
	EQS	RM708,888	107.8 kWh	782 km	/		
	S-Class	RM718,888	28.6 kWh	113 km			/
	GLC Coupe`	RM403,888	13.5 kWh	43 km			/

Table 3 shows the majority type of EVs in Malaysia are BEVs and PHEVs, and the production of HEVs is still low. Besides, the FCEVs are not available yet in Malaysian industries. Globally, FCEVs like Toyota Mirai are currently not in Malaysia's market and that model was popular in other countries. Although EV sales in Malaysia are currently minimal, research has revealed that the EV sector has the potential for growth if EV adoption awareness is enhanced **Error! Reference source not found.**. Malaysian consumers of automobiles seem to favour those that are affordable, offer good value, and have a high resale value **Error! Reference source not found.**. Thus, the knowledge of EVs should be exposed to Malaysians as a motivation for widespread EV adoption. However, by the end of the fourth quarter of 2023, Proton collaborating with Geely Holding Group will introduce a new EV to Malaysia under its "New Energy Vehicle" (NEV) segment **Error! Reference source not found.**. This new EV can encourage Malaysians to purchase EVs at an affordable price. It has been forecast that the market and demand for electric vehicles will continue to rise in forthcoming years **Error! Reference source not found.**.

Besides, in the presentation of the 2023 budget, the government granted tax exemptions to EV users until 31st December 2027 to encourage Malaysians to use EVs **Error! Reference source not found.**. Despite the potential to decrease petrol consumption by encouraging the adoption of EVs, Malaysia is not lagging behind in this EV sector **Error! Reference source not found.**. Additionally, the knowledge of EVs should be exposed to Malaysians as a widespread EV adoption. Malaysians need to be aware that charging EVs is more affordable than petrol to get them to use the vehicle. This is because most CSs are considered the time range. For instance, JomCharge sets the rate as RM1.20/min. The user of an EV would only have to pay RM24 if the charging process takes 20 minutes to complete. Thus, EVs will be welcoming to Malaysians.

In order to enhance the EVs adoption in Malaysia and minimize the transportation issues, photovoltaic electric vehicle charging stations (PEVCS) need to be placed in ideal locations. Due to their positive environmental impact, ability to address various mobility challenges, and potential to improve air quality, PEVCS have become a significant inspiration for sustainable mobility **Error! Reference source not found.**. As has been noted, the photovoltaic (PV) technology has achieved significant cost savings and commercialization **Error! Reference source not found.**. By allocating PEVCS in Malaysia, range anxiety among EV users can be reduced. As mentioned in Iravani **Error! Reference source not found.**, range anxiety remains a significant obstacle to promoting EV adoption. This is because, for EV users concerned about charging their vehicles while driving, CSs are essential **Error! Reference source not found.**. However, to determine the ideal location for PEVCS in Malaysia, several criteria should be considered. This study had conducted the Need Analysis in the initial phase regarding the allocation of PEVCS in Malaysia **Error! Reference source not found.**. From the previous study, 177 criteria were found, and only 52 criteria were selected to conduct the Need Analysis. These 52 criteria were selected based on the circumstances and landforms in Malaysia.

After conducting a Needs Analysis, only 41 criteria were deemed relevant for determining the optimal locations for PEVCS in Malaysia. These 41 sub-criteria encompass various aspects, including society (8), economy (10), environment (7), technology (6), accessibility (6), and proximity (4). For this study, only criteria that achieved a percentage agreement of 80% or higher in the Needs Analysis are considered. Any criteria that did not meet this threshold are excluded based on respondent disagreement. Table 4 to Table 9 provides a list of the selected criteria used in the assessment of the ideal PEVCS locations in Malaysia. Following this, the study proceeded with instrument validation. Based on experts' feedback and comments, the 41 criteria are reduced to 12. Last but not least, the government and policymakers can incorporate these criteria as essential elements in developing plans that will promote the spread of PEVCS, support environmental sustainability, and encourage the widespread adoption of EVs among Malaysians **Error! Reference source not found.**. Thus, the most notable findings include the incorporation of specified criteria for mapping in ArcGIS software, enabling the development of a model to predict the ideal locations for PEVCS deployment in Malaysia. In this study, Multi-Criteria Decision-Making (MCDM) methods are employed throughout the model development process.

Table 4
Analysis of society's main criteria

No	Sub-criteria	Percentage (%)	
		Yes	No
1.	Traffic convenience	91.67	8.33
2.	Service radius	83.33	16.67
3.	Service capability	100.00	0.00
4.	Research and education	100.00	0.00
5.	Promotion of EVs potential	91.67	8.33
6.	Harmonization of PEVCS with urban development and state grid planning	83.33	16.67

7.	Habit compatibility	83.33	16.67
8.	Safety for driver and passengers	91.67	8.33

Table 5
Analysis of economy's main criteria

No	Sub-criteria	Percentage (%)	
		Yes	No
1.	Construction cost	100.00	0.00
2.	Annual operation and maintenance cost	91.67	8.33
3.	Land value	91.67	8.33
4.	Investment payoff period	83.33	16.67
5.	EV ownership in the service area	91.67	8.33
6.	Distance to the power cut	83.33	16.67
7.	Parking fee	91.67	8.33
8.	Number of supplied EVs	83.33	16.67
9.	Monthly average charging frequency by region	83.33	16.67
10.	Station equipment	83.33	16.67

Table 6
Analysis of environment's main criteria

No	Sub-criteria	Percentage (%)	
		Yes	No
1.	Greenhouse gas (GHG) and fine particles emission reduction	83.33	16.67
2.	Air quality	83.33	16.67
3.	Distance of landslide risk	91.67	8.33
4.	Slope of land	83.33	16.67
5.	Possibility of expansion	83.33	16.67
6.	Protected area	83.33	16.67
7.	Flooding risk	91.67	8.33

Table 7
Analysis of technology's main criteria

No	Sub-criteria	Percentage (%)	
		Yes	No
1.	Power quality influence	100.00	0.00
2.	System reliability	91.67	8.33
3.	System security	100.00	0.00
4.	Number of installed rapid charging stations	100.00	0.00
5.	Number of charging connectors	100.00	0.00
6.	Solar energy potential	91.67	8.33

Table 8
Analysis of accessibility's main criteria

No	Sub-criteria	Percentage (%)	
		Yes	No
1.	Population density	91.67	8.33
2.	Shopping malls	83.33	16.67
3.	Roads/ Road access	91.67	8.33
4.	Current EVCS	91.67	8.33
5.	Existing petrol station	91.67	8.33
6.	Park areas	100.00	0.00

Table 9
Analysis of proximity's main criteria

No	Sub-criteria	Percentage (%)	
		Yes	No
1.	Proximity to the main road	91.67	8.33
2.	Proximity to public transport	83.33	16.67
3.	Proximity to petrol stations	100.00	0.00
4.	Proximity to point of interest	83.33	16.67

7. Conclusion

EVs can run entirely or partially on electricity. There are four types of EV such as HEV, PHEV, BEV, and FCEV. The technical specifications and broad categories of EVs are also covered in this paper. Malaysia adopted the standards and practices for conductive connection charging of electric vehicles as outlined by MS IEC 61851 and SAE J1772. The EVs adoption among the users can be determined by using mathematical modelling such as the discrete choice model, social assessment model, SEM, and so on. Afterward, this study discusses the growth of EVs in Malaysia. Most EV companies sell BEVs and PHEVs compared to HEVs. None of the FCEVs are available in Malaysia's market. The governments should offer incentives, builds more CSs, and create more awareness campaigns for the adoption of EVs in Malaysia. Hence, the future works will be carried out using MCDM methods to calculate the weights of the criteria from the judgement of experts.

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