

Review

Challenges of Electric Vehicles and Their Prospects in Malaysia: A Comprehensive Review

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Abstract: Electric vehicles (EVs) in Malaysia are gaining more attention and interest from the public. However, the electric vehicle's exposure, awareness, and sales are still low compared to other countries. In this review, the challenges associated with implementing the electric vehicle culture in Malaysia are thoroughly reviewed, including the obstacles that the Malaysian government, policy-makers, EV manufacturers, and EV users face in terms of EV cost, travel demand, charging station availability, impact on the power grid, and battery capacity. Then, all the identified challenges have been addressed by considering the user behavior, travel demand, socio-economical culture of Malaysia, current policies taken by the government of Malaysia, and the psychological outlook of Malaysians towards EV adoption. Moreover, potential suggestions have been proposed that the government of Malaysia may adopt during policy planning and when seeking to provide incentives to the users. Finally, a concrete conclusion has been drawn by disseminating the vision about the future of EVs in Malaysia. The proposed review of the technologies, challenges, prospects, and potential solutions associated with EV adoption in Malaysia can provide a base for proper strategic policy and help policymakers frame strategies to achieve the targets. This review could help achieve sustainable EV transport, and the successful implementation of Malaysian National Automotive Plan 2020, with the goal of adopting next-generation green vehicles.

Keywords: energy; electric vehicle; battery electric vehicle; market price; battery disposal



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1. Introduction

The global power industry is gradually shifting from traditional non-renewable to sustainable energy sources to maintain a friendly and long-lasting global climate. Over the last two centuries, the increasing amount of fossil fuel consumption has already taken its toll [1,2]. The increase in global transportation as of 2019 was 0.5%, reduced from a value of 1.9% annually at the beginning of the 21st century [3]. International transportation still generates around 24% of the world's CO₂ emission from fuel combustion [4]. The carbon-emission percentage is much higher for industrially rich cities. For instance, according to the China Vehicle Environmental Management Annual Report (CVEMAR) published in 2018, vehicle emissions contribute to 52.1% of particulate matter (PM) air pollutants in Shenzhen and 45% in Beijing [5]. The ongoing fuel shortages and global warming have emphasized the need for more practical handling of transportation and power generation units. Fossil fuel-dependent industries are being considered for carbon taxes, thus, checking their vast growth [6]. Replacing the traditional internal combustion engines (ICE) with electrical battery-driven vehicle (EV) technology is encouraging more and more countries

around the world to curtail the greenhouse gas (GHGs) emissions from the transportation sector [7–9]. However, in its initial stage, electrification of the transportation sector suffers from high vehicle purchase cost, the lack of sufficient charging facilities [10], and the ability of the charging batteries to provide service for the expected timeline and travel distance [11]. Many innovations, policies, and regulatory activities have been dispatched through first-tier industries and government agencies to alleviate the barriers to the widespread use of EVs [12]. Thriving research activities on the horizon of battery storage systems have fortunately provided some prospects for the growth of EV industries. For instance, Tesla has claimed to develop a newer variant of the Lithium-ion battery that can back up the EV for around 300 miles in a run [13]. Samsung's Lithium-ion battery with 20 min charging cycle runs EV up to 375 miles [14,15]. Government agencies such as the US Department of Energy have dispatched measures to initiate charging ports and stations near the large EV parking spaces [16].

Malaysia's transportation sector is booming, resulting in a large energy demand. In 2012, the growth of newly registered private vehicles was nearly 9%, and the energy demand from the transportation sector was around 37%, higher than any other individual sector [17]. However, transport in Malaysia intensively suffers from low energy conversion efficiency of combustion engines (18.88% in 2019) [18]. Therefore, increased private vehicles have increased the overall CO₂ emission rate significantly [19]. In 2012, nearly 84% of all vehicles were owned by private entities [20]. To make matters worse, the lack of non-renewable practices and policies for the green industry became troubling because Malaysia pledged in the United Nations Climate Change Conference (UNFCCC), hosted in Copenhagen in 2009, that by 2020 it will reduce annual carbon emissions by 40% [21]. Since the transportation sector was the biggest culprit to the annual GHG emissions, a new way out was required. Incorporating EV culture into the Malaysian economy showed itself as a prospective solution. But the challenge is to inaugurate mass use and purchase of EVs. Factors such as purchase and maintenance cost, regulatory policies, vehicle service points, and road infrastructure became matters of concerns to divert the car-purchasing behaviors of the Malaysian from ICEs to EVs.

Furthermore, among the prospective EV users, it is observed that psychological factors such as risk perception, corporate culture, and company image play significant roles for the fleet purchasers; whereas attitudes, lifestyle, personality, and self-image become essential for private individuals. Interestingly, among the private and fleet consumers, the environmental issue comes as the lowest priority in purchasing the EV. Besides that, the EV industry promotes the opportunity to increase the volume of vehicles manufactured locally. With Malaysia's current socio-economical outlook, it is hard to convince Malaysians to own an EV and sell it at a reasonable budget. This is because the retail price reduces when there is enough opportunity to grow an effective and economic EV business model and local manufacturers come forward; in both aspects, Malaysia is still far behind.

A few excellent works have been performed on electric vehicle adoption from the Malaysian perspective in recent years. Research focuses primarily on the adoption of electric vehicles via empirical modeling of daily expected use, the consumer behaviors and relevant factors associated with EV usage, impact assessment of the EV charging on Malaysian low-tension domestic power grid, and finally, purchase intention among different generational consumers. However, the current literature lacks a thorough generic overview of the whole current and future prospects of EVs in Malaysia, with the following considerations: current market prices; trends in EV manufacturing inside and outside the Malaysian border; projections of the price of raw materials and components such as solid-state drivers, batteries, and controllers; the current EV market profile and the hurdle in EV startups and mass adoption; locating EV charging infrastructure counts and estimating the quantitative growth of household and commercial charging infrastructure; the impact of EV on current power grid infrastructure and operation and bringing out the best possible power-sharing strategy for EV charging/discharging periods; mass behavior regarding EV adoption at present and the feasibility of innovating incentives and policies to

encourage people to EV culture; setting up a large EV charging network, service points, and easily locating the nearest garage; boosting new startups for EV parts manufacturing and assembling; and finally, bringing in policies to overrule the use of conventional combusting engine with hybrid vehicle with bidirectional power flow capability that could further lead to efficient micro and mini-grid deployment. Moreover, an overall idea of the current EV adoption (the specific challenges and potential solutions gateway) in Malaysia is crucial to making newer research policies and original research work, and to produce an effective EV-based business model for the Malaysian market. As such, as of 2022, the profile of EV users, the associated challenges in the vast penetration of the EV in-vehicle market with higher service with reasonable price, and feasible solutions that could improve extensive utilization of EV vehicles in Malaysia all require a thorough investigation.

In this paper, the authors have reviewed research articles, conference proceedings, government reports, and company data that have all provided intensive investigation related to EV, to efficiently and structurally summarize the key challenges and associated solutions, and the feasibility of those solutions in Malaysia, from the Malaysian economical and socio-cultural perspectives. While carrying out the investigation, strategies deployed elsewhere in the world with similar socio-economical and geographical settings have been of great importance.

The main contributions of this paper are given below:

- Identifying the current EV practices in Malaysia.
- Pointing out the key challenges in implementing EV technology.
- Proposing solutions to address the challenges currently being faced by EV users, manufacturers, and policymakers in Malaysia.
- Investigating the impact of EVs on the lifestyle and power grid structure of Malaysia.
- Modeling the human psychology behind the EV market.
- Outlining the prospects of EVs in Malaysia.
- Highlighting the technological competency to advance EV research and manufacturing across the globe.

The rest of the paper is designed as follows: Section 1 introduces the EV technology. Section 2 indicates the methods used in this review work. Section 3 provides basic information and prospects for EVs across the globe. Section 4 suggests the drawbacks and key problems of EV practices in Malaysia. In Section 5, guidelines and solutions to tackle the major problems (outlined in Section 4) are included. Section 6 highlights the current EV policies worldwide and the targets of the Malaysian government. Finally, in Section 7, the paper is concluded.

2. Methods

2.1. Scope of Study and Framework

This study focused on the challenges of EV culture implementation in Malaysia and the possible solutions to address each challenge. The entire research comprises selected data collected from the literature, Malaysian official reports, and company data regarding EV deployment and adoption, as well as suggested required changes in operation, manufacturing, and policy to boost the mass utilization of EVs in the Malaysian context. While selecting the related literature, the authors have considered the following strategy. First, the key challenges to the vast EV growth throughout Malaysia are summarized. Second, each challenge is picked up and broken down into components/factors that are the crucial points to address/solve the challenge. After that, relevant literature is searched and located to comprehensively analyze those points and provide feasible solutions for the Malaysian economy. If no relevant literature was located from a Malaysian perspective, the focus is shifted onto articles that showed significance and addressed the similar challenge in other countries economies and socio-cultures closely matched with Malaysia, such as South Korea, Singapore, China, and Japan. If no work is located on the issue at hand, theoretically sound company data, original thesis works, and secondary implementation of current technology are considered that could provide a potential solution to the challenges and

pave the way for further original research to address the issue. Finally, the authors have asked diverse questions about EV planning, policies, prospects, and customer satisfaction to local manufacturing companies and researchers. The study framework is summarized in the flow diagram shown in Figure 1.

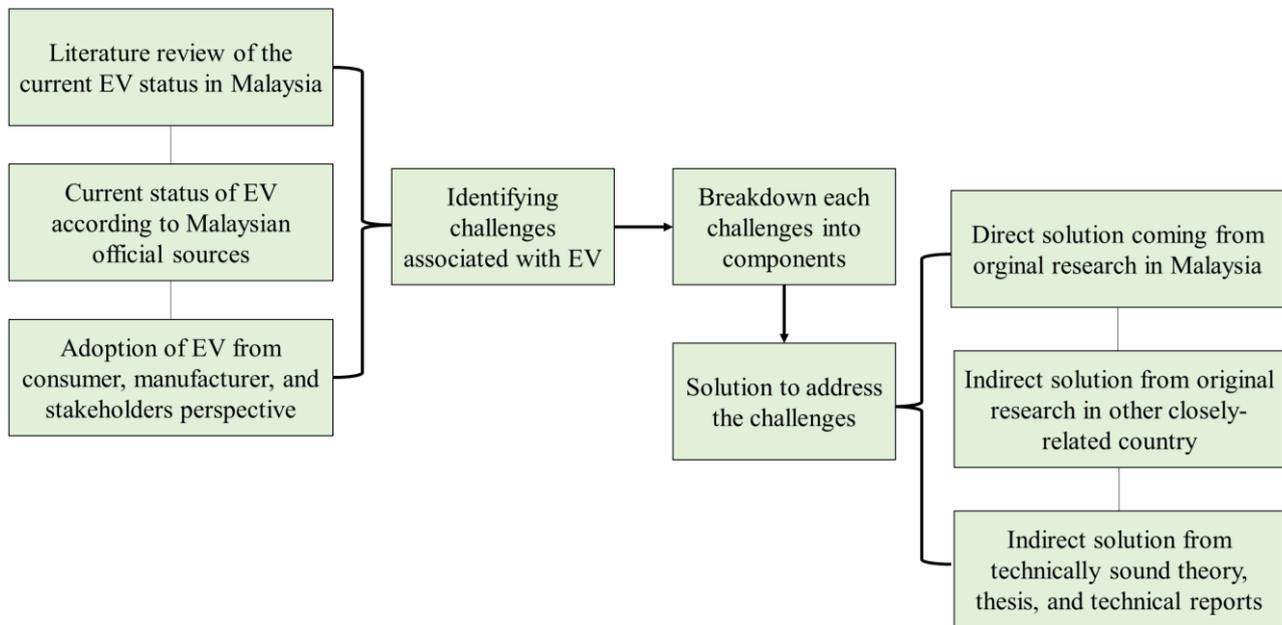


Figure 1. Research Framework.

2.2. Literature Review Process

This study considered a structured way to review the current literature and summarize the prospects, challenges, and possible solutions to vast EV adoption throughout Malaysia. First, a relevant literature pool is created from the search results of keywords comprising “EV”, “Malaysia”, “policy”, “growth”, “challenges”, and “prospects”. Table 1 demonstrates the key research works regarding EVs from a Malaysian perspective. The modeled pool of original and review articles is filtered and narrowed between 2015 and 2020. The original articles are sorted into the specific issues/challenges they tried to address related to the EV manufacturing process, battery management, EV infrastructure in Malaysia, government policy for EV in Malaysia, and inclination towards EV culture from consumer and stakeholders perspectives. The process considered here closely matches with ref. [22] and is shown in Figure 2.

Table 1. Important research works on EV culture from a Malaysian perspective.

Ref.	Year	Issue Considered	Methodology	Key Outcomes
[23]	2020	analysis of consumer EV purchase intention	theory of planned behavior (TPB), Norm Activation Model (NAM) structural equation model (SEM) for empirical analysis of the factors influencing	72.89%-interest in EV—UG students 50%-interest in EV—Age 35–45 60%/40%-interest in EV—Male/Female
[24]	2020	analysis of consumer EV purchase intention	development of a research model based on the Theory of Planned Behavior, integrated with environmental knowledge as an additional variable	outcomes imply the need for governments and practitioners to execute appropriate approaches in nurturing the public’s motivation

Table 1. Cont.

Ref.	Year	Issue Considered	Methodology	Key Outcomes
[25]	2020	well-to-wheel life cycle assessment of GHGs for ICEV, HEV, EVs	Using the existing data in Malaysia, life cost analysis (LCC) of two EVs was computed and compared with HEVs and ICVs	Nissan Leaf and BMW i3s EVs with LCC of 1.75 USD and 2.5 USD per km are not cost-competitive changes in the components of the operating costs significantly influence the accumulated cost of ownership of the EVs
[26]	2020	EV and battery electric buses (BEBs)	The core of this work builds on a novel framework to determine the energy demand of BEBs and their potential as a replacement for diesel-powered buses in transportation networks.	a penetration impact of the BEB charging demand during daytime and nighttime in an urban area in Kuala Lumpur
[27]	2019	Impact of EVs on the current power sector	The first step is searching for relevant data, the second is data screening, and the third is data selection. The data was mainly collected from National Electric Mobility Blueprint Report	The electricity reserve margin without electric vehicle demand is between 22.54% to 26.18% estimate cost will be 111,319,000 RM per year for 10,000 units EV connected to the grid; electricity cost and infrastructure cost With present grid, the implementation of 100,000 units of EV on the road is possible
[28]	2017	analysis of consumer EV purchase intention	To date, public attitudes towards PHEV/EVs have been considered under very diverse conceptual frameworks. Take the three main features of the Theory of Planned Behavior (TPB) model, attitude PHEV/EVs' adoption, Subjective Norm (SN), and Perceived Behavioral Control (PBC) into account.	the collective outcome of 'hyperbolic discounting' has a direct effect between the consumers' environmental concern-based intention and the actual adoption of PHEVs/EVs
[29]	2017	estimate the number of electric vehicles (EVs), hybrid electric vehicles (HEVs) as well as end-of-life vehicles (ELVs) generated until 2040	dynamics modeling method was used	passenger vehicle market will hit saturation point in 2030 at 12 million active vehicles In 2040, HEV is estimated to be 1.43 million units, while EV is estimated to be 43,000. By reducing vehicle ownership tax, adapting mandatory inspection, and improving emission regulation, HEV and EV can be increased by an additional 70%.
[30]	2017	well-to-wheel life cycle assessment of GHGs for ICEV, HEV, EVs	Greenhouse gas emissions associated with electric vehicle charging: The impact of the electricity generation mix in a Malaysia	running EVs with the national grid will produce an average of 7% more GHG emissions than HEVs at the same distance. However, they will produce an average of 19% less GHG emissions than the ICEVs
[31]	2016	an on-board solar photovoltaic system for EV	analyze the integration of solar photovoltaic and electric vehicles in farm mechanization HOMER software, field test validation, MPOB Keratong research station	the onboard solar photovoltaic system is the best-suited method 10 watts of additional power was required for the electric vehicle to move at constant velocity with the addition of 43 kg of solar panels and its frame
[21]	2014	analysis of consumer EV purchase intention	This research determines the key predictors influencing electric vehicles usage intention	observed seven key predictors be statistically significant towards electric vehicles usage intention

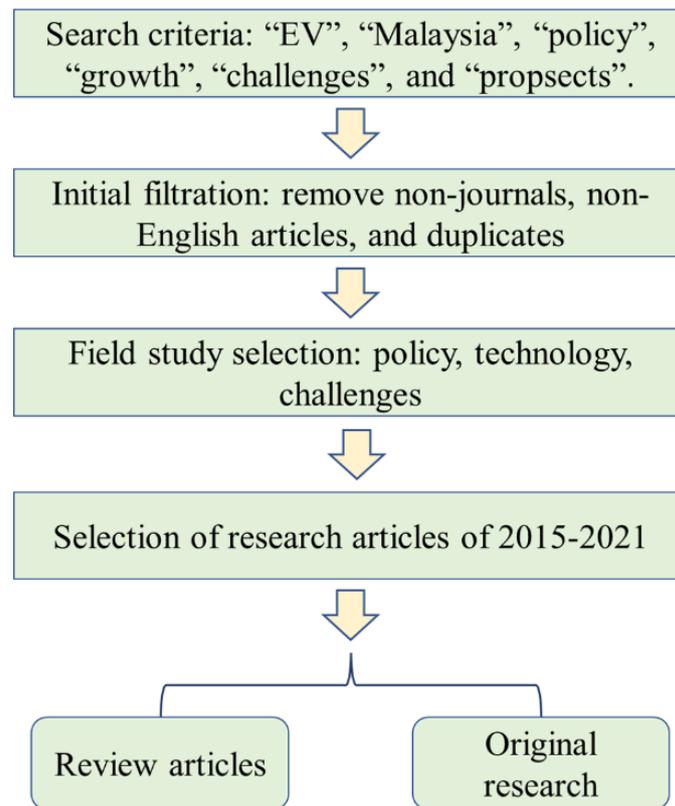


Figure 2. Literature review process.

3. The Electrical Vehicle and Its Prospects

3.1. Electric Vehicle

The electric vehicle runs on electricity alone. It is powered by electric propulsion motors that use the energy stored in a battery. There is no internal combustion engine, fuel tank, fuel pump, or fuel line. To recharge the battery, it needs to be plugged into a charger. It does not emit tailpipe emissions because it runs entirely on electricity. Figure 3 shows the simplified drivetrain of an electric vehicle and its power train [32]. An electric car charger port is used to charge the battery pack as only electricity can be charged. The onboard charger will then take the AC supply and convert it to DC to charge the traction battery pack. The traction battery pack stores the electricity needed by the electric traction motor. Electric motor traction uses the power to drive the vehicle's wheels, which uses the transmission to transfer mechanical power. At present times, permanent magnet brushless direct current (PMBLDC) motors are the choice of automobile industries [33]. A DC/DC converter helps convert the high DC power from the traction battery to the lower-voltage DC power. It will then run the vehicle accessories and recharge the auxiliary battery that powers up vehicle accessories. The power electronic controller will manage the flow of electrical energy by the traction battery controlling the traction motor's speed and the torque produced.

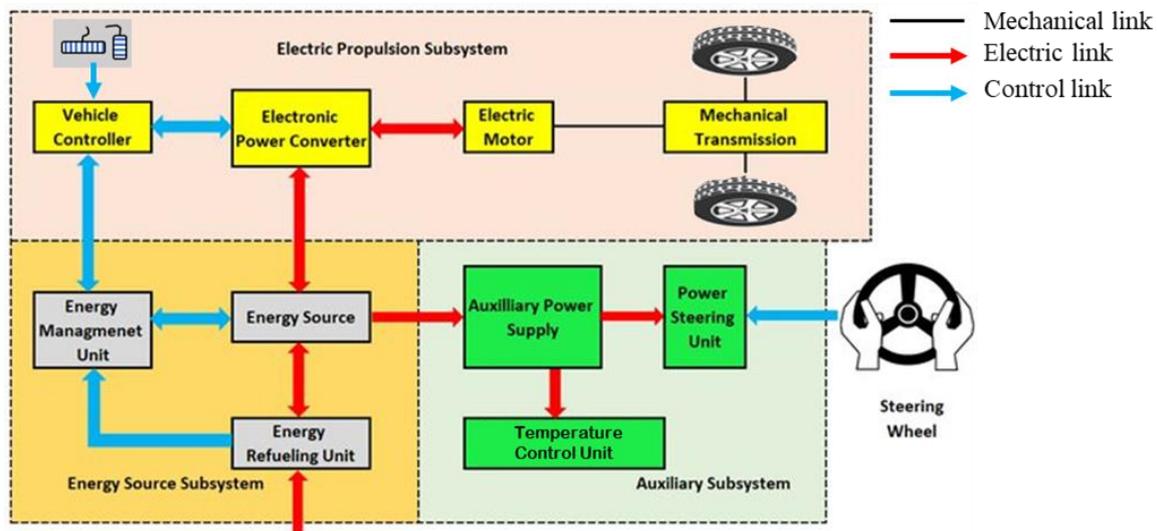


Figure 3. Illustration of an electric vehicle [32].

3.2. Prospect of Electric Vehicle

Incorporation of the EV culture is economically feasible. Whereas the traditional ICE can typically not run at higher than 50% efficiency [34], the EV can run at 85–90% efficiency [35]. Compared to gasoline vehicles that only convert 12–30% of gasoline power to a vehicle's wheels, the EV converts 77% of the grid power to the vehicle's wheels [36]. The estimated efficiency of an EV is 3.59 times higher than that for a conventional vehicle within a 100- to 300-mile range [37]. Plug-in EVs (PEVs) and plug-in hybrid EVs (PHEVs) can boost fuel economy, lower fuel expenditure, and, most importantly, reduce emissions. EV generates 40% fewer GHGs compared to the ICEs [38]. In 2018 alone, EVs resulted in only 38 Mt CO₂-eq, compared to 78 Mt CO₂-eq for ICEs, resulting in no EV on the service [39]. According to the International Energy Agency (IEA), the increased use of the EV fleet had consumed around 58 TWh of electricity in 2018 [40]. China, the largest EV manufacturer, constitutes 44%; Europe 24%, and the USA 22% [40]. China alone accounts for 80% of the total electricity demand for EVs [41].

Though technological sophistication is estimated to bring down the emissions from the ICEs by around 1.9% annually up to 2040, it is foreseeable that the growth and vast adaptation of EVs would reach around 30% of the world's passenger vehicle fleet by 2032 [42]. In 2018, the IEA projected that the global EV counts would reach around 130 million by 2030 [43]. Such a significant EV adoption would impact the existing power grid and energy sector. Sporadic charging and discharging behavior of the EVs in use will affect the system's power quality and load factor; the traditional grids with transformers will be overloaded during the peak hours of operation, and renewable grids with power electronics converters will be faced with increased total harmonics distortion [44]. Thus, the power system needs reinforcement to cope with variable EV loads. However, upgrading distributed generation (DG) infrastructure and grid utilities requires extra cost margins, making the scheme uneconomical. One effective way is to consider the EV charging station as a high-capacity energy storage device and implement the vehicle-to-grid (V2G) technique.

An electric vehicle does not cause any tailpipe emission of GHGs or other air pollution. However, this depends on the mix of electricity sources used. Although electricity production can contribute to pollution, especially air pollution, the US Environmental Protection Agency (EPA) classifies EVs as zero-emission vehicles since EVs do not produce direct exhaust or emissions. The European Union has set a standard on carbon dioxide emission following the Paris Agreement for every vehicle; thus, internal combustion is no longer a favorable option for the customer. Compared to normal ICEs, four-wheeled electric vehicles (E4Ws) cause only 30–50% of environmental costs due to electricity production [45]. EVs can reduce urban air pollution by using renewable energies, including solar, hydro, wind,

and nuclear [46]. EVs also can reduce noise pollution since its engine produces a low noise level. In addition, EVs can help reduce dependency on fossil fuels by 28% [47]. According to the Argonne National Laboratory, substituting ICEs with EVs in the metropolitan area will reduce the volatile organic compound (VOC) and carbon monoxide (CO) by 100%, sulfur oxide (SO_x) by 75%, nitrous oxide (NO_x) by 69%, and particulate matter (PM) by 31% [48].

Moreover, empirical studies have demonstrated that EVs consume lower energy while driving in urban spaces. By the principle of regenerative braking, EVs allow for the recovery of energy while braking. Specifically, the electric motor works as a generator by sending power from the vehicle wheels to the electric motor stored in the battery system. Previous studies found that EVs were much more efficient when driving on “intermittent” urban routes when compared to uninterrupted freeways because the regenerative braking system can regenerate energy [49]. Regenerative braking systems are also said to significantly extend the life of conventional brakes and, as such, shrink brake repair and replacement costs. The opposite occurs in ICE vehicles, which exert additional energy in urban driving because of braking and thermal losses.

Other advantages of EVs are less interior noise and vibration, better low-speed acceleration, convenient home-charging, high fuel economy, and zero tailpipe emissions when the vehicle operates exclusively on its battery. The total cost of ownership (TCO) of EVs is lower than the TCO of ICE. The TCO includes direct and indirect costs, taxes, fees, depreciation, financing, insurance, fuel, maintenance, and repairs [50], since the EV has fewer moving parts than a conventional vehicle. An electric vehicle is also an energy-saving vehicle compared to ICEs. The saving may be as much as 30% compared to an ICE for fuel savings. In most countries, electricity is cheaper than petrol; thus, driving or owning an EV is cheaper than the ICE for service, maintenance, and repair expenses. The electrification of the vehicle in India has helped the country save 44,000 L of gasoline and helps reduce CO₂ by 109,884 kg per day [51]. A study conducted for a well-to-wheel life cycle concluded that EVs save 35% more energy than ICEs [52]. The efficiency of the electrical power structure and transmission is a crucial aspect to consider to extract all the benefits of the EV. Electricity in most countries in the world is cheaper than petrol or gasoline. For instance, electric vehicle consumption is 0.2 kWh/km; thus, for 100 km, it would be 20 kWh. The electricity cost for the first 200 kWh is only 0.28 RM, which is very affordable and cheap compared to gasoline or petrol [53]. Two-wheel electric vehicle (E2W) such as scooters or bicycles are also a good consideration. They do not require any infrastructure for their charging as they come with a portable battery pack that can be recharged using a regular socket outlet in the house or office. Electric buses are also contributing to the lower tailpipe emission in most countries. The EV vehicle adoption in Malaysia has been progressing quite rapidly in the last few years, and thus, stress on the Malaysian grid is constantly increasing. Figure 4 shows the annual projected growth of electricity generation and maximum demand for the Malaysian power grid [27].

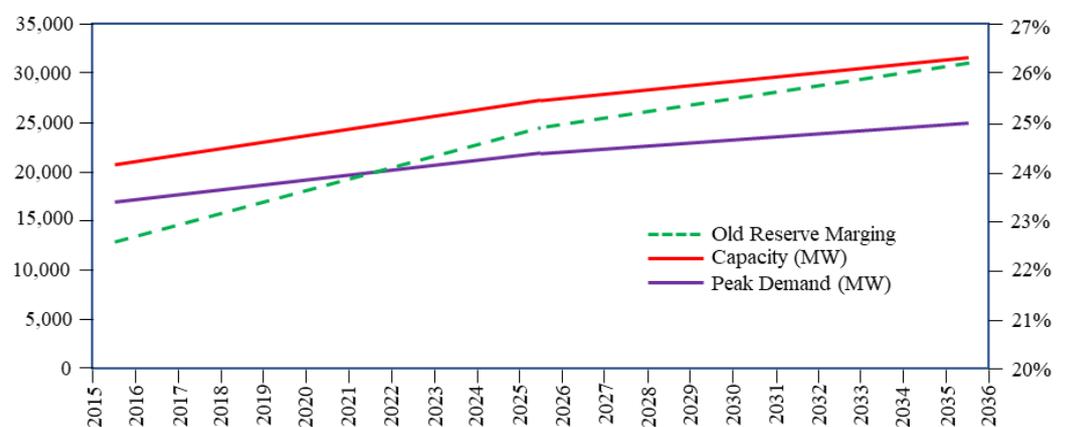


Figure 4. Malaysia’s annual electricity generation and maximum demand projection. Adapted with permission from ref. [27]. 2019 Idris et al.

4. Challenges of EV

4.1. Current Market Price

The high price of prevalent EVs plays a significant role in shadowing the vast acceptance of EV culture. Currently, Malaysia is targeting an EV contribution of 20% of the total vehicle sales by 2025 and 50% by 2035 [54]. Thus, it is imperative to scrutinize the issues that result in such a high purchase price of EVs and try to lessen the high pricing by embedding newer, technically feasible principles and concepts.

4.1.1. High Market Price

The electric vehicle price in Malaysia is expensive compared to the conventional car. The cost of an eco-friendly vehicle, for instance, Myvi 1.5 L AV, is 23.7% cheaper than a MINI Cooper SE with almost the same body structure [55]. On the other hand, Nissan Leaf is 42% more expensive than the Nissan Almera, a sedan with the same passenger capacity [56]. This high price for an electric vehicle is one reason buyers have second thoughts about owning an electric car.

Moreover, the electric vehicle market is relatively new compared to the millions of new and second-hand internal combustion engine vehicles (CV) of different types and price ranges. Table 2 represents a comparison between EVs and CVs, where there is a 12,000 USD gap between the price of an internal combustion engine and an electric vehicle. The price difference is due to the low sales volume and the onboard electronics and the electric motor used for the electric vehicle. The indirect base cost of an EV is also higher than an ICE.

Table 2. Retail Price Comparison between Electric Vehicles and Conventional Vehicles.

Car Model	Retail Price (RM)
Electric Car	
MINI Electric Cooper SE	221,878.00
Nissan Leaf	188,888.00
BMW i3s	278,800.00
Porsche Taycan	584,561.00
Conventional Car	
Myvi 1.5 L AV	52,697.00
Myvi 1.3 L G	43,029.00
Nissan Almera 1.0 L Turbo VL	79,906.00
Proton X50 Standard	79,200.00
Proton Persona	42,600.00

Furthermore, the battery cost is another single contributor to the price difference. It is reported that the Nissan Leaf and BMWi3s have higher manufacturing recommended sales price (MSRP) compared to the Ionia HEV Plus, Jazz 1.5 Hybrid, and Perodua Myvi 1.5. High AT, as the price of components to build an EV is very high during the manufacturing process compared to the operation and disposal stage [25]. The direct and indirect costs of the CV and EV are often considered to impact the average price per vehicle manufactured (Figure 5) [57].

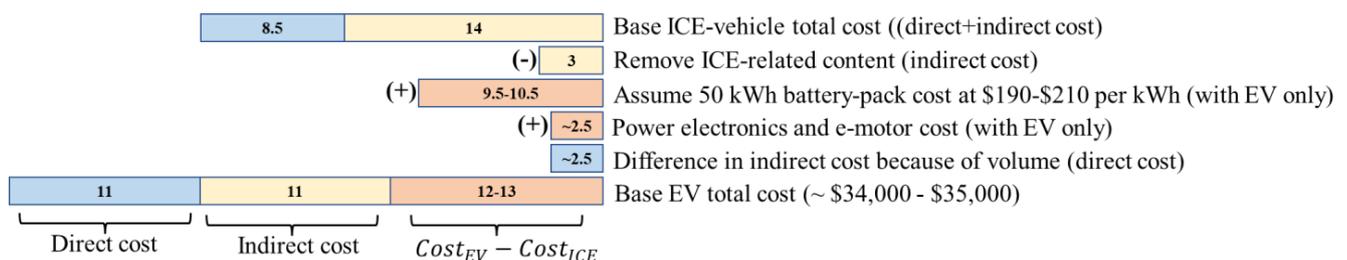


Figure 5. Estimated average cost per vehicle, in thousands of USD [57].

Another reason for the high market price of an electric vehicle is the limited diversity of the car in the Malaysian automotive market and imposed taxes on the imported cars. Only a few electric vehicles are sold in Malaysia: Nissan Leaf, BMW i3s, Mini Cooper Electric, etc. Like other developing countries, a complete built-up (CBU) unit is more expensive than a completely knocked down (CKD) unit in Malaysia. A CBU unit is an imported car from foreign countries, and it comes with heavy excise duties, which most likely range from 60% to 105%, increasing the car's final price [58]. CKD unit is the car assembled by a local manufacturing company; available and sold in Malaysia, making it affordable and cheaper for Malaysians to buy since it qualifies for the government's incentives and exemptions from excise duties.

4.1.2. Battery Price and Raw Materials

One of the major contributing factors to the high cost of EVs is the battery price. It is estimated that the battery price is between a quarter and two-fifths of the cost of the entire electric vehicle. This is owing to the high cost of the raw materials needed in the battery's manufacture, specifically the cathode. The cathode is one of the two electrodes to store and release the charge. Materials such as cobalt, nickel, lithium, and manganese could be used as cathodes but each come with a significant cost burden. Thus, much research has been conducted to reduce the cost of batteries by changing the material of the battery so that the cost can be optimized. Table 3 provides an estimated energy storage system (ESS) specification for different types of EV [33]. Table 4 comprehensively describes conventionally used EV vehicle batteries [33].

Table 3. Specifications of conventionally used energy storage systems for different types of vehicles. Adapted with permission from ref. [33]. 2019, Kumar et al.

Electric Vehicle (EV) Types	System Voltage (V)	Battery (kWh)	Ultra Capacitor (UC) Energy (Wh)	Fuel Cell (FC) Energy (kWh)	Electric Motor (EM) (kW)
Conventional ICE	12	-	-	-	-
Micro-Hybrid EV	12–42	0.02–0.05	30	-	3–5
Mild-Hybrid EV	150–200	0.125–1.2	100–150	-	7–12
Full-Hybrid EV [59]	200–250	1.4–4	100–200	-	40
Plug in Hybrid EV [60]	300–500	6–20	100–200	-	30–70
All EV [60]	300–500	20–40	300	150–200	50–100

Table 4. Operating features of commonly used electric vehicle batteries. Adapted with permission from ref. [33]. 2019, Kumar et al.

Type of Battery	Nominal Voltage (V)	Energy Density (Wh/kg)	Specific Power (W/kg)	Life Cycle	Self-Discharge (% per Month)	Operating Temperature (°C)	Production Cost (\$/kWh)
Lead-acid (Pb-acid)	2.0	35	180	1000	<5	−15 to +50	60
Nickel-cadmium (Ni-Cd)	1.2	50–80	200	2000	10	−20 to +50	250–300
Nickel-metal hydride (Ni-MH)	1.2	70–95	200–300	<3000	20	−20 to +60	200–250
Nickel-iron (Ni-Fe)	1.2	60	100–150	2000	20	−10 to +50	150–200
ZEBRA	2.6	90–120	155	>1200	<5	−245 to +350	230–345
Lithium-ion (Li-ion)	3.6	118–250	200–430	2000		−20 to 60	150
Lithium-ion polymer (LiPo)	3.7	130–225	260–450	>1200	<5	−20 to 60	150

Table 4. Cont.

Type of Battery	Nominal Voltage (V)	Energy Density (Wh/kg)	Specific Power (W/kg)	Life Cycle	Self-Discharge (% per Month)	Operating Temperature (°C)	Production Cost (\$/kWh)
Lithium-iron phosphate(LiFePO4)	3.2	120	2000–4500	>1200	<5	−45 to 70	350
Zinc-air (Zn-air)	1.6	460	80–140	200	<5	−10 to 55	90–120
Lithium-sulfur (Li-S)	2.5	350–650	-	300	8–15	−60 to 60	100–150
Lithium-air (Li-air)	2.9	1300–2000	-	100	<5	−10 to 70	-
Ultra capacitor-Double layer capacitor	-	5–7	1–2 M	40 years	-	-	-
Lead-acid (Pb-acid)	2.0	35	180	1000	<5	−15 to +50	60
Nickel-cadmium (Ni-Cd)	1.2	50–80	200	2000	10	−20 to +50	250–300
Nickel-metal hydride (Ni-MH)	1.2	70–95	200–300	<3000	20	−20 to +60	200–250
Nickel-iron (Ni-Fe)	1.2	60	100–150	2000	20	−10 to +50	150–200
ZEBRA	2.6	90–120	155	>1200	<5	−245 to +350	230–345
Lithium-ion (Li-ion)	3.6	118–250	200–430	2000	<5	−20 to 60	150
Lithium-ion polymer (LiPo)	3.7	130–225	260–450	>1200	<5	−20 to 60	150
Lithium-iron phosphate (LiFePO4)	3.2	120	2000–4500	>1200	<5	−45 to 70	350
Zinc-air (Zn-air)	1.6	460	80–140	200	<5	−10 to 55	90–120
Lithium-sulfur (Li-S)	2.5	350–650	-	300	8–15	−60 to 60	100–150
Lithium-air (Li-air)	2.9	1300–2000	-	100	<5	−10 to 70	-
Ultra capacitor-Double layer capacitor	-	5–7	1–2 M	40 years	-	-	-

The total final cost of a battery comprises the raw materials, cell/module purchased, hardware, battery packaging, and the manufacturer's final price of battery installation. In 2019, research focused on BatPac. It showed that the cost of raw materials such as positive and negative electrodes, electrolytes and separators, and the purchased hardware are extreme in contributing to the cost of a battery. In addition, the finalization or the finishing process of a battery also dominates the share of the battery cost. However, the labor cost per pack does not heavily impact the battery price. In addition, imported parts to build a single car and packaging of single parts will make the manufacturer likely to increase the production cost. Thus, the retail price becomes higher. Moreover, the techno-economic feasibility of EVs needs to be ensured by conducting battery life cycle cost (LCC) analysis. In an investigation focusing on the EV culture of Brunei, it was demonstrated that an initial subsidy of 4100 USD and an increase in gasoline prices to 0.70 USD/liter would allow EVs to compete with ICEs comfortably in the market.

4.1.3. No Mass Production

Another contributing factor to the high price of EVs is the lack of a potential marketplace for the EV. In Malaysia, the number of EVs displayed in the retail points is less than a hundred. The lack of a prominent EV culture and marketplaces hinders the motivation for the mass production practice of EVs in Malaysia. Eventually, it will fall to manufacturers and dealers to set a spiking retail price for the electric vehicle. A similar situation has been reported in China. It is said that automakers in China are having difficulty in fully implementing electric car production lines as the demand in China is relatively low despite many incentives given out, which is described as being “hot policy” but “cold market” [61]. The conclusion was driven by the low number of electric cars sold in 2017, which only accounted for 1.62% of the total number of vehicles sold in that particular year in China.

From the industry perspective, it is also difficult to reduce the production cost for EVs. For example, BMW introduced its first electric car in 2013. However, it did not mass produce the BMW electric car until 2020 because the technology was said to be not profitable to mass-produce at that time [62]. However, a price difference between the fourth and fifth technology of BMW electric car is reported to be two-digit. Thus, even stepping to the next generation of technology cannot curtail the manufacturing cost significantly while meeting the expected features and functionalities. Apart from that, a total revamp of the manufacturing and assembly lines of ICE need to be carried out to accommodate the production and assembly of the EVs adequately. This is because the assembly of an EV is utterly different from an ICE.

Moreover, an electric vehicle can be tested during assembly to assess its workability, which differs from an ICE, which can only be tested when completely built because it produces a tailpipe emission. These changes in the manufacturing processes come with a high cost, and thus it makes the manufacturer think twice before considering the mass production of the EVs.

4.1.4. COVID-19

As the world is undergoing a challenging time due to the pandemic since 2020, the production and sales of new vehicles are put on hold as most countries are implementing lockdown, and manufacturers have to wait for the lockdown to be lifted [63,64]. The shortage of supplies, especially batteries, greatly impacts the manufacturer. For instance, Audi halted output for its electric sport utility vehicle (SUV) in February 2020 due to battery-supply bottlenecks and shorts of 1600 units from its 2020 target [65]. Jaguar and Mercedes are also pausing production due to the unavailability of crucial components for the battery, usually supplied from LG Chem, Korea. Moreover, policies for using lower work hours and fewer employees in the workspace for public safety from the spread of the pandemic have also resulted in an increasing number of unemployed workers; electric vehicle manufacturing companies are thus trying to garner their profit by uplifting the EV sell price.

4.2. Travel Demand (Battery Capacity)

Since EVs run on electricity, range anxiety is one of the driver’s most significant concerns [66]. The drivers must ensure that the EV is fully charged before going out for their next long drive. This limited capacity of electric batteries reduces the driving range. It makes the consumer disinterested in owning an EV since, in some cases, drivers might need to reroute from their original travel trajectory to refill the batteries. The range of an EV is also dependent on the load being carried by the EVs, and other factors such as cabin climate control, etc. In one survey, around 75% of American drivers stated that the driving range is the main drawback of owning an EV [67]. To make matters worse, deviation from the usual departure schedule could result in the driver being stranded with no power to run the EV [68].

The EV uses high-density lithium-ion batteries, requires minor maintenance, is less susceptible to memory effects, and needs no scheduled cycling [69]. However, according to

Han, Lu [70], 100% battery discharge is not a good practice to ensure the maximum battery life cycle; such an approach makes the batteries degrade faster over several charging and discharging cycles. Therefore, charging rate, environment temperature, battery management, and charging behavior also affect the battery life and the EV range. The usage of lithium-ion batteries is usually considered the best option for EVs. However, the Li-ion battery technology does not reach the theoretical highest boundary for energy density.

Furthermore, the lithium-ion battery is said to reach its physicochemical limit. It takes 17 h to fully charge an EV, which is not feasible for a potential EV consumer, especially for commercial long-trip scenarios. Therefore, the research should focus more on improving the battery energy density and temperature range and developing control systems that cater to the mileage.

Table 5 summarizes EV battery capacities and ranges for EVs inside and outside the Malaysian border. According to the table, the range of the travel distance depends on the battery capacity. Higher battery capacity results in longer distances. Thus, to travel from Kuala Lumpur to Chukai, Terengganu, the Mitsubishi iMiev, MINI Cooper SE, BMW i3s, and Nissan Leaf need to recharge halfway as the distance to be traveled is 297 km (Figure 6). However, there is no charging station in Chukai, and only a few charging stations are currently located along the Lebuhraya Pantai Timur (LPT). This is a problem for small battery capacity vehicles. In addition, it will increase the driver's anxiety about being stranded on the road without a battery charged sufficiently to reach the destination.

A few research studies conducted in 2016 have concluded that a bigger battery capacity results in a heavier battery weight (Figure 7); thus, it affects the vehicle weight and eventually reduces the range of the electric vehicle [71–73]. As a result, in Table 5, the battery manufacturer must develop lightweight batteries with high energy density to make a more extended range of travel possible. This will decrease the hesitancy of people to own an electric car.

Table 5. Electric Cars' Battery Capacity and Range.

Car Model	Battery Capacity (kWh)	Range (km)
EV available in Malaysia		
Mitsubishi Imiev	16.0	150
MINI Electric Cooper SE	32.6	234
Nissan Leaf	40.0	270
BMW i3s	42.2	260
Porsche Taycan	79.2	354–431
EV available outside Malaysia		
Smart EQ forfour	16.7	95
Renault Twingo Electric	21.3	130
Honda e Advance	28.5	170
Mazda MX-30	30.0	170
BMW i3	37.9	235
Hyundai IONIQ Electric	38.3	250
Renault Zoe ZE40	41.0	255
Volkswagen ID.4 Pure	52.0	285
Audi e-tron 50 quattro	64.7	280
Audi Q4 e-tron	76.6	385
Mercedes EQC 400	80.0	370
Ford Mustang Mach-E ER AWD	88.0	420

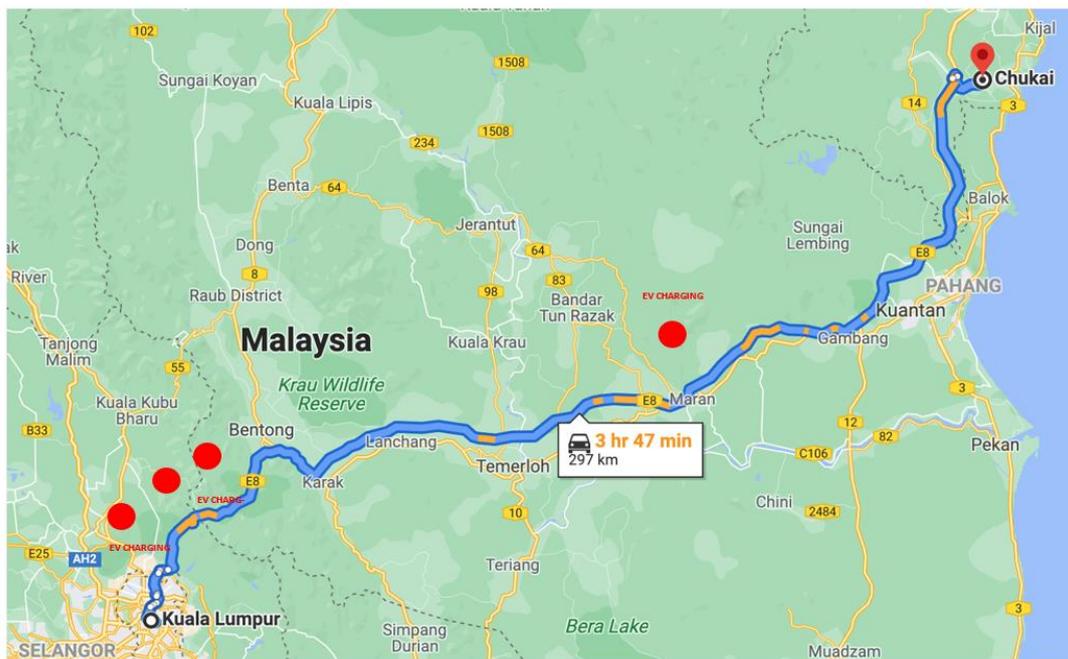


Figure 6. Location of EV Charging Station along LPT (Red dots refer to the available charging stations' location).

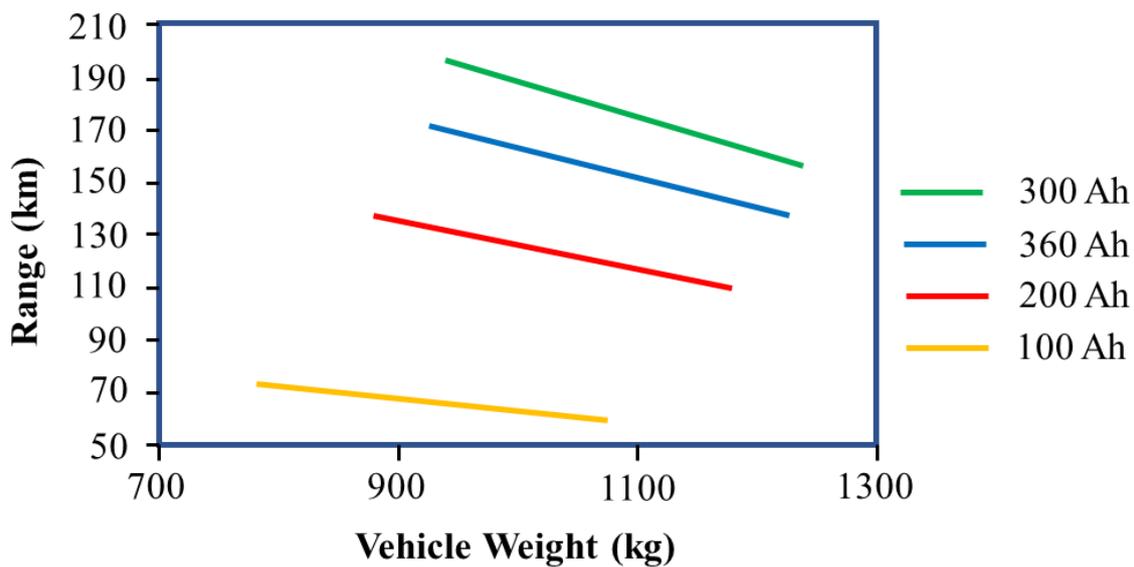


Figure 7. Effect of vehicle weight on the range. Adapted with permission from ref. [73]. 2016 Mruzek et al.

4.3. Charging Infrastructure

The lack of availability of charging stations along the driving path is another core issue for EV users. Charging stations in most countries are concentrated around a specific neighborhood, which creates a dilemma for the users as to when and where to get served [68]. For example, as reported by the Malaysian Automotive Association (MAA), Malaysia currently has 4000 EV charging stations which are primarily distributed in big cities on the western side of Malaysia; Kuala Lumpur, Selangor, Pulau Pinang, and Johor Yusof [74], as shown in Figure 8 [75,76] and not widely available in the east and east coast of Malaysia.

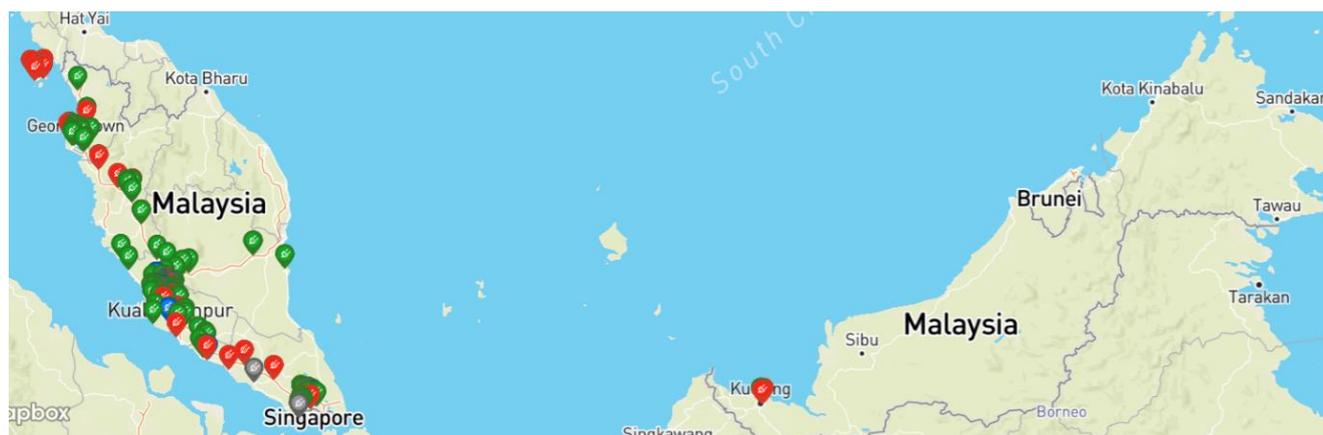


Figure 8. Distribution of Charging Stations in Malaysia. Adapted with permission from ref. [76]. 2022 EV Charger.

Four chargers are highly circulated across the EV market, indicating Level 1, Level 2, Level 3, and Level 4 chargers [77]. Level 1 and Level 2 chargers operate using alternating current (AC); the electricity can be fed directly from the local distribution system and converted into direct current (DC) via an onboard inverter in an all-electric car. Level 3 and Level 4 chargers operate by DC and are commonly installed only in commercial locations. According to ChargeNow, BMW's global e-Mobility service monitor in Malaysia for EV chargers, Malaysia has only 3.7 kW, 7 kW, 11 kW, and 22.0 kW AC and only three units of DC chargers nationwide [78]. Thus, Malaysia requires a higher charging infrastructure with a higher capacity and fast charging capabilities.

However, to accommodate the growing number of chargers required, there comes the challenge of dispatching efficient charging mechanisms, which directly calls for an upgrade in the distribution network, including distribution lines and cables, transformers, and feeders. This requires extensive network stability analysis and needs reconfiguration of power energy delivery methods to ensure that the phase imbalance, harmonic injections, and protection system is sufficient for the additional charging infrastructures [47]. In Norway, it is observed that when EVs are charged in a considerable density in a closed proximity or neighborhood, it causes a spike in power dip. To cope with such a momentary but high magnitude of load-scheduling, expensive reinforcement for the grid is required. Establishing large-scale charging also calls for proper network and intelligent technology management.

Moreover, it is crucial to analyze the design aspects of power systems; the grid or any power station is sized based on the demand diversity, not the maximum demand. A study by My Electric Avenue showed that 32% of low voltage (LV) feeders (312 kV circuits) are affected when 40–70% of customers own an EV. This study is only based on the 3.5 kW (16 Amp) chargers [79]. This is one of the challenges in establishing charging infrastructure in residential areas. In such a case, the underground cable will have to be dug out and replaced by a more prominent capacity conductor to bear the increased load demand.

Establishing public charging infrastructure with fast chargers is another significant economic challenge. According to the Malaysian EV Owners Club (MyEVOC), the public charging procurement and installation process of 10 rapid charging stations with 50 kW DC chargers requires at least 1.5 million RM to 2 million RM. The cost will be much higher if extra electrical work is required. Thus, it is imperative to analyze the correct location to install the public charger so as to require minimum additional works related to power infrastructure and have a lesser impact on the power profiles of the housing areas. It is also important to overcome the information gap between gathering and sharing data related to EV implementation. The EV charging pattern and charging station should be broadcasted, and failure in sharing will affect both the power companies and EV users. The information on EV driver travel habits, routes, and discharging trends will help determine the strategic location to effectively and extensively invest in the charging infrastructure development.

Furthermore, as most utility providers apply peak and off-peak pricing for the electricity, the data sharing will enable users to choose charging methods based on their budget.

Another challenge while making policies for charging infrastructure is the limited number of currently available standards for the chargers. Different regions of the world have considered different types of standards for EV charging. The standards being used in North American countries (the SAE-J1772 [80]) and China (the GB/T 20234 [81]) are classified based on the level and type of power (DC/AC) being used to charge. The IEC-62196 [82], proposed in 2001, is primarily used in European countries and part of China. The IEC-62196 classified the charging process based on the nominal power used and the associated charging time. Among others, a standard set by CHAdeMO is used in Japan and by Tesla when manufacturing EV components and infrastructure. The IEC-62196-2 [83] and IEC 61851-1 [84] comprehensively deal with the design and consideration of the EVCS's outlets and plugs and the EV's connectors and inlets. The difference between American and European standards lies in the charging mode; American standards consider the power type (AC or DC), and European standards focus on the power output delivery [85]. Therefore, it is essential to properly understand the standards and make policies in line with them. The use of varying standards will be very challenging, specifically for home charging, as the owner needs to know which charger must to be used for the electric car purchased by them.

4.4. Charging Time

The charging time also varies according to the level of the chargers (Level 1 to Level 4). Level 1 corresponds to the built-in charger in most EVs using household power sockets and does not require additional circuitry. It is found that the charging of a 24 kWh Nissan Leaf using a Level 1 1.4 kW residential outlet will need nearly 17 h to charge the battery fully [86]. Level 2 chargers are three-phase chargers that can charge the EV to full capacity in approximately 7 to 9 h. For example, a Level 2 charger (6.6 kW) requires 7 h to fully charge the battery of a Nissan Leaf [69]. Level 3 and Level 4 chargers use advanced DC charging techniques to charge the EV battery directly. These superchargers can charge 80% of the battery in 15 to 20 min [68]. However, charging with superchargers more than two times a day is not advisable to preserve improved battery life. Thus, charging an EV battery using a normal charger will be much more time-consuming unless the EV owner has Level 3 or 4 chargers or lives near the spots that provide superchargers. Moreover, the charging is no longer attractive and feasible for an EV housed with a 70–100 kWh battery [87]. For instance, it will take 50 h to charge a 70 kWh battery of a Tesla car if a normal wall outlet is considered, and 11 h using a 6.6 kW outlet [88].

Table 6 represents a list of charging times required for different EV models with their onboard battery capacity and the rating of the charger used. For example, home charging requires only 3 kW and 7 kW chargers. On the other hand, a 22 kW charger needs a three-phase connection and is typically expensive to install. Usually, the purchased EV car comes with a wall plug charger for that particular manufacturing company. For instance, the charger rating for a Nissan Leaf is 11 kW (AC) and 6.6 kW for home charging. This is a huge advantage for the purchaser as it will give ample time to charge the electric car, especially during the night. This also helps to increase the available charging time before the car is used during the morning office hours. In this regard, the EV owners should plan their time and activity focusing on the charging period to avoid unforeseen circumstances, such as the vehicle running out of battery charge. Furthermore, since the charging period is quite lengthy, and the available charging infrastructure is quite sparse, ample time will be wasted if the user has to wait in a queue to get their EV recharged from a public charging station. Thus, charging time plays a major role in the psychology of the users when choosing an EV and in the decision to become an EV user by the mass population.

Table 6. Electric cars' Charging time.

Model	Battery (kWh)	Charger Rating (kW)	Charging Time
Nissan Leaf	40	6.6	7 h
		50.0	1 h
MINI Electric Cooper SE	32.6	11.0	2.5 h
		50.0	35 min
BMW i3s	42.2	11.0	3.1 h
		50.0	45 min
Porsche Taycan	79.2	11.0	8 h
		50.0	2 h

4.5. Safety and Risk

The safety and risk measures in handling an EV sometimes overwhelm people. Since the EV culture is new, there is less chance of properly maintaining the user's vehicle in their household as is often the case with CVs. This results in ambivalence in purchasing an EV. EVs should comprehensively be provided with protection. As an electric car is operated fully on an electrical system, it should be a good reminder and practice to evaluate electricity's risks and safety issues. Electrical parts of the propulsion system must be protected from direct contact and covered with a protective layer. It can also be placed where it is not accessible directly or outside the car. If there are any issues with the electrical part, it should only be taken off by using proper tools or keys. The electric vehicle charging ports should also be isolated to avoid electrical shock. Other than that, the battery parts of the EV have the risk of explosion and potential electrical, mechanical, and chemical danger. The design of an electric car should avoid any short circuit and electric shock for the battery, whereby it can be provided with safety features such as a fuse and locking mechanism when multiple batteries are used. The battery should also be placed in a stable position to prevent damage during a car crash. In an accident, the inherently high-density battery could catch fire. Thus, the reliability of the battery and thermal management systems should always be high priority. Charging time should also be properly maintained so the battery outlets are not kept open and unattended.

Moreover, the effect of EV forces on the human brain during driving needs to be estimated properly. In [89], a twelve degrees of freedom (12 DOF) human biodynamic model is incorporated with a two-in-wheel electric car model to investigate the effect of vertical vibration on the human brain based on different types of road profiles and maneuvers. It is concluded that the comfort level experienced by the driver or passenger is significantly reduced by traveling at the rate of 72 km/h for a 5 to 6 h journey on a smooth road with passive suspension systems, suggesting that vehicular conditions, as well as road profile, does affect its users.

In [90], a simulation model of a two rear in-wheel motors is used to analyze the effect of vehicle load on longitudinal and lateral forces. It is observed that an additional load added on the side of the direction of lateral motion increases the lateral force generated and causes the tires to approach the tire friction circle limit, thereby reducing EV performance. It is also important to improve the EV braking control system to increase the safety and stability of the vehicle, especially when driving on icy roads. According to [91], an anti-lock braking system (ABS) and regenerative brake control could improve the braking performance of small EVs.

It is also required to have a skilled technician during maintenance for the electrical and mechanical parts of the vehicle as the electric vehicle is relatively new, especially in Malaysia. This ensures that all parts are assessed and handled correctly to avoid safety issues. It is wise to have regular check-ups on the basic maintenance for safe operation, including checking the earth leakage current and battery status. The tools used for electric car maintenance should also be properly insulated, and protective gear or safety clothing should be strictly followed during electric vehicle checking.

Three main risk factors should be considered during charging time (Figure 9) [92]. As for the owner, owners must be cautious regarding the over-current, over-voltage, and short circuits during charging. Power grid providers should properly maintain the power quality, sags, power line harmonics, and voltage dips near the charging points. Finally, constant maintenance ensures no insulation and leakage issues during fast and ultra-fast charging. To ensure the charging equipment is safe for the public, a few standards have been devised in China that can also be followed elsewhere. The standards related to the safety and protection of EVs are summarized in Table 7 [92].

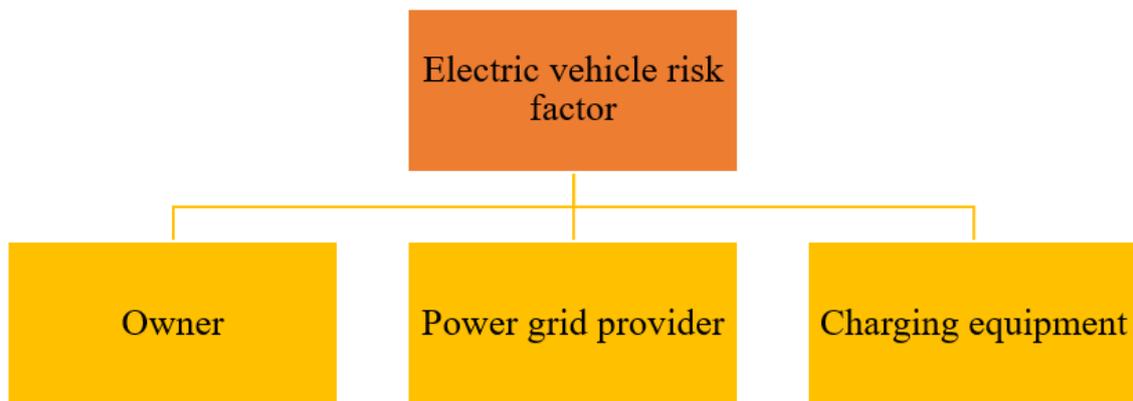


Figure 9. Electric vehicle risk factor.

Table 7. Safety protection standard for electric vehicles [92].

Testing Items	Reference Standard
USER	
Impulse current	GB/T 18487.1-2015 9.7
Overcurrent protection	GB/T 18487.3-2001 10.3
Overvoltage protection	GB/T 18487.3-2001 10.3
Temperature requirement	GB/T 18487.1-2015 13
Charing cable overload protection	GB/T 18487.1-2015 11.6
Charing cable short circuit protection	GB/T 18487.1-2015 12.2
Noncontact electric shock protection	GB/T 18487.1-2015 12.3
Electrical interlocking inspection of protective conductors for electric vehicles	GB/T 18487.3-2001 9.1
POWER GRID PROVIDER	
Voltage deviation	GB/T 18487.1-2015 10.5
Unbalanced three-phase voltage	GB/T 12325.1-2008
Total harmonic distortion	GB/T 15543-2008
Voltage flicker	GB/T 14549-93
Voltage sag and short supply interruption	GB/T 30137-2013
CHARGING EQUIPMENT	
Contact protection	GB/T 18487.1-2015 7.2
Capacitor discharge	GB/T 18487.1-2015 7.3
Protective earthing conductor	GB/T 18487.1-2015 7.4
Contact current	GB/T 18487.1-2015 11.2
Insulation resistance	GB/T 18487.1-2015 11.3
Dielectric strength	GB/T 18487.1-2015 11.4
Impulse withstand voltage	GB/T 18487.1-2015 11.5
Lightning protection	GB/T 18487.1-2015 11.7
Electrical clearance and creepage distance	GB/T 18487.1-2015 10.4
IP protection level	GB/T 18487.1-2015 10.5

5. Potential Solutions and Future Research

For EVs to be well received by the consumers and full adoption of EV in the transport system, some areas need to be enhanced. Some of the major challenges outlined in the previous section are addressed with current literary practices. This would help in an improved circulation of EVs in the Malaysian local market and will be able to garner public interest in buying more EVs for themselves.

5.1. Current Market Price

The battery cost is the major contribution to the high market price of an electric vehicle. Battery cost accounts for around 50% of the total cost and directly influences the affordability of electric vehicles to the consumer [93]. Thus, it is crucial to identify battery cost reduction strategies to solve the high market price of EVs. One way is to have a local battery cell manufacturer that can increase the availability of critical cell components such as lithium, cobalt, and graphite. Locally available components also cost less than the imported goods, including tax and unnecessary expensive fees, and stress with the delay that comes with it. Moreover, additional industrial practices need to be implemented to produce and extract raw materials for battery and EV components while removing problems such delivery delays, high production costs, and shortage of components. This will eventually result in a smooth production line for the EV battery pack.

The battery pack price has noticeably declined over the last decade; an 89% reduction has occurred from 2010 (11,000 USD/kWh) to 2019 (156 USD/kWh). By 2023, the battery price is expected to decline to 100 USD/kWh. As shown in Figure 10 [94], the battery pack's cost decreased primarily due to the steady growth of the battery market size. In addition, the higher battery demand and manufacturer competition have improved manufacturing equipment, reduced manufacturing capital expenditure, and increased high energy density cathode penetration [94]. As a result, the cost of the cathode materials has also been reduced since 2018 [95]. A decline in the battery cost will eventually lower the cost of electric vehicles [96]. Apart from the reduced cell cost, assembly costs should also be reduced. The battery and assembly cost reduction should not affect the battery efficiency margin or charge density level. For example, it is estimated that the cost of the battery pack for the Chevrolet Bolt (60 kWh, 145 kW battery pack) in 2025 will reach ~8000 USD compared to 11,500 USD in 2017 [97]. Another study focused on the Nissan LEAF's battery reported that its cost was previously 500 USD/kWh in 2013, and it costs only 200 USD as of 2020 and is expected to further reduce to 100 USD/kWh in the future [85]. When that happens, the driving range of EVs will extend, and EVs will become cheaper and more attractive than conventional internal combustion vehicles.

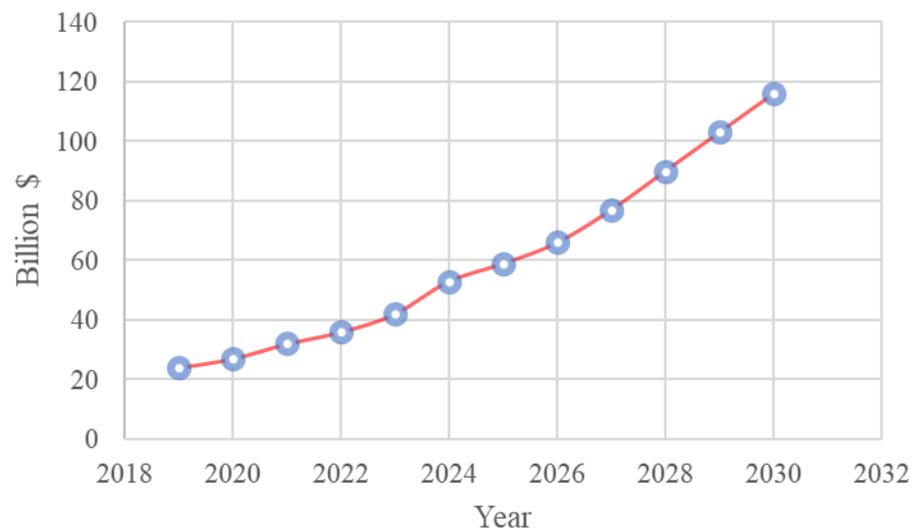


Figure 10. Annual lithium-ion battery market size [94].

Technological advancement and research and development (R&D) per vehicle also contributed to the retail price of an EV and are described under indirect cost. Other indirect costs include depreciation, amortization, and administration expenses. The indirect costs are also expected to be curtailed from 10,584 USD (in 2017) to 3200 USD by 2025 [96].

Another way to cut the cost of EVs is to increase the collaboration of the big equipment manufacturers (OEM) with EV startup fleets to start custom-designing the vehicle by themselves. This reduces the complexity of EV design and discards the need for extra displays, buttons, wiring, unnecessary structural components, and modules. Custom EVs designed under the industry R&D wing could also improve EVs' efficiency by providing more space for the battery pack, which in return gives out a higher driving range. Such a practice will increase the volume of electric vehicles in the market with various prices, features, and specialties. This will eventually make the market more competitive, reducing the cost for the consumers.

Figure 11 shows the global sales of EVs from the year 2010 to 2019 [63]. It is noticeable from the figure that EV sales in China have seen rapid growth from the year 2010 to 2018. Although China's current market has reached a steady limit, European markets are expensively carrying out EV sales, partly due to the increased inclination to tackle climate change, socio-economic outlook, and acceptance of the Paris agreement. It is also important to observe from Figure 11 that the developing and under-developed economies, especially the third-world countries, have negligibly contributed to EV sales and practices. However, the number of sales is increasing rapidly every year, and it is expected to increase steadily for 5–10 years. The increase in sales volume will decrease the market price soon. With the decline in battery price, the related cost of an electric vehicle will also continue to drop; however, any innovation in the battery technology should be backed by sophisticated technological competency, chemical potentiality, scalability, and space for further improvements. It is estimated that by 2025, the price of an electric vehicle shall be reduced with a margin of 5100–5700 USD per vehicle (Figure 12) [57]. The growing EV market and increased competition between manufacturers to produce EV vehicle parts, high-density batteries, and fast-charging features will further curtail the EV retail price.

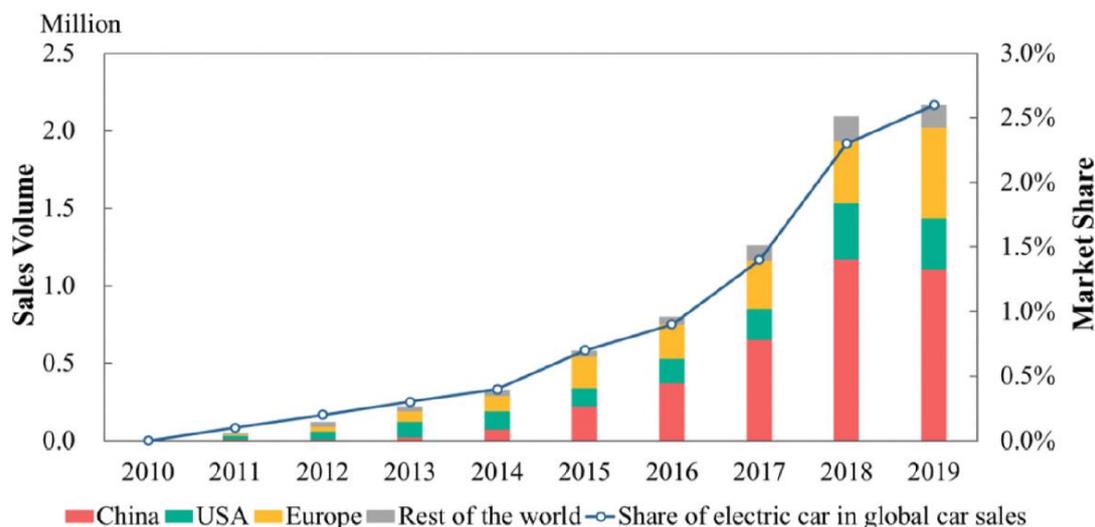


Figure 11. Sales of electric vehicles globally. Adapted with permission from ref. [63]. 2021 Wen et al.

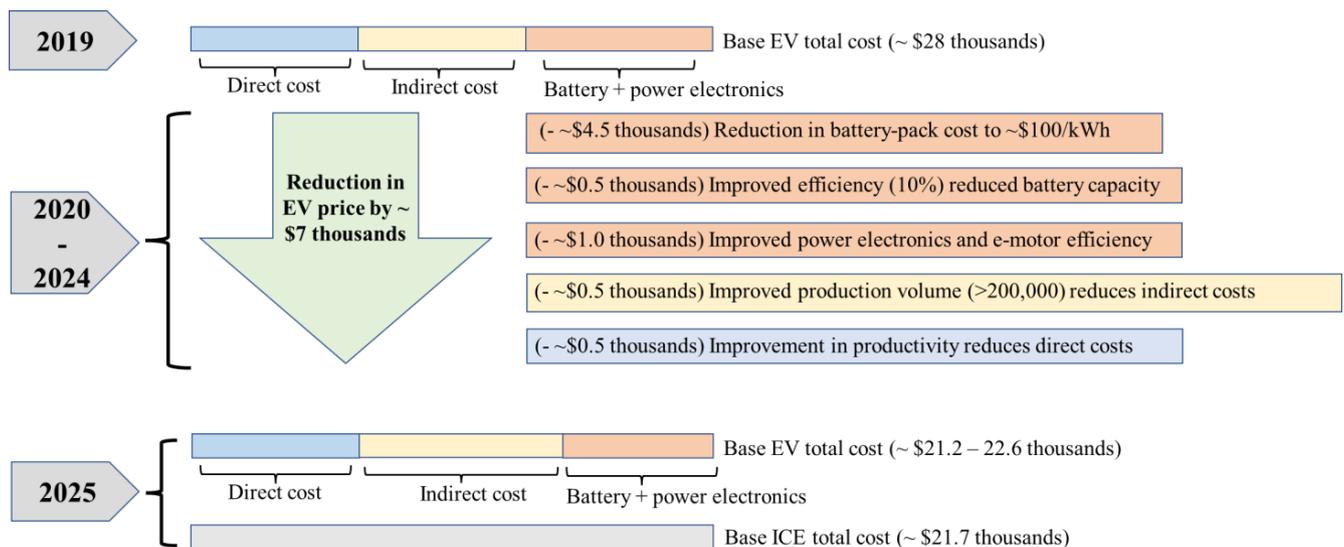


Figure 12. Estimated cost of EV in 2025, thousands of USD [57].

5.2. Travel Demand (Battery Capacity)

As range anxiety is the biggest barrier to the largest EV adoption, the need for safer, cheaper, fast charging, and high-density battery is high. The EV Everywhere Grand Challenge has been established by the US Department of Energy (DOE) to continue to make lithium-ion batteries more affordable for consumers. The grant aims to attain 125 USD/kWh, 250 Wh/kg, 400 Wh/L, and 2000 W/kg by 2022 [98,99]. Other than that, the DOE is also looking into a new concept in lithium-ion technologies that have the potential to double the performance and significantly reduce the cost, as well as inaugurating the “Beyond lithium-ion” practice, which includes lithium-metal, lithium-sulfur, lithium-air, and non-lithium material. Japan aims to quadruple the battery energy density to 500 Wh/kg by 2030 by using lithium-air and lithium-sulfur batteries [100].

A few exceptional battery technology development techniques also exist that utilize lithium iron phosphate, magnesium-ion, lithium-metal, lithium-air, aluminum-air, sodium-air, and graphene to improve the battery capacity of EVs [85]. The concept of solid-state battery technology has almost hit the maturity level. It is considered to be very promising in terms of building high-capacity capacitors and high-density storage units. A class of high-capacity solid-state batteries will hit the EV markets within the next 5–10 years [101]. Additionally, Nissan Global recently introduced a new high-capacity, lightweight, and compact design of lithium-ion batteries to the market. This contemporary 62 kWh battery adopts a nickel–cobalt–manganese (Ni-Co-Mn) positive electrode material and laminated-structure cells to provide higher energy density and more reliability with increased travel distance [102]. As shown in Figure 13, from 2010 to 2019, the battery capacity was nearly tripled, and the cruising distance improved by more than 120% [103].

Among other practices, the layered structure of the Ni-Co-Mn as the positive electrode material is often considered. The layered arrangement increases battery storage capacity by allowing several lithium-ions to be stored. A laminated battery cell structure is also prevalent, which features a mundane construction but a very high level of cooling performance; this saves space and reduces the overall size of the battery pack [104]. Furthermore, due to its exceptional longevity and reliability, this battery capacity comes with a warranty of 160,000 km drive or an eight-year-long service period [105]. Figure 14 summarizes a few unconventional growths of battery cell configuration to reduce battery housing size and improve battery lifetime and performance [103]. Figure 14 summarizes battery assembly configuration to reduce battery housing size and improve battery lifetime and performance [103].

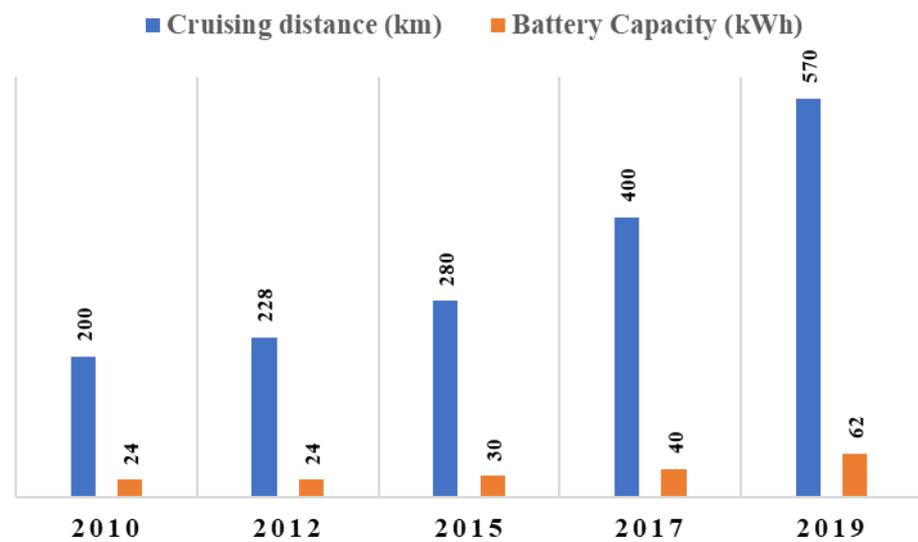


Figure 13. Improvement of Lithium-ion Battery [103].

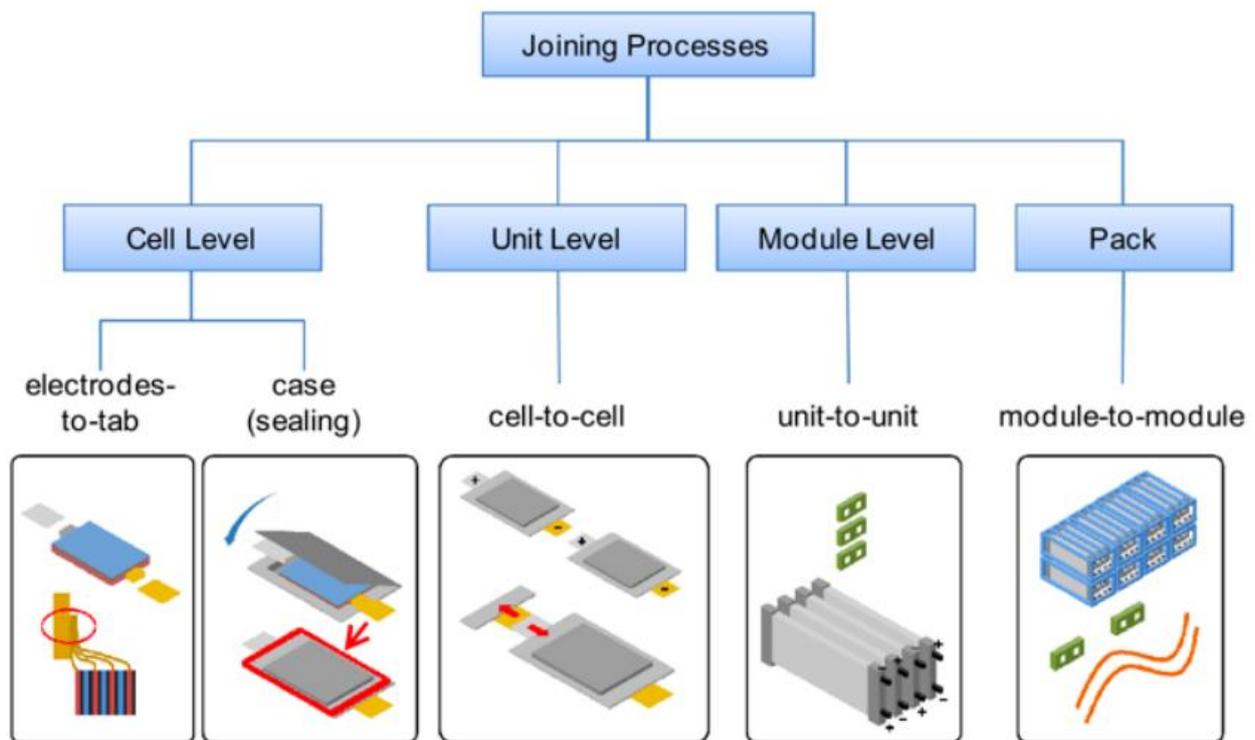


Figure 14. Automotive battery assembly packs [103].

However, before fully shifting towards newer and innovative technological advancements coming from newer types of materials, the cell chemistries of lithium-ion batteries should be fully optimized. New materials could then be considered for improvement in terms of high energy density, low-battery size, lower battery weight, and dispatch controlling arrangements for proper charge-discharge cycle scheduling and thermal stability maintenance. In addition to seeking newer battery technology, advancement in battery management systems (BMS) can significantly boost the EV run range per unit battery discharge. BMS is important to control and manage the amount of energy the battery provides while matching the detailed safety and reliability as stated in the EVs' specifications.

A proposed BMS architecture focused on safety and reliability is demonstrated in Figure 15 [106]. This architecture provides sufficient space to include data storage, data

processing and acquisition, communication, electrical management, and thermal management. Furthermore, since very high temperature is a common problem with EV batteries and power electronics present in EVs, thermal reliability should always be maintained. However, additional research needs to be carried out on the BMS system to make a feasible solution for a long-trip run of the EVs per charging session.

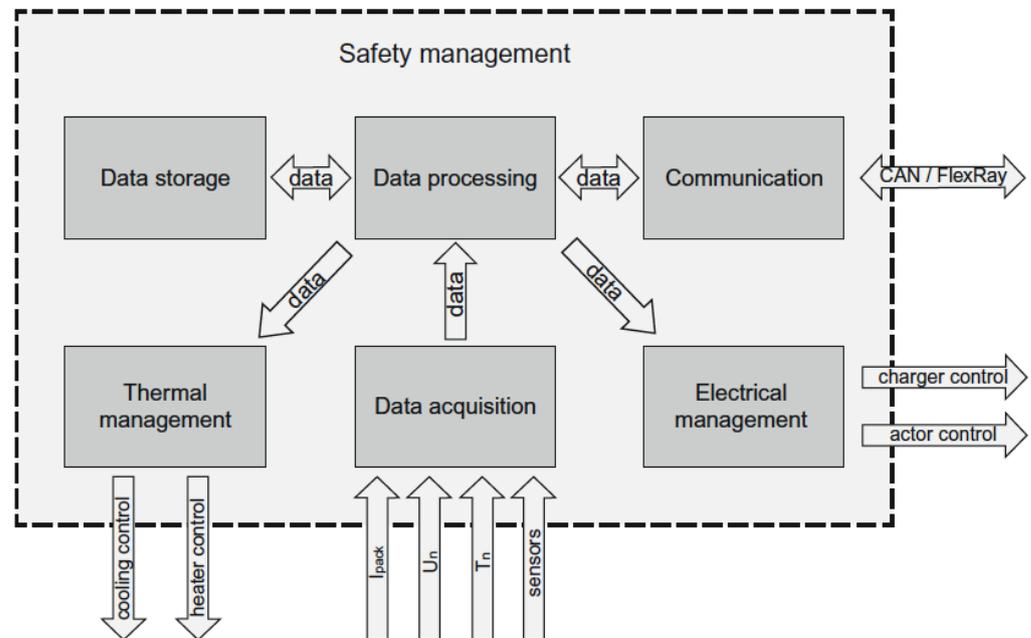


Figure 15. Components of the Battery Management System (BMS). Adapted with permission from ref. [106]. 2015 Hauser et al.

An electric vehicle's weight and body shape also influence the available range. The number one contributor to the heavy-weight vehicle is the weight of the battery pack. The higher the capacity of the battery, the heavier the battery; for instance, the weight of a 1.1 kWh lithium battery is about 10 kg, 7.4 kWh lithium battery is 80 ± 20 kg, and 31.8 kWh is 290 ± 160 kg [107]. Thus, it is imperative to introduce the development of a lightweight battery pack to extend the travel distance for an electric vehicle. Moreover, a recent study conducted with an EV weighing 900 kg and housed with a 24 kWh battery pack in NEDC, Zilina, and Prague concluded that the smaller the aerodynamic drag coefficient is, the EV can achieve a longer travel distance (Figure 16) [73]. The aerodynamic drag coefficient (c_x) of a vehicle thus is an important factor and needs to be as low as possible so that the vehicle's body shape will affect less on the driving range.

Besides, energy scavenging from two or more energy sources could extend the driving range and optimize the battery discharge cycle. For example, a topology of the battery and supercapacitor uses the onboard battery as the main energy source, and supercapacitors are embedded as the additional energy source. These supercapacitors can further be charged during the regenerative braking process, as shown in Figure 17. Other combinations of dual-energy sources include battery and flywheel, battery and fuel cell, and supercapacitors [5]. The flywheel helps in storing the excess energy from the regenerative braking system. The battery primarily supplies the energy in the fuel cell and battery combo. The fuel cell works as an additional storage unit and comes into play when the battery storage falls under a predefined margin.

Moreover, it is also feasible to house more than two types of energy sources consisting of a battery, fuel cell (FC), supercapacitor (SC), and photovoltaic (PV) cell (Figure 18) [5]. The hybrid power train is primarily driven by the battery or fuel cell to supply power and hold excess energy in this configuration. These two sources are augmented by the auxiliary (SC and PV cell).

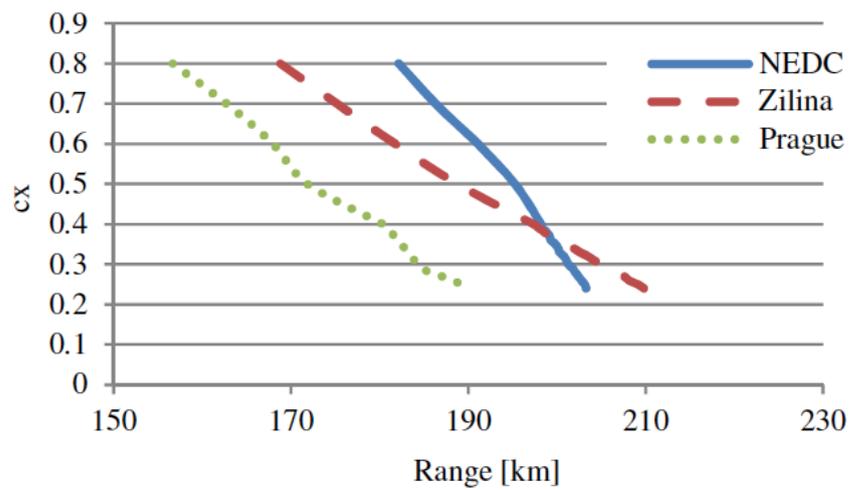


Figure 16. Influence of drag coefficient on electric vehicle’s range. Adapted with permission from ref. [73].

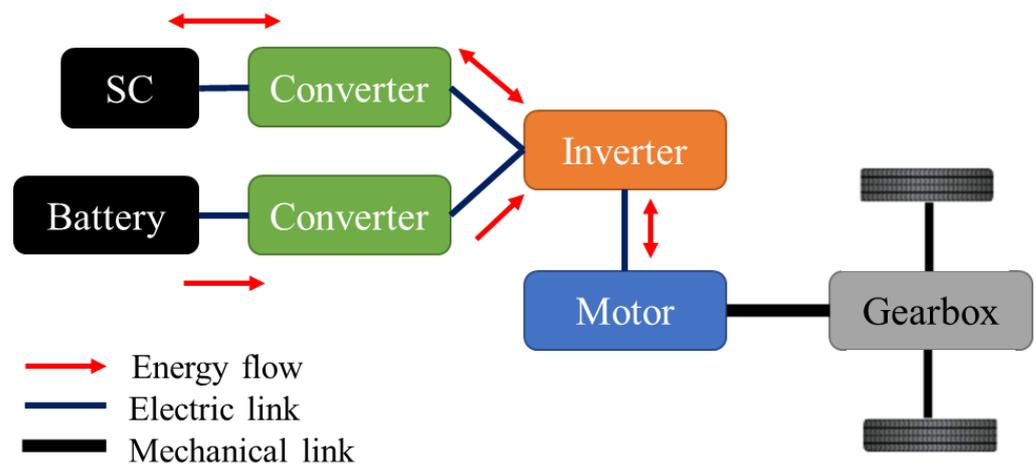


Figure 17. Dual-energy sources for EV [5].

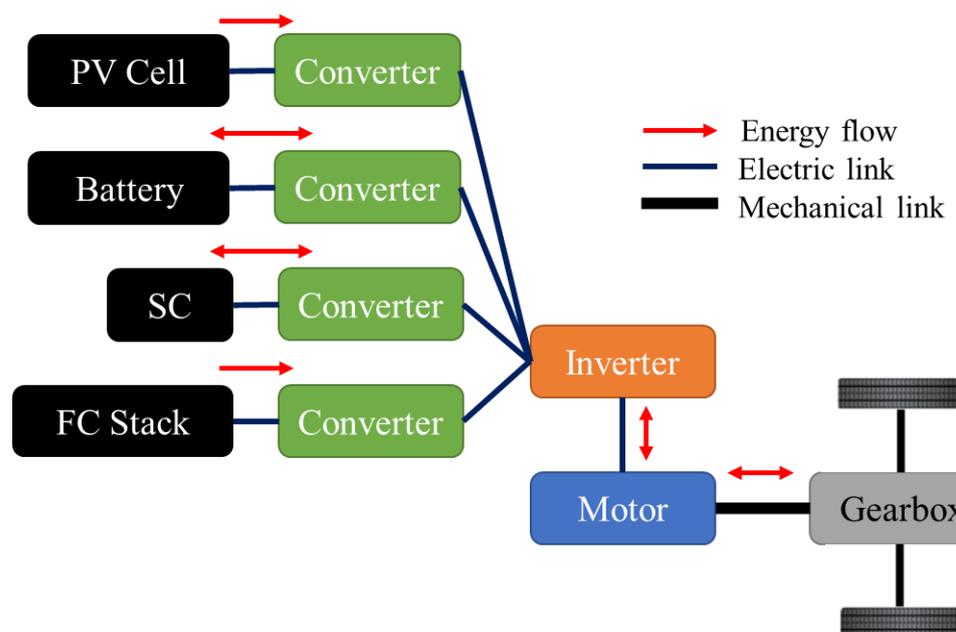


Figure 18. Hybrid power train for EV using multiple energy sources [5].

5.3. Charging Infrastructure

Charging infrastructure is a very complex part of EV planning. Type of charging to be employed, location to the main highway, parking space provided, and burden on the grid are important in EV charging infrastructure planning. It is stated in the literature that conductive charging is the most mature charging technique used for EV charging. The traditional AC chargers have power limitations, and DC chargers, although they provide high-power levels, also reduce the battery life span [1]. In a quasi-dynamic charging system, EVs are charged when they are stopped for short intervals, such as in traffic jams. To properly estimate the charging station capacity, a research work based in the United Arab Emirates considered the unplanned locations of charging stations (CSS) and station capacity and then employed a queuing-theory-based charging station sizing algorithm verified by a multi-objective binary and non-dominated sorting genetic algorithm [108]. The research concluded that the resultant CSS profile is better in terms of satisfaction of EV users, cost savings, better station utilization, and reduced impact on power grids and the environment. In [109], a binary lightning search algorithm (BLSA) is proposed for optimal rapid charging station (RCS) planning, considering the costs of transportation loss, buildup, substation energy loss, and harmonic power loss. The proposed methodology provides better RCS estimation accuracy, and daily total cost in RCS planning of the proposed method, including harmonic power loss, decreases by 10% compared with conventional methods.

The information and profile of commercial charging infrastructure should be adequately disseminated. A centralized database must be maintained and routinely updated to provide drivers with information on the charging infrastructure location, type of charging and charger used, cost of charge refueling, and service quality. A comparative view of on-board and off-board EV charging is shown in Figure 19 [1].

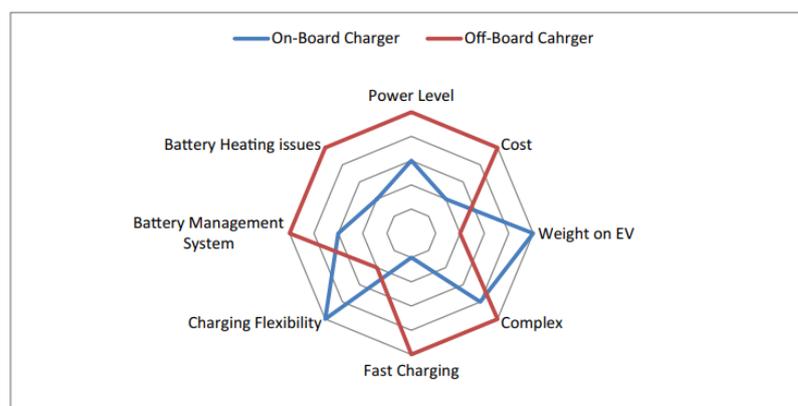


Figure 19. Graphical comparison between on-board and off-board EV chargers [1].

This will help the driver schedule their trip, estimating where and when they will need a recharge of the batteries. The 'A Better Routeplanner' website and mobile application is one example that can help long-distance drivers estimate precisely where to charge the EV at the next stop. This app also helps estimate whether or not the EV can reach the destination without charging when it is fully charged at the start of the journey. Apart from that, the BMS could be extensive to support different adaptive charging protocols, number of battery cells, sizes and configurations, vehicle-to-grid capabilities about the charging transactions, and advanced booking charging slots [85].

To have a reliable charging infrastructure, a reliable power source is crucial. This ensures no power disruption during charging that may lead to battery damage. Recent advancements in mini, micro, and smart grid systems are a competent way to overcome the challenges related to charging infrastructure. A smart grid is an intelligent electricity grid with information and communication facilities [110]. The attributes of a smart grid can be seen in Figure 20 [110].

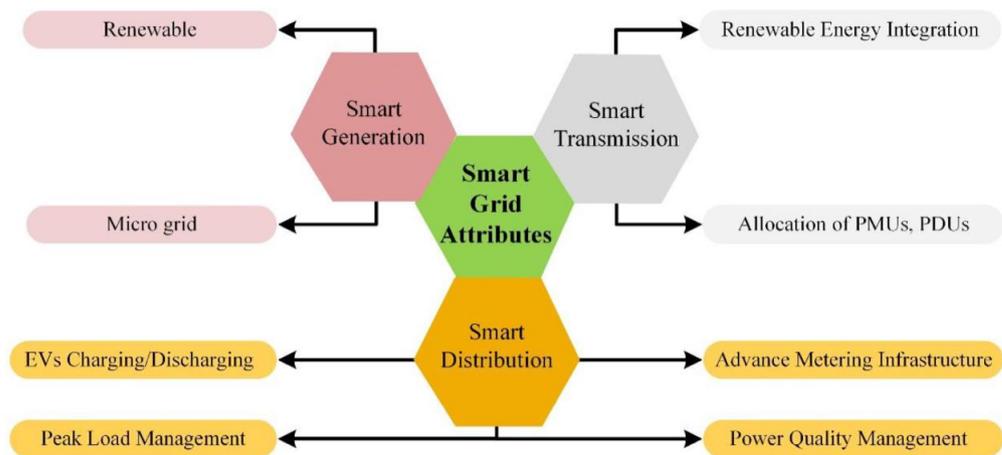


Figure 20. Attributes of Smart Grid [110].

Furthermore, a coordinated charging system should be in place so that the consumer and the power suppliers’ operational performance could be profitable via dispatching strategic measures to properly schedule the load demand of EV charging time following strict pricing policies [111]. In [112], an optimal charging coordination method for a random arrival of PEV incorporates capacitor switching and on-load tap changer adjustment to improve the grid voltage profile when the PEV fleet is connected to the grid for charging purposes. The method is then simulated on the IEEE 32 bus, and the outcomes reduce cost and distribution system stress. Moreover, according to [113], the vehicle charging control (P-control) and grid voltage regulation control (V-control) could be implemented in the back-end DC/DC converter and front-end AC/DC converter of the charger, respectively, to regulate the grid voltage to the pre-charge voltage while maintaining the DC-link voltage at 150 V during various charging currents of up to 5 A. The DC-link voltage level was set at 800 V, and the DC-link capacitance was selected as 2200 μ F during the observation.

The smart distribution unit primarily deals with the proper and stable power system monitoring and control nearest to the EV charging points and analyzes any contingency during the operation. In a micro/smart grid system, the grid and utility operators can independently manage and power-produce resources to meet the dynamic load demand. The smart grid will also enable consumers on the demand side to manage their electricity usage in accord with established EV pricing parameters, such as time of use (ToU), real-time pricing (TRP), and critical peak pricing (CPP), summarized in Figure 21 [110].

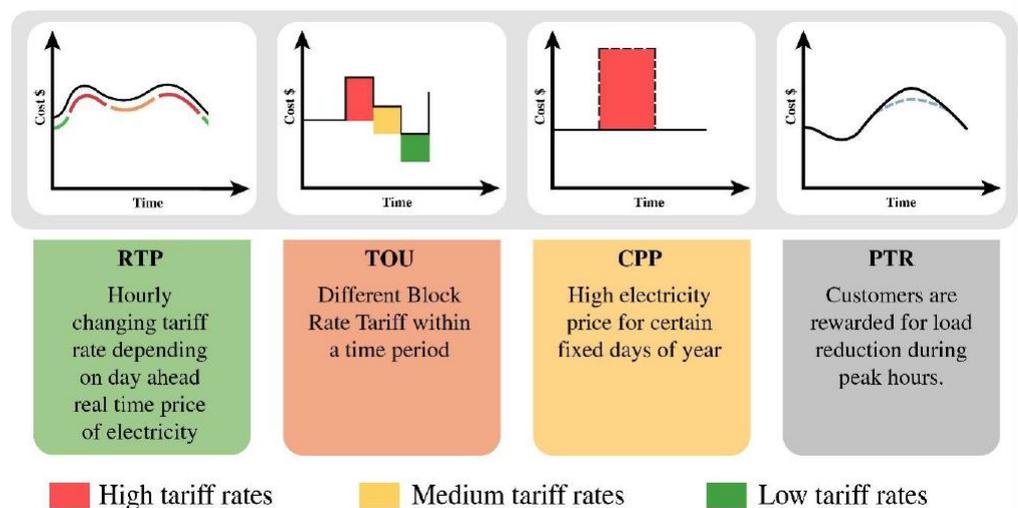


Figure 21. Definition of different pricing schemes [110].

On top of that, wireless charging or wireless power transfer (WPT) is another potential candidate to reduce pressure on the charging infrastructure. WPT can be installed sparsely, a few centimeters under the asphalt, cement, or other road material; thus, EV can be charged on the move. For this technology to work, the EVs must be equipped with a receiving pad and compatible systems to proceed with energy exchange via magnetic induction between the sending and receiving pads. Moreover, dynamic WPT-based charging points can also be installed on the dedicated drive lane for EV users and within the remits that most countries subsidize to use the EV drivers as a token of appreciation for EV transport and to attract more EV practices [114]. Charging pads are embedded at home, in public parking, or public charging stations in the stationary WPT scheme. With the help of an indicator and power control module, an EV can be charged wirelessly with minimal action from the driver. During the charging process, the driver's sole duty is ensuring that the car is parked at the right location.

Nowadays, bidirectional charging is widely considered as it benefits both the EV user and the utility provider. During bidirectional power flow, in addition to EV being charged from the grid as per the convention, EV can also behave as a virtual energy storage fleet and could be utilized to return power from the vehicle to the grid (V2G) during peak hours. This V2G scheme, when embedded in the smart grid system, provides space to integrate power coming from distributed generating points and EV charging points via bidirectional metering infrastructure. However, the high degree of EV fleet penetration rate of 50% or higher will cause network voltages to violate the voltage deviation tolerance of 7% [115]. Apart from that, EVs can also be used to power households via vehicle-to-home (V2H) technology. V2G and V2H help improve the power system's stability, control small-signal disturbances, and proper load scheduling.

5.4. Charging Time

An ultra-fast charger may seem like an ideal option to reduce the time consumption to recharge the EV battery; for instance, a fast DC charger can recharge an EV battery in only 30 min, and a 350 kW rated extreme-fast charger can charge an EV battery within just 10 min [116]. However, the vast use of fast chargers requires extensive modification to the network to safely carry a higher current density. In addition, the heat and thermal tolerance of the power cable needs to be improved. Moreover, to avoid any wastage in cost and power, the location of the fast charger should be chosen wisely. The focus should be on the expected service capacity, quality of harmonic, and low installation cost. In this regard, installing EV stations along the long-distance travel corridors is good. Table 8 shows the charging characteristics of popular EVs using lithium-ion batteries [117].

Table 8. Charging characteristics of commonly used Li-ion EV batteries [117,118].

Vehicle Model	Battery Capacity (kWh)	Maximum Driving Range (km)	Approximate Charging Time for Full Charge (h)		
			Level 1 (120 Vac)	Level 2 (240 Vac)	Level 3 (dc), at 80% (State-of-Charge)
Chevrolet Volt PHEV	16.0	610	10–16	4–5	N/A
Ford Focus EV	23.0	122	<20	4–5	N/A
Tesla Model S EV	85.0	426	>24	9–15	0.5
Nissan Leaf EV	24.0	117	12–16	6–8	0.5
Mitsubishi i-MiEV	16.0	100	22	7–8	0.5
Fisker Karma PHEV	20.1	370	<15	4–5	N/A
BMW i3	22.0	160	7–10	3–5	0.5
Toyota Prius PHEV	4.40	870	3	1.5	N/A
Honda Fit EV	20.0	132	<15	4–5	N/A

The EV vehicle battery is a crucial part of controlling the service of the EV itself. EV control charging strategies falls into scheduling, clustering, and forecasting strategies. In [119], it is suggested that there is still an absence of a benchmark or framework set to compare the research work related to EV control strategies. However, it is concluded that artificial intelligence models perform better than probabilistic models [119]. Different research has been carried out to propose the best battery controlling methods. In the case of battery cell design optimization, at the level of the cell, module, pack, and EV level, evolutionary computation (EC) techniques rather than conventional modeling or optimization methods can boost the battery performance monitoring and EV safety features [120]. During battery charging, it is imperative to monitor the charge level of the batteries. For Li-ion batteries, the equalization controller (CEC) algorithm performs well in equalizing both undercharged and overcharged cells and equalizes the cell within the safe operating range of 3.81 V [121]. It is estimated that market prices of Li-ion batteries are anticipated to be approximately 75% of the present price by 2030, and the battery pack price is 25–30% of the price of an electric car [122]. A battery management system (BMS) can schedule the charging and discharge of a rechargeable battery cell within the ideal working range of the state of charge (SOC), i.e., 20–90%, to improve cost efficiency [122]. In a review of the BMS for balancing circuits, cell-to-heat (C2H), cell-to-cell (C2C), cell-to-pack (C2P), pack-to-cell (P2C), and cell-to-pack-to-cell (C2P2C), it is concluded that hybrid energy storage devices (ESD) can be preferable for the EV system. The EV system requires smart drive train architecture, high capacity and long lifecycle ESD, and highly efficient balancing circuits.

Often, more than one input energy source is considered to drive EV wheels, and hybrid energy storage systems (HESS) are considered. The performance of HESS can be improved by combining battery and supercapacitor features. An optimal adaptive, fuzzy adaptive controller is used to control the energy shared between the battery and supercapacitor [123]. In [124], an extended Kalman filter (EKF) and traditional coulomb counting (CC) structure are used for estimating the state of charge (SOC) of a hybrid power management (HPM) system composed of fuel cell HEV and supercapacitors. It is observed that HPM can deliver a maximum speed of 177 km/h, an enhanced fuel economy of 93.38 km/kg, 0–100 km/h acceleration in 9.0 s, a hydrogen consumption of 0.303 kg and a cruising range of 500 km for a FCHEV with a weight of 2180 kg (equivalent to 2017 Toyota Mirai) [124]. EV battery with photovoltaic (PV) panels is a common consideration [117]. The panel size and relevant battery capacity should be properly designed for optimal operation. For optimized sizing of the onboard photovoltaic grid-connected electric vehicle charging system, particle swarm optimization (PSO) is a satisfactory consideration [125]. Recently, the H₂-based fuel cell EV (FCEV) is becoming essential. In a study carried out in South Korea, possible pathways for the successful adoption of FCEV using the fuzzy-set quality comparative analysis (fs/QCA) method are investigated, and it is summarized that a higher penetration of H₂-fueling stations could boost the FCEV adoption rate [126].

Setting up battery exchange stations is another quick option to curtail the EV battery charging time. When the electric car battery becomes empty, the driver can visit the exchange center and replace the whole battery with another fully-charged battery of similar type and properties. Although battery replacement causes more expense than the traditional battery charging process, and failure to get a suitable battery is more likely to disrupt the entire journey schedule, this process generally discards hours-long battery recharge waiting time. The driver should communicate with the battery exchange point beforehand to improve service quality and inquire about the battery's availability and replacement components. In this regard, mobile application-based communication and warehouse database-sharing could be implemented.

It is essential to prescribe fast charging control methods that imply a lower harmonics burden on power grids and increase battery backup time and battery lifetime. In ref. [127], an appropriate state of charge (SOC) optimization and charge control method is proposed considering hybrid PSO and GSA (PSOGSA) algorithms which can significantly improve the EV battery charging operation. However, during a practical dynamic loading

situation, the estimated accuracy of the battery model diverges from the true value. To address the parameter deviation problem, in 2021, a dual forgetting factor-based adaptive extended Kalman filter (DFFAEKF) is adopted that can estimate the battery parameters with root mean square error (RMSE) less than 0.95% [128]. The proposed method can also demonstrate fast convergence to actual values during the dynamic operating condition and erroneous initial preset. In [129], a model predictive control (MPC) for off-board plug-in electric vehicle (PEV) chargers with photovoltaic (PV) integration using two-level four-leg inverter topology is proposed for appropriate charge controlling. The proposed model results in lower than 1.5% total harmonic distortion and low active and reactive power ripple of less than 7% and 8%, respectively, on the grid. PEV battery also experiences a low charging and discharging current ripple of less than 2.5%.

5.5. User Behaviour

Three important values in the development of electric vehicles are: (i) market performance comfort, (ii) government leadership in policymaking, and (iii) industrial profit and public image. However, to ensure steady growth of EV development, the consumer's perspective should also be weighted in. For instance, consumers are often very particular and demanding regarding EVs' running and maintenance costs and the life cycle performance of the EV batteries [130]. Consumers' behavioral attributes fall under three categories of adopting an EV: instrumental, symbolic, and hedonic attributes. The instrumental attributes are all about the electric car itself, including the EV technology, the total cost of ownership, performance, battery capacity, and charging time. Hedonic attributes denote consumers' feelings about owning and driving an electric car. Lastly, the symbolic attribute is the sense of achievement from owning a technologically advanced EV that positively contributes to fighting climate change and combatting global warming [131]. Finally, the psychology of the consumer directs an experienced consumer of EVs to be more confident in the decision-making process to spend higher fees to purchase an EV that comes with premium qualities and services than a new customer.

To date, public attitudes towards PHEV/EVs have been considered under very diverse conceptual frameworks; among the main features there is the theory of planned behavior (TPB) model, attitude PHEV/EVs' adoption, subjective norm (SN), perceived behavioral control (PBC), norm activation model (NAM), structural equation model (SEM), and diffusion of innovation (DOI) theory. For example, in China, an analysis of consumer EV purchase intention concluded that the EV adoption rate largely depends on gender, age, education level, income, and ownership of cars [132]. Moreover, it is found that norms & non-monetary incentive policy measures have no significant impact on changing the public intention toward EV culture [132]. Therefore, it is important to consider both the consumers' technological adoption and diffusion of EVs for proper estimation/prediction of consumers' intention toward EV culture [133].

DOI theory [134], one of the oldest social science theories, could be considered to better understand the adoption of EVs by Malaysian citizens. According to the DOI, after launching a new idea/innovation, there appear to be five categories of adopters, the total population (100%) divides into innovators (2.5%), early adopters (13.5%), early majority (34%), late majority (34%), and laggards (16%) [135]. The adopters are influenced by five main factors: relative advantage, compatibility, complexity, trialability, and observability. The innovator and early adopter categories should adopt an EV without requiring any information to convince them. However, most people in the early and late majority categories would rely on success stories, evidence, compatibility, and observability before trying an EV unit. Thus, according to DOI, a way out is to create focus groups where the innovation should first be divulged, an EV market should initiate, and then their success would motivate others [136]. The government could play a vital role in this regard [137].

First, the government needs to erect several charging stations on defined routes to accommodate the recharging need of any EV. Second, the government should replace the government-owned public vehicle services on those routes with EVs and inform other

private passenger bus service companies to replace a few of their ICEs vehicles with EVs to run on that route. Third, the top political leaders and top officials should be requested to use EVs as leaders of a cleaner world, and the use of EVs should be highlighted as prestigious and respectful. Fourth, the tech giants residing in Malaysia should be requested to start working with EV prototypes and should be offered free EV charging at the defined routes. In addition, the fleets of electric utility trucks could also serve as early adopters; they could develop charging infrastructure to recharge. Their use can also tune the peak and off-peak load demand, thus reducing the electricity costs. At this early stage of DOI, skilled drivers across the country should be offered a test drive, and mass publicity of their feedback and experience should be carried out. In the next stage, the government should initiate generous financial subsidies and incentives to grow the EV market, EV users, and EV manufacturers, and vast advertisement and branding of the EV companies and sell centers will be crucial to cater to higher early majority and late majority adopters [138]. Finally, large carbon tax and partial treatment of ICEs could help divert the laggard category to use EV.

Figure 22 demonstrates the psychological and situational factors that influence the behavior of a potential EV buyer [139]. Based on Ajzen's theory of planned behavior (TPB) model, an individual will assess the consequence of buying an EV car based on their beliefs, attitudes, and intent to act when provided with behavioral choices and alternatives. Meanwhile, the values-beliefs-norms (VBN) model states that the values and beliefs of the EV users should become interconnected for the norms that follow. Moreover, from psychological perspectives, the social, egoistic, and biospheric become crucial and stable determinants in the pro-environmental actions [139]. Therefore, car-buyers feedback alters the individual user's beliefs, habits, and attitudes regarding EV practices. This then embeds feasible regulatory policies to uphold the economy and environment with the availability of infrastructure for EVs. However, car users are only moderately aware of the environmental benefit that comes with the EV compared to conventional ICEs. Therefore, awareness needs to be instilled so there will be no misconceptions about the subject. The most crucial factors influencing the purchase decision are the price, fuel or electricity economy, comfort, size, practicality, and reliability. Thus, understanding the total cost of ownership of an electric car is important.

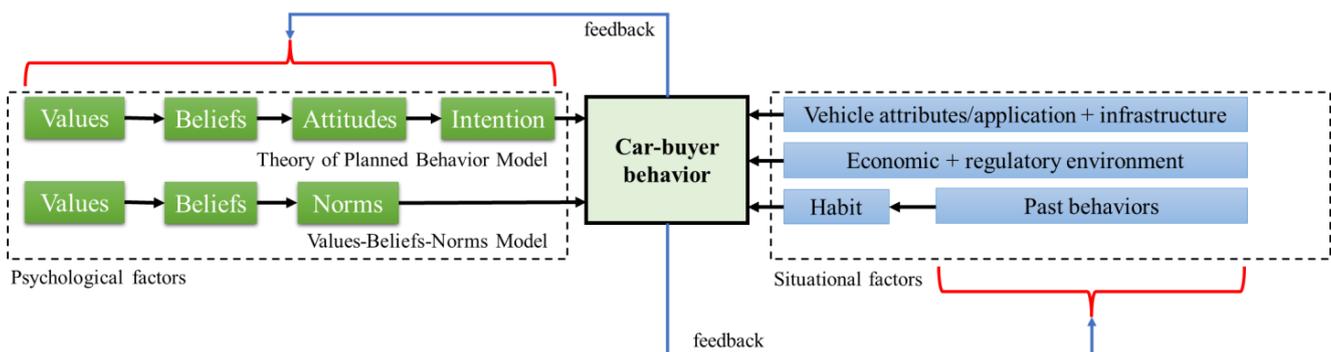


Figure 22. Factors influencing car-purchaser behavior [139].

The life cycle cost (LCC) is another crucial component that tunes the users' perspective on EV [19,140]. LCC is the total cost associated with an asset during its useful life. The total LCC is divided into three major parts: purchase cost, operational cost, and disposal cost. Purchase cost consists of the manufacturer's suggested retail price (MSRP), subsidies and purchase tax, and the Level 1 or Level 2 charger [141]. Operation cost comprises the maintenance cost, insurance fee, cost of battery recharging (electricity bill), and parts (such as battery and tires). It comes into play within a few years of the EV's operating period. Finally, disposal cost comprises the vehicle's scrap value and the recycling costs associated with recyclable parts, such as the battery, metallic units, printed circuit board, and converter/inverter units [140].

A recent study has estimated the total cost of an electric vehicle (Nissan LEAF) is 8533 USD for 10 years Malmgren [142]. Although the purchase cost of the Honda Civic is less than the Nissan LEAF, the additional incentive and economic development increases the cost of the former. Maintenance-wise, the electric car costs are lower since it has fewer moving parts than conventional internal combustion engine vehicles and fewer chances for wear and tear. For an EV, the maintenance cost mainly consists of the money associated with replacing tires and brakes. Other electronic parts related to the drive train do not require regular maintenance. When incentives from the government and manufacturers are added, the total cost to own an electric car becomes less than an internal combustion car in the long run. Also, the electric vehicle's total cost reduces if the annual mileage could be extended with lower battery size and cost, but a high-density battery is used [143]. On the other hand, the anxiety about the travel demand is a psychological aspect that needs to be broken down. For instance, in European countries, the EV could be routinely used for an average of 40–80 km drive, which is well enough for personal trips and daily uses [144]. A preplan and tentative scheduling with the charging points can boost the travel experience in a larger distance. In the current literature, fascinating research works are being carried out to make the communication between the car and charging infrastructures transparent to the user's intended trip experience.

6. Current EV Target and Policy Required

Malaysia has yet to develop a specific electric vehicle policy for the country. However, the National Automotive Policy 2020 (NAP 2020) has shifted the spotlight to energy-efficient vehicles (EEV) and next-generation autonomous vehicles, including EVs. By 2025, all vehicles in Malaysia shall at least reach Level 3 autonomy. Level 3 is conditional automation design. The driver can keep their hands, eyes, and feet off the wheels when driving but is responsible for a prompt take over if the system provides any danger alerts. Based on the NAP 2020, by 2040, all internal combustion vehicles will no longer be incentivized. The incentives will only be given to electric vehicles, fuel cell cars, or other environmentally friendly green cars.

According to the Malaysia Automotive, Robotics, and IoT Institute (MARII), a new accelerated electric vehicle policy will not overrule the NAP 2020 but will be considered part of the NAP. Furthermore, this new policy is expected to address incentives-related policies for EVs, for instance, excise duty, import duty, and sales tax enforcement, to benefit both the local manufacturer and the consumers. Also, the users may enjoy newer facilities, including road passes, green parking, toll rebates, and incentives for installation and up-gradation of electrical wiring from single phase to three phases for home chargers.

The feasibility of the policies and regulations set across various developed and developing countries, where the use of EVs is becoming more and more prevalent, needs to be revised and analyzed from a Malaysian perspective. However, some countries have already made important initiatives to improve EV market share, adoption, research and development practices, grant and incentives for projects and manufacturing farms, subsidies to the EV users for EV purchase and diffusion, and to lessen challenges of driving range, charging time, and price.

The core issue/hurdle of EV adoption lies in its high market price. It is observed that financial incentives, such as subsidies and tax incentives, play a vital role in decreasing the up-front price of EVs. At present, Malaysian EV market is nascent and requires more active EV users to sustain a profitable EV market. Such a market will help cater to more EV manufacturer farms, dealers, and suppliers. Moreover, a competitive market structure will follow and improve the EV service quality per price. From the production line perspective, reducing the market price while improving the quality of service requires a change towards newer innovations and features in charging infrastructure, charge control mechanism, battery storage handling and management, on-board control drivers and wheelers, and the overall design. Comparative higher benefits from EV units compared to ICEs will motivate the ICE user to shift towards EV and thus will help hit the goal of GHGs emission

curtailment and environmental sustainability. Countries such as the USA and China came to manage large EV users by first initiating generous subsidies and incentives. In 2009, the government of the USA initiated a tax-credit financial incentive, ranging from 2500 to 7500 USD per unit EV purchase; the amount depends on the on-board battery capacity and gross weight [145]. This scheme becomes viable for the prospective EV user to obtain an EV unit and the EV manufacturer to sustain EV buyers. The scheme is modeled to start a phase-out scheme when a specific EV manufacturer company reaches 200,000 units of EV sales; thus, reducing the risk of the initial loss of a new manufacturer and helping them sustain in an immature EV market [146]. The phase-out worked in two steps, reaching 50% after six months and 0% after a year. Incentives in terms of rebates, tax exemptions, and tax credits are prevalent in the areas such as California, Washington, New Jersey, Louisiana, and Maryland, and discard the upfront price from 2000 to 3000 USD per vehicle [147].

In China, the government first initiated the purchase tax curtailment for EV users from 2014 to 2017, then extended it to 2020. Moreover, the central government of China initiated a consumer subsidy program that could be renewed every two to three years. In 2010, a subsidy equivalent to between 635 and 7941 USD was available per PHEV and 9530 USD for BEV [148]. The subsidy was nearly 40% to 60% of the EV sell price. From 2010 to 2020, the Chinese government has increased/decreased/renewed the subsidy to diversify the EV market and increase the EV users. By 2040, China has targeted to reach 40% of vehicle market share from EVs. Other than that, federal and state governments, electric utility operators, and other entities may help support accelerating the purchasing of electric vehicles via monetary and non-monetary incentives. The incentives can also come in carpool lane access and charging subsidies. For example, the United States of America (USA) has planned nearly 198 incentives across fifty states to expand the EV market for both industries and consumers' benefit [145]. Among the incentives, individual credit refers to the rebate received upon purchasing a new EV. Then there is the tax credit that varies from state to state and depends on the battery size and model of the vehicle [149]. Finally, fleet credit is introduced for larger entities such as business companies, startups, and local government and university research divisions. The subsidy scheme also is extended to support the installation of charging stations across the USA, up to 4000 USD per charger. Moreover, the USA and the Chinese government are disbursing a colossal amount of research grants to top universities' research labs to help explore more economically feasible, durable, and environmentally friendly battery storage units [148]. The Malaysian government needs to similarly incentivize the EV user, manufacturer, and R&D sector to reduce the major barriers.

The policies considered by the government of South Korea are also exemplary. They had placed a one-time purchase subsidy for electric cars of 12 million KRW, which in 2016 increased to 14 million KRW [150–152]. This has encouraged consumers to purchase and benefit from the subsidy to buy the EV ahead of schedule. As a result, it is reported that the demand for EVs in 2017 spiked, with over 13,800 more vehicles sold than the previous year [153]. Other than that, the Korean government has also offered the purchase tax reduction, and EV owners are benefited from reductions in insurance premiums, expressway tolls, and parking fees. According to Kwon, Son [154], the EV sales in Jeju Island, South Korea, have surpassed any other big cities in the country. It accounted for 55.2% of all EVs purchased in South Korea [155]. This success is due to the active initiative the Jeju Self-governing Province took in terms of expanding the public charging infrastructure, supporting in-home charger installation, and promoting additional incentives to Jeju residents on top of the benefits already offered by the Korean government. The only requirement to be eligible for the subsidy was that the applicants must be a resident of Jeju island and have not received subsidies before. Moreover, an upfront purchase subsidy was granted to an owner if they have continued the EV ownership for at least two years. Since Malaysian geography closely matches the Korean borders, and several islands are also present in Malaysia, independent measures could be taken to control and boost EV use within a region of interest.

As shown in Figure 23, the USA annual cost of EV ownership is expected to become lower than having a diesel or gasoline-based vehicle by 2024 [156]. The government of Norway has exempted vehicle registration tax and value-added tax (VAT) and reduced the EV vehicle license fee to interest more users to have EVs [157]. Similar policies and incentives could also be considered for Malaysian citizens. Moreover, the government may also incentivize the local (public, private, or autonomous) EV cell manufacturers. In 2019, ETAuto reported that following the announcement by India's Finance Minister, Nirmala Sithraman, the corporate tax for the new EV part manufacturers was reduced by 4.39% (from 21.55% to 17.16%). This reduced corporate tax boosted the domestic production of EV parts such as charging equipment, batteries, electrical and electronic parts. This can also be implemented in Malaysia to be an important milestone for manufacturers to focus on the electric vehicle.

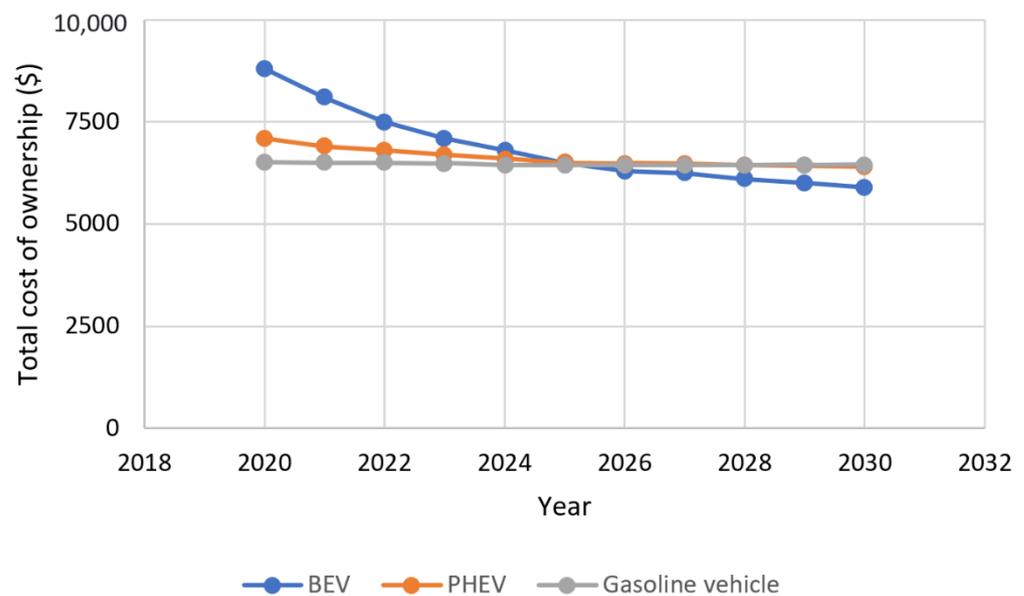


Figure 23. Annual cost of EV ownership in the USA. Adapted with permission from ref. [156].

Despite all the incentives and subsidies offered by the national and local government, EV owners on Jeju Island have varying satisfaction levels. The owners were more satisfied with the incentives during the operation than the purchase and non-monetary benefits such as battery warranty [158]. The said incentives during the operational period cover the electricity rate discount as EV owners must pay for Level 2 chargers, which has added more financial burden to the owners. It was stated that the owners are willing to pay 434,000 KRW to save 1 min of charging time [154]. However, government incentives and policies could still play a big role in maintaining a sustainable EV culture. For instance, the Chinese EV market relies heavily on government incentives. During COVID-19, the sale of electric vehicles dropped; however, when the pandemic became under control, the government resumed giving incentives for the EV. The “New Energy Vehicle (NEV) to Countryside” program has offered incentives to the rural dwellers to own small-sized EVs, which instantly pushed the EV sales back to a tolerable margin [63].

Monetary incentives are consistently a positive motivation and increase the effectiveness of a policy. Based on the online survey conducted by Rakuten Insight in June 2019, tax rebates, subsidies on electric car purchases, and the availability of charging stations in the vicinity of housing and work have motivated 77.45% of South Korean respondents to own an EV [159]. Within the Malaysian border, the designated lane for EV users could become another positive factor in implementing EV-related policy. Malaysian socio-economical profile is very promising for a reliable and sustainable growth, implementation, and practice of EVs [29,160,161]. The government must design policies to welcome private and foreign investors to invest in the EV industry. Furthermore, there needs to initiate lucrative incentive

arrangements for the citizens to buy EVs and establish EV charging infrastructure and R&D wings across universities and top industries to increase local manufacturing capabilities.

7. Conclusions

In conclusion, this review highlights EVs' current profile and prospects in Malaysia. Moreover, the challenges associated with the mass adoption of an EV and feasible ways to address those challenges are investigated here. This research observed that Malaysia is still far from fully implementing electric vehicle technology. Only a tiny fraction of users consider electric cars due to the high purchase price of an EV unit. The core challenges of initiating an extensive EV culture for Malaysia include very little charging infrastructure, lack of EV policy and local EV manufacturers, deficiency of economical vehicle design, fewer government incentives to the EV users, incompatible power grid structure, low travel distance of an EV, lack of EV service points, and high taxes on the imported EVs. A few steps will have to be implemented to increase the EV users. Proper charging infrastructure and higher battery density should be implemented to improve the driving range of an EV. The automobile industry needs experts to improve battery size and optimize service per purchase investment. Incentives and benefits in terms of purchase tax, annual vehicle tax, public parking lot fees, extended battery warranty, usage of the bus lane, and other non-monetary incentives should be provided to attract potential EV users to own an electric car. In addition, sufficient in-home and public charging points need to be installed. It is observed that with proper guidelines and restructuring of the current power grid equipment and EV deployment policies, it will be feasible for Malaysia to incorporate green electric vehicles into the core part of everyday life. With proper nurturing of the EV culture, Malaysia could become one of the prominent EV hubs in Asia within the next decade.

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