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Electric Vehicle Review: BEV, PHEV, HEV, or FCEV?

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Abstract

Electric vehicles (EVs) are rapidly advancing as a sustainable transportation solution in the global effort to reduce carbon emissions. There are four main types of EVs: battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), and fuel cell electric vehicles (FCEVs). This article reviews each EV type's advantages, limitations, and prospects based on energy efficiency, carbon emissions, technological development, and infrastructure readiness. The findings indicate that BEVs hold the most significant potential for personal vehicles and urban transportation, while FCEVs are more suited for heavy-duty and long-distance applications. PHEVs and HEVs are considered transition solutions, but their relevance is expected to decrease as technology and global policies evolve. BEVs provide zero emissions. PHEVs provide high flexibility, while HEVs do not require charging infrastructure, and FCEVs offer zero emissions and long-range and fast charging times. FCEV can travel up to more than 800 KM, which is very promising for the distance travelled problem, which is a challenge for electric vehicles.

Keywords: electric vehicle; renewable energy; batteries; hydrogen; fuel-cell.

1. Introduction

In recent decades, the world has faced major climate change challenges that primarily caused by human activities and especially in the transportation sector [1], [2]. Transportation is one of the main contributors to global carbon emissions, contributing around 25% of total greenhouse gas emissions, even in Asia contributing up to 39% [2]-[6]. To address this issue, many countries have turned their attention to electric vehicles (EVs) as a sustainable solution [7]-[10]. EVs are considered a cleaner alternative to fossil fuel vehicles, as they can significantly reduce carbon emissions, especially when powered by renewable energy sources [10].

Electric vehicles include several types of technology; battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), hybrid electric vehicles (HEV), and fuel cell electric vehicle (FCEV) [11]-[13]. Each type has unique characteristics, advantages, and disadvantages, making it suitable for certain applications. BEVs, for example, are known for their high energy efficiency and zero emissions during operation, while FCEVs offer a solution for heavy and long-distance transportation due to their long-range and fast hydrogen refueling [12], [14]. However, infrastructure and energy efficiency limitations are challenges for each technology.

The development of EV technology continues to accelerate along with the increasing global demand for environmentally friendly vehicles [15], [16]. On the other hand, government policies, such as EV purchase incentives, gradual bans on fossil fuel vehicles, and net-zero emissions targets, have also encouraged EV adoption in various countries [15], [17]-[19]. Major automotive companies are also competing to develop electric vehicles that are more efficient, affordable, and in line with consumer needs [20]. However, an important question remains: of the four types of EVs available, which technology has the best prospects for the future [21]?

This study aims to review in depth the potential, advantages, and challenges of each type of EV. This study includes an analysis of energy efficiency, carbon emissions, infrastructure readiness, and the most suitable applications for each type of vehicle. Thus, this study is expected to provide comprehensive insight into the role of EVs in transforming global transportation.

The contribution made in this paper will let researchers select proper technology for developing electric vehicle technology. Through this discussion, it is hoped that readers can understand the development and prospects of EVs and the important role of this technology in global efforts to reduce the carbon footprint. In

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addition, this study also provides insight into the type of EV that is most suitable for specific needs, both on an individual and industrial scale. The combination of the right technology, supportive policies, and infrastructure development will be the key to the success of EV implementation in the future.

2. Electric Vehicles (EVs)

With a variety of technologies available, EVs offer flexibility for a variety of needs and applications [8], [21], [22]. Battery Electric Vehicles (BEVs) are type of EV that relies entirely on batteries as an energy source, producing zero emissions during operation. As a pioneer in green vehicle innovation, BEVs are often the preferred choice in regions with developed charging infrastructure 23], [24]. On the other hand, Plug-in Hybrid Electric Vehicles (PHEVs) combine an internal combustion engine and an electric motor, providing high flexibility with longer range and the ability to operate electrically in certain regions [23], [24].

Additionally, HEVs, while not requiring external charging, still rely on an internal combustion engine, making them an ideal transitional solution in areas with limited infrastructure [25]-[28]. Meanwhile, FCEVs offer hydrogen-based technology, producing only water vapors as emissions, and having very long ranges and fast refueling times [29]-[34]. With a wide range of EVs available, each technology has a unique role in supporting the decarbonization of the transportation sector, depending on local needs, infrastructure readiness, and environmental priorities [35].

2.1 Battery Electric Vehicle (BEV)

BEV is an electric vehicle that uses electrical energy as a power source to drive its motor [36]. Unlike fossil fuel or hybrid vehicles, BEVs rely entirely on rechargeable batteries, so they do not produce carbon emissions during operation [8]. BEVs are known as an environmentally friendly transportation solution designed to reduce dependence on fossil fuels and support the decarbonization of the transportation sector [37]-[42]. BEVs convert electrical energy stored in batteries into mechanical energy to drive the vehicle's wheels [43]. The main systems are detailed in Table 1.

Table 1. BEV main systems

Component	Description	References
Battery	Stores the electrical energy needed to drive the motor. Lithium-ion batteries are the most common type due to their high efficiency and large storage capacity	[11], [14], [19], [36], [39], [44]-[48]
Inverter	Converts direct current (DC) from the battery to alternating current (AC) used by the electric motor	[7], [14], [22]-[24], [27], [29], [33], [36], [47]-[49]
Electric motor	Converts electrical energy to mechanical energy to drive the wheels	[23], [24], [28], [35], [36], [43]
Power Controller	Manages the distribution of power from the battery to the electric motor as needed, such as acceleration or constant speed	[22], [36]

BEVs offer a variety of benefits, both for users and the environment. The advantages and disadvantages of BEVs are given in Table 2. Despite their many advantages, BEVs also face several obstacles that need to be overcome to increase adoption [50], [51].

In Indonesia, BEVs have great potential for adoption, especially in urban areas. Big cities such as Jakarta, Bandung, and Surabaya, which are facing air pollution problems, can use BEVs to create a cleaner environment. The government has also started building charging infrastructure and providing tax incentives to encourage the use of electric vehicles. However, the expansion of SPKLU and the development of local batteries will be key to increasing the attractiveness of BEVs in the domestic market [52].

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Table 2. Advantages and disadvantages of BEV

Advantages		Disadvantages	
Component	**Description**	**Component**	**Description**
Zero emission [17], [21], [25], [29], [31], [39], [53]	BEVs produce no exhaust during operation, helping to reduce air pollution and carbon emissions	Limited range [12], [26]	The range on a single charge (average 250–500 km) is still a concern, especially for long-distance travel.
High energy efficiency [25], [28], [39]	Electric motors have much higher energy conversion efficiency than internal combustion engines (ICE)	Charging time [22], [46], [54]	The time required to charge a BEV battery is longer than that needed to refuel conventional vehicles. Fast charging technology is available, but the supporting infrastructure is still limited
Low operating costs [8], [12], [20], [24], [25], [29], [30], [32], [47], [48], [53]	Electric charging is cheaper than fossil fuels, and BEVs have fewer mechanical components that require maintenance	Vehicle price [28], [48], [55]	BEVs are still more expensive than fossil-fueled vehicles, although their operating costs are lower
Driving experience [8], [50], [56]	BEVs offer smooth and quiet acceleration because the electric motor operates without engine noise	Battery recycling [57]-[61]	Battery waste management, such as recycling and material processing, is an environmental challenge that must be addressed immediately

With increasing awareness of climate change and the need for sustainable transportation solutions, BEVs are expected to dominate the electric vehicle market in the future. Technological advances in battery efficiency, fast charging, and decreasing production costs will strengthen BEVs' position as the main vehicle of choice. With its rich nickel resources for battery production, Indonesia has a great opportunity to become a key player in the global supply chain of the electric vehicle industry.

BEVs are a real step towards a cleaner and more sustainable future transportation. With the support of the right infrastructure, policies, and public awareness, BEVs can be an ideal solution to overcome modern transportation challenges in Indonesia and the world.

2.2 Plug-in Hybrid Electric Vehicle (PHEV)

PHEV is a type of hybrid electric vehicle that uses two main power sources: an electric motor powered by a battery and an internal combustion engine (ICE) powered by fossil fuels [24], [30]. Unlike HEV, PHEV has a battery that can be recharged via an external power source (plug-in))[23]. With this combination, PHEV provides the flexibility of using electricity for short trips and fossil fuels for longer trips[9], [9], [11], [24], [26]-[28], [53].

PHEV can be operated in several modes. The system in PHEV automatically sets the operating mode based on battery condition, power requirements, and driver preferences [20], [24], [38]. Table 3 provides the mode options in PHEV.

PHEVs offer several advantages that make them a transitional solution towards full electrification. Despite their many benefits, PHEVs face several obstacles limiting their adoption. A comparison of the advantages and disadvantages of PHEVs is given in Table 4. In Indonesia, PHEVs have great potential to be implemented, especially as a transitional solution towards fully electric vehicles. With the charging infrastructure still developing, the flexibility of PHEVs that can use fossil fuels provides an advantage. In addition, PHEVs are suitable for people who want to try electric vehicle technology without sacrificing the comfort of travel distance.

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Table 3. Mode Selection in PHEV

Mode	Description
Electric mode [62]-[65]	The vehicle uses only the electric motor until the battery is dead or nearly dead. This mode is ideal for short trips or in urban areas
Hybrid mode [27], [28], [34], [47], [63], [65]	The electric motor and combustion engine work together to provide optimal power
ICE mode [21], [36], [62], [65]	The combustion engine takes over when the battery is dead or for long-distance trips

However, the adoption of PHEVs in Indonesia is still constrained by the relatively expensive price and limited model choices. Government support through tax incentives and subsidies can help increase public interest in this technology.

PHEVs are considered an ideal medium-term solution towards full electrification, especially in developing countries like Indonesia. As awareness of electric vehicle benefits and the development of charging infrastructure increases, PHEVs can play an important role as transitional vehicles. In the long term, PHEV usage may decline as BEV prices and technologies improve. Still, for now, PHEVs remain a relevant option to bridge the gap between conventional and pure electric vehicles. With energy efficiency, flexibility, and reduced emissions, PHEVs are a practical solution supporting the journey towards a cleaner and more sustainable transportation future.

Table 4. Advantages and disadvantages of PHEV

Advantages	Disadvantages
a. Energy Efficiency: PHEVs can use electricity for short trips, reducing fossil fuel consumption [21]	a. Vehicle Price: PHEVs are more expensive than fossil fuel vehicles or HEVs due to the dual technology (electric motor and combustion engine) [11], [12], [21], [28], [48], [55], [66]
b. Flexibility: Users do not have to worry about range because the combustion engine can be used as a backup [8], [22], [25], [30], [50]	b. Limited Battery Capacity: The battery capacity of PHEVs is generally smaller than BEVs, so the pure electric range is often limited (20–80 km) [12], [14], [24], [29], [32], [39], [48], [51], [53], [54]
c. Emission Reduction: When using electric mode, PHEVs do not produce exhaust emissions, making them environmentally friendly for urban use [3], [4], [7], [8], [21], [22], [25], [30], [41], [42]	c. Complex Maintenance: Because it has two drive systems, PHEV maintenance tends to be more complicated than that of conventional vehicles or BEVs [7], [8], [20], [21], [24], [25], [47], [50], [58]
d. Convenient Charging: PHEVs can be recharged at home, at work, or at public charging stations, providing charging flexibility [8], [20], [22], [24], [25], [30], [48], [51], [53]	d. Charging: The charging infrastructure for PHEVs in Indonesia is still under development, although users can still rely on fossil fuels [8], [14], [20], [22], [27], [32], [38], [53], [54], [66]

2.3 Hybrid Electric Vehicle (HEV)

HEV is a type of vehicle that combines an internal combustion engine (ICE) with an electric motor to produce power. Unlike PHEV, the battery in HEV cannot be recharged via an external power source but is charged automatically via energy generated by the combustion engine or braking process (regenerative braking).

HEV is designed to improve fuel efficiency and reduce exhaust emissions compared to conventional vehicles. HEV uses a system that automatically regulates the combustion engine and electric motor use for maximum efficiency. The working modes of HEV are given in Table 5. This system allows HEV to adapt to driving conditions and power requirements dynamically, providing a balance between performance and efficiency.

HEVs offer several benefits, making them popular as an early solution for environmentally friendly vehicles. The advantages and disadvantages of the HEV system are given in Table 6. HEVs suit the Indonesian market, especially amid the transition to fully electric vehicles. Without dependence on charging infrastructure, HEVs can be used directly in all regions, including areas without electric charging station facilities. In addition, HEVs offer significant fuel efficiency, which is an advantage amidst the fluctuation of fuel prices. However, the adoption of

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HEVs is still limited due to the relatively high price and limited public awareness of the benefits of hybrid technology. Tax incentives and supportive government policies can help increase the attractiveness of HEVs in the domestic market.

Table 5. Several working modes of HEV

Mode	Descriptions
Low Acceleration [8], [20], [24], [26], [30], [32], [37], [46], [47], [62], [63]	Electric motors are used to propel vehicles, harnessing battery energy
When High Acceleration or Heavy Load [20], [24], [30], [45], [46], [62], [63]	The combustion engine and electric motor work together to provide additional power
Regenerative Braking [67]-[70]	The kinetic energy generated during braking is converted into electrical energy to charge the battery
At Constant Speed [21], [23], [28], [31], [36], [62], [65]	The combustion engine usually works alone to maintain fuel efficiency

HEVs are considered an interim solution towards full electrification. In countries with immature charging infrastructure, such as Indonesia, HEVs can be the foremost choice to reduce dependence on fossil fuels. However, as the electric vehicle infrastructure develops and the production costs of BEVs decrease, the use of HEVs is expected to decline.

Table 6. Advantages and disadvantages of HEV systems

Advantages	Disadvantages
a. High fuel efficiency: combining a combustion engine and an electric motor helps reduce fuel consumption, especially in urban travel with lots of stop-and-go [28]	a. Higher price: HEVs are more expensive than conventional vehicles due to the complex hybrid technology [21], [33], [55], [66]
b. Reduced emissions: HEVs produce lower exhaust emissions than conventional fossil-fuel vehicles [2], [4], [8], [20], [22], [25], [30], [35], [41], [45]	b. Remaining emissions: although lower, HEVs still produce emissions because they still use an internal combustion engine [20], [21], [24], [25], [27], [38], [39], [42], [50], [51], [65]
c. No need for electric charging infrastructure: since their batteries are charged through the combustion engine and regenerative braking, HEVs do not require electric charging stations [20], [21], [25], [26], [30], [32], [48], [51], [53], [62]	c. Limited battery capacity: the battery capacity of HEVs is relatively small, so the electric motor cannot be used exclusively for long trips [12], [14], [20], [22], [24], [25], [29], [32], [38], [39], [44]-[48], [50], [51], [53], [54], [58]-[60], [62], [63]
d. Good performance: an electric motor provides instant torque, increasing vehicle acceleration [8], [24], [25], [33], [39], [44]-[48], [68]	d. More complicated maintenance: combining two drive systems makes HEV maintenance more complex than conventional vehicles [47], [54]

Overall, Hybrid Electric Vehicles play an important role in reducing transportation emissions and increasing energy efficiency in the era of transition to sustainable transportation. Its flexibility in using electric and fossil fuel technologies makes it an attractive option for people who want to contribute to environmental preservation without sacrificing driving comfort. Figure 1 is an example of a battery used in an EV. This photo was taken during training at Beifang Automotive, Beijing, China.

2.4 Fuel Cell Electric Vehicle (FCEV)

FCEV is an electric vehicle that uses a fuel cell to generate hydrogen-generated electricity. Unlike BEV, which stores energy in a battery, FCEV generates electricity directly through a chemical reaction between hydrogen stored in a tank and oxygen from the air. FCEV provides a zero-emission solution because the only by-product of this process is water. FCEV works by relying on fuel cells as the main energy source. The process is as follows:

a. Hydrogen storage: hydrogen is stored in a high-pressure tank in the vehicle.

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b. Electricity production in fuel cell: hydrogen flows to the anode, while oxygen flows to the fuel cell cathode. The chemical reaction between the two produces electricity, heat, and water.
c. Electricity Use: the electricity produced drives the electric motor, while water is released as a by-product.
d. FCEV has a small battery system to store additional energy, such as energy produced through regenerative braking.

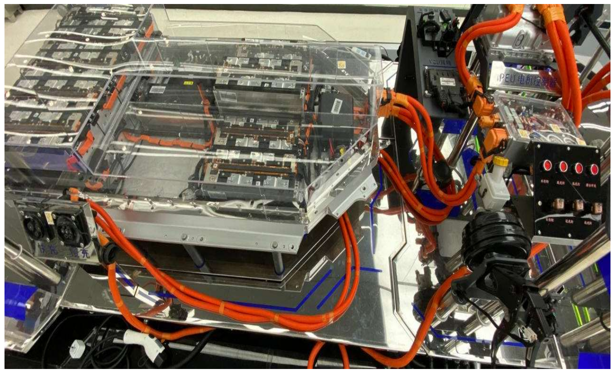

Figure 1. Battery arrangement in an EV in Beifang Automotive

In Indonesia, implementing FCEV faces significant challenges, especially due to the lack of hydrogen-filling infrastructure. In addition, the cost of hydrogen production and distribution in Indonesia is still high, and this technology is less well-known to the public. However, FCEVs have great potential in heavy-duty transportation sectors such as buses and long-haul trucks, where long-range and fast charging times are critical. FCEVs offer many advantages and disadvantages that make them quite promising for future transportation, as shown in Table 7.

Table 7. Advantages and disadvantages of FCEV

Advantages	Disadvantages
a. Zero emissions: FCEVs produce only water as a by-product, making them environmentally friendly [2], [7], [18]-[20], [27], [30], [35], [38], [49], [52], [71]	a. Limited infrastructure: the availability of hydrogen filling stations is very limited, especially in developing countries like Indonesia [12], [32], [66]
b. Long range: FCEVs can travel long distances on a single hydrogen charge, equivalent to fossil fuel vehicles (around 500–700 km) [8], [12], [27], [29], [30], [32], [33], [46], [62]	b. High price: fuel cell technology and hydrogen storage are still expensive, making the price of FCEV vehicles high [28]
c. Fast charging time: hydrogen charging takes only 3–5 minutes, much faster than BEV battery charging [7], [25], [46]	c. Hydrogen production: most hydrogen is produced using fossil fuels, so the process is not entirely environmentally friendly. Green hydrogen from renewable energy is still in the development stage [14], [20], [25], [29], [30]-[33], [39], [53]
d. Reliable performance: FCEVs offer smooth acceleration and high efficiency, even in extreme weather conditions [29], [30]	d. Hydrogen safety: hydrogen is a highly flammable gas requiring a very safe storage and handling system [30], [32], [46]

FCEV is considered a long-term solution for green transportation, especially for heavy vehicles and sectors that are difficult to electrify with batteries, such as maritime and air transportation. This technology is also suitable for countries with great potential for producing green hydrogen. Table 8 shows the four important aspects of the EV system.

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Table 8. An important aspect of selecting an EV

Aspect	BEV	PHEV	HEV	FCEV
Emissions [19], [20], [45], [47], [50], [51], [53], [58], [64], [65], [66], [69], [72]	Zero	Low	Currently	Zero
Energy Efficiency [2], [5], [7], [8], [14], [17], [20], [47]-[49], [51], [53], [57]-[60], [62]-[64], [68], [70], [71]	Very High	Tall	Currently	Low
Distance [12], [23], [24], [26], [29], [31], [33], [44]-[46], [54], [69]	Medium (250–500 km)	Length (500–700 km)	Length (500–800 km)	Very Long (>800 km)
Infrastructure [8], [11], [12], [14], [33], [37], [38], [42], [48], [50], [53], [54], [59], [66]	Developing	Available	Not Required	Limited
Charging Time [7], [8], [14], [20], [22], [25]-[27], [32], [33], [38], [39], [41], [46], [50], [53], [54]	Slow (30 minutes–8 hours)	Medium (5–10 minutes)	No need	Fast (3–5 minutes)

As hydrogen technology advances and production costs decline, FCEVs could become a competitive alternative to BEVs. In the short term, the success of FCEVs largely depends on developing hydrogen infrastructure and adopting policies that support renewable energy. With the advantages of long-range, fast charging times, and zero emissions, FCEV have great potential to become an integral part of global sustainable transportation solutions.

3. Result and Discussion

The adoption of EVs in Indonesia faces several obstacles that need overcoming to support the transition to more sustainable transportation [66].

3.1. Infrastructure limitations

One of the main challenges is the lack of supporting infrastructure, especially public electric vehicle charging stations. Public electric vehicle charging stations are mainly concentrated in big cities, such as Jakarta and Surabaya, while semi-urban and rural areas are still difficult to reach. In addition, the capacity of the electricity network in several regions of Indonesia is not optimal, with some areas even facing unstable electricity supply problems. The additional burden from EV charging can increase the risk of network disruption if not appropriately handled.

3.2. The High Price of Electric Vehicles (EVs)

Electric vehicles, especially the BEV type, are still much more expensive than fossil fuel vehicles [73]. This is an obstacle for most Indonesians with low to middle purchasing power. One of the leading causes is the high cost of batteries, which accounts for up to 40%-50% of the total cost of a vehicle [74], [75]. Although Indonesia has large nickel reserves as a raw material for batteries, battery production technology and other materials still rely heavily on imports, thus affecting vehicle prices.

3.3. Suboptimal Policies and Regulations

Although the government has committed to EV development, the incentives provided are still limited [19]. For example, tax incentives or EV purchase subsidies are not yet attractive enough to encourage mass adoption [56], [74], [75], [76], [77]. In addition, national standards for EV components and technologies still need to be established so that manufacturers and consumers have clear guidance. The lack of regulations regarding battery waste management is also a concern, considering that used EV batteries can be an environmental threat if not managed properly.

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3.4. Low Public Awareness

Outside of large cities, public awareness of the benefits and potential of EVs is still low [55]. Many do not yet understand that EVs can help reduce air pollution and long-term operating costs. In addition, the perception that EVs are less practical than conventional vehicles, especially regarding range and charging time, is a barrier to adoption. The limited choice of electric vehicle models, especially in the commercial vehicle and motorcycle segments, also limits public interest in this technology.

3.5. Technology and Environmental Challenges

Table 9. EV challenges in the future

Category	Challenge	Description
Infrastructure [1], [8], [11], [12], [14], [20], [22], [25], [27], [32], [33], [37], [38], [42], [48], [50], [53], [54], [59], [66]	a. Limited electric charging stations	• The number of charging stations is still very limited and concentrated in large urban areas. • Not evenly distributed to semi-urban or rural areas
	b. Suboptimal electricity network capacity	• Some areas, especially remote areas, still experience limited electricity supply or unstable electricity networks. • The added load from EV charging can increase the risk of disruption to the electricity network.
Economic [1], [12], [21], [25], [34], [37], [49], [53], [58], [59], [64], [69], [75]	a. The price of electric vehicles is still high	• The price of EVs, especially Battery Electric Vehicles (BEVs), is higher than fossil fuel vehicles. • This is an obstacle for most consumers who have low purchasing power.
	b. The cost of batteries is expensive	• Batteries are the most expensive component in an EV, accounting for around 30-40% of the total vehicle cost. • Battery technology also requires imports of critical materials such as lithium and nickel, although Indonesia has large nickel reserves.
Policies and Regulations [8], [25], [41], [55], [64]	a. Limited government incentives	• Tax incentives or subsidies for EVs are not yet broad or attractive enough to drive mass adoption. • EV adoption policies do not yet have clear targets in some sectors, especially public transportation and logistics.
	b. Lack of national standards for EVs	• Technical standards, such as specifications for chargers and other components, are not yet completely uniform, which can confuse manufacturers and consumers.
Community Awareness and Adoption [25]	a. Low awareness of EVs	• Indonesian society still has minimal information about the benefits of EVs, especially outside big cities. • The perception that EVs are less practical than fossil fuel vehicles is also a barrier.
	b. Limited choice of EV models	• The choice of electric vehicles in the Indonesian market is still limited to certain segments (for example: premium sedans), while the commercial vehicle or EV motorcycle segments are smaller, even though this is a large market.
Environmental [57], [58], [59], [60], [61]	Battery waste management	• There is no comprehensive management system for recycling or disposing of used EV batteries, which could become an environmental problem.
Technology [7], [12], [22], [23], [24], [29], [33], [35], [36], [40], [49], [50], [51], [53], [57], [61], [64], [65], [72], [73]	a. Long charging time	• Compared to fossil fuel vehicles, EV charging time (fast charging around 30 minutes to several hours) is considered impractical for consumers.
	b. Dependence on imported raw materials	• Although Indonesia is rich in resources such as nickel, battery technology and other key components are still largely imported, affecting vehicle prices and dependence on international markets.

Technologically, the relatively long charging time of EVs compared to conventional fueling is still a barrier [31], [33], [53]. Although fast charging is available, this process still takes up to 30 minutes, which is considered impractical for many users [9], [10], [43], [73]. On the other hand, the absence of a comprehensive recycling system for used batteries raises concerns regarding environmental impacts [10], [76]. Battery waste, if not appropriately managed, can pollute soil and water. Future EV challenges are given in Table 9.

3.6. Efforts to Overcome Obstacles

The government and related parties need to take strategic steps to overcome these obstacles. First, accelerate the development of Public electric vehicle charging stations in all regions, including remote areas, and integrate renewable energy, such as solar power, to support charging. Second, it provides broader and more attractive incentives, such as EV purchase subsidies, tax incentives, and affordable financing schemes. Third, public awareness should be increased through educational campaigns about the benefits of EVs and the development of more affordable vehicle models, such as electric motorbikes.

Finally, a battery recycling ecosystem must be built to manage waste sustainably and mitigate future environmental impacts. Table 10 provides the advantages of each type of EV technology along with challenges and recommendations.

By comprehensively addressing these barriers, Indonesia can accelerate EV adoption and maximize its potential to support the decarbonization of the transportation sector. EVs are a promising solution to reduce greenhouse gas emissions and dependence on fossil fuels. The four main types of EVs: BEVs, HEVs, HEVs, and FCEVs have their advantages and challenges.

Table 10. EV advantages, challenges, and recommendations

Type of EV	Superiority	Challenge	Recommendation
BEV	Zero emissions	Limited charging infrastructure	Improving charging infrastructure
PHEV	Low operating costs	Dependence on battery technology	Investment in battery research and related technologies
HEV	High performance	Not completely environmentally friendly	Encourage adoption as a transition solution
FCEV	Flexibility of electricity and fossil fuel use	High cost	Tax incentive policies for PHEVs

4. Conclusion

BEVs are the most promising option for personal vehicles and urban transportation due to their efficiency, technological support, and growing infrastructure. FCEVs have great prospects in the heavy and long-distance transportation sector, although they require large investments in hydrogen infrastructure. PHEVs and HEVs are relevant as transitional solutions but tend to be replaced by BEVs and FCEVs in the long term. The combination of BEVs and FCEVs is believed to be the dominant transportation solution in the future. BEVs and FCEVs contribute zero emissions. PHEVs provide high flexibility, while HEVs do not require charging infrastructure. The future EV choice is FCEVs, considering zero emissions, long-range, and fast charging times.

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