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Advancing Electric Vehicle Safety and Adoption in Indonesia: Insights from Global and Local Perspectives †

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Abstract: Electric vehicles (EVs) are central to global efforts in reducing carbon emissions and transitioning toward sustainable transportation. This literature review emphasizes the critical role of safety in advancing EV adoption in Indonesia by drawing insights from global advancements and addressing local challenges. Key findings highlight that while EVs promise significant environmental benefits, safety concerns, such as battery thermal runaway risks and structural reliability in diverse road and climatic conditions, remain significant barriers. Issues such as battery safety, including thermal runaway risks, and the reliability of structural designs in Indonesia's diverse road and climatic conditions are pivotal. Globally, advancements in battery management systems (BMS), crash-resistant vehicle designs, and autonomous driving technologies provide effective pathways to mitigate these safety risks. Locally, the development of safety standards tailored to tropical climates and robust infrastructure is essential. Leveraging Indonesia's natural resources, such as nickel, offers opportunities to produce safer and cost-effective batteries. Additionally, policy frameworks like Presidential Regulation No. 55/2019 must prioritize safety measures, including rigorous testing, recycling protocols, and public education. This study concludes by advocating for an integrated approach that combines technological innovation, enhanced safety features, and supportive policies to accelerate EV adoption in Indonesia. Future research should focus on improving safety technologies, lifecycle assessments, and renewable energy integration to ensure the long-term success of EV adoption in the country.

Keywords: electric vehicle safety; charging infrastructure; driver assistance systems; policy development; structural integrity

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1. Introduction

Electric vehicles (EVs) are increasingly regarded as a cornerstone in global efforts to mitigate carbon emissions and combat the adverse impacts of climate change [1,2]. As the world transitions to cleaner energy solutions, the transportation sector stands out as a significant contributor to greenhouse gas emissions [3], accounting for approximately 15% of global carbon dioxide (CO_2) emissions in 2019 [4,5]. In Indonesia, the transportation sector contributes a staggering 53% of national CO_2 emissions [6], making it a critical area for decarbonization [7]. The government, through initiatives such as Presidential

Regulation No. 55/2019, has outlined ambitious goals to accelerate EV adoption as part of its strategy to reduce greenhouse gas emissions by 29% by 2030 [8,9]. However, despite its vast potential, Indonesia's EV market remains in its infancy, with adoption rates below 0.3% as of 2022 [10]. This is a stark contrast to countries like China and Norway, where EVs have become an integral part of the transportation ecosystem [11].

One of the key barriers to EV adoption in Indonesia is public skepticism regarding safety [12,13]. While EVs offer significant environmental and economic advantages, concerns about battery safety, charging infrastructure reliability, and the overall readiness of the supporting ecosystem persist [14]. High-profile incidents involving battery fires have heightened public apprehension, underscoring the need for robust safety measures and transparent standards [15]. Furthermore, Indonesia's limited charging infrastructure and inconsistent power grid reliability raise questions about the safety of long-distance EV travel [12], especially in regions with underdeveloped infrastructure [16,17]. Addressing these safety concerns is crucial for fostering public trust and encouraging widespread adoption [10,11,18].

On the technological front [19], advancements in battery management systems and vehicle-to-grid (V2G) technology hold promise for enhancing the safety and reliability of EVs [20,21]. Innovations in thermal management systems and solid-state batteries are reducing the risks associated with overheating and combustion, making EVs safer for consumers [22]. Moreover, policies that mandate rigorous testing and certification standards for EVs and charging infrastructure can play a pivotal role in alleviating public concerns [23]. Lessons can be drawn from global leaders like Norway and the European Union [24], where stringent safety regulations and extensive public awareness campaigns have successfully addressed safety-related hesitations [25,26].

This study aims to explore the intersection of technology, policy, and public perception in the adoption of EVs, with a specific emphasis on safety considerations. By conducting a comprehensive literature review, this research seeks to identify global best practices, evaluate existing challenges, and propose strategies to enhance the safety, efficiency, and sustainability of EVs in Indonesia. The findings are expected to provide actionable insights for policymakers, industry stakeholders, and the public, fostering a safer and more sustainable transportation future.

2. Literature Review

2.1. Classification of Electric Vehicles

The classification of electric vehicles (EVs) into Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Fuel Cell Electric Vehicles (FCEVs) highlights the diverse technological approaches aimed at reducing greenhouse gas emissions, improving energy efficiency, and promoting sustainable transportation [2,27]. Each classification addresses specific use cases, advantages, and challenges, offering a spectrum of solutions for different geographic, economic, and infrastructural contexts [28]. In Indonesia, this classification provides valuable insights into how EV adoption can be tailored to the nation's unique needs [29,30].

Battery Electric Vehicles (BEVs) are fully electric vehicles powered exclusively by rechargeable batteries [31]. These vehicles are the most environmentally friendly in operation, producing zero tailpipe emissions [32]. They rely on advanced battery technologies, primarily lithium-ion, to store and deliver energy to the electric motor [33]. Over the years, significant improvements in battery capacity, energy density, and thermal management systems have enhanced the driving range and reliability of BEVs [34], making them increasingly viable for both personal and commercial use [35,36]. In Indonesia, BEVs are gaining traction in urban centers where short commutes [37], coupled with growing charging

infrastructure, make them a practical choice. For instance, Jakarta has seen an increase in BEV adoption due to supportive government policies [38], including tax incentives and free registration fees for EVs [39]. However, BEV adoption outside urban areas faces obstacles such as limited access to charging stations, "range anxiety", and high dependency on fossil fuel-generated electricity [40].

Fuel Cell Electric Vehicles (FCEVs) use hydrogen as their primary energy source. These vehicles convert hydrogen into electricity using a fuel cell, producing only water vapor as a byproduct [41]. FCEVs are particularly well-suited for applications requiring long ranges and quick refueling, such as public transportation, logistics, and heavy-duty vehicles [42]. Despite their potential, FCEVs face significant challenges in Indonesia [43]. The lack of hydrogen production facilities and refueling infrastructure is a primary barrier [44]. Moreover, the high costs associated with hydrogen storage and distribution further complicate their deployment [45]. However, Indonesia's abundant renewable energy resources, such as solar and wind, offer opportunities to produce green hydrogen [46]. With the right investments in infrastructure and policy support, FCEVs could become a viable option for reducing emissions in sectors where battery-powered EVs face limitations [47,48].

Each classification offers distinct advantages and limitations, making their adoption context-dependent. BEVs, with their zero-emission operation, are ideal for densely populated urban areas where emissions reduction is critical, and driving ranges are shorter. PHEVs serve as a practical solution for regions with limited infrastructure, offering the flexibility of hybrid operation while reducing reliance on fossil fuels. FCEVs, though less developed in Indonesia, hold promise for long-distance and commercial applications, particularly in the public transportation and logistics sectors. For Indonesia, leveraging the strengths of each EV classification is crucial to achieving sustainable transportation. Key strategies include the following: Infrastructure development: building charging stations for BEVs and PHEVs while initiating pilot projects for hydrogen refueling stations to support FCEVs. Local manufacturing: encouraging domestic production of batteries and fuel cells to reduce costs and strengthen the supply chain. Policy and incentives: offering differentiated incentives for each EV-type based on their applications, such as tax exemptions for PHEVs in rural areas and subsidies for BEVs in urban zones. Public education: raising awareness about the unique benefits of each EV type to align consumer choices with their transportation needs and environmental priorities.

2.2. Challenges in Implementing Electric Vehicles in Indonesia

Indonesia faces significant challenges in establishing a robust charging infrastructure to support the adoption of electric vehicles (EVs) [7]. Currently, charging stations are sparsely distributed and heavily concentrated in major metropolitan areas such as Jakarta, Surabaya, and Bali, while rural and less urbanized regions remain underserved. This limited infrastructure exacerbates "range anxiety", a critical barrier to adoption, as consumers worry about the availability of charging stations during longer commutes. Furthermore, planning and implementing a cohesive national charging network is complicated by the country's geographical diversity and archipelagic nature, which necessitates tailored solutions for remote islands. The lack of fast-charging stations further discourages adoption, especially for users requiring quick recharging capabilities.

The integration of EVs into Indonesia's existing power grid presents a multifaceted challenge. Indonesia's electricity grid, which relies predominantly on coal, is already strained and faces difficulties in balancing supply and demand during peak hours. The mass adoption of EVs would significantly increase electricity demand, potentially leading to grid instability, especially during simultaneous charging events. While Vehicle-to-grid (V2G) technology offers a promising solution by enabling bi-directional energy exchange to

stabilize the grid, its implementation in Indonesia is hindered by technological, regulatory, and infrastructural gaps. Effective deployment of V2G requires significant investments in grid modernization, energy storage systems, and advanced grid management.

The environmental benefits of EVs are diminished in Indonesia due to the country's heavy dependence on coal for electricity generation. While EVs produce zero emissions during operation, their overall carbon footprint remains high when the source of electricity is considered. Without a substantial shift towards renewable energy in the power mix, the adoption of EVs risks merely displacing emissions from vehicles to power plants. Additionally, the production and disposal of lithium-ion batteries create environmental and logistical challenges, particularly concerning the mining of critical minerals like nickel and cobalt, which are abundant in Indonesia but often extracted with significant environmental costs.

The high upfront cost of EVs compared to internal combustion engine (ICE) vehicles continues to deter widespread adoption in Indonesia. While the government has introduced incentives such as tax reductions and subsidies, their effectiveness is limited due to restricted market coverage and lack of additional support mechanisms. Moreover, the high cost of importing EV components further inflates prices, highlighting the need for local manufacturing capabilities and supply chain development. Financial incentives need to extend beyond vehicle purchases to include support for charging infrastructure and battery recycling facilities, ensuring a holistic approach to EV ecosystem development.

Safety concerns around lithium-ion batteries pose a significant barrier to consumer confidence in EVs. Thermal runaway—a phenomenon where the battery overheats uncontrollably—remains a critical risk that can result in fires and other hazards [3]. The lack of uniform safety standards and testing protocols in Indonesia exacerbates these concerns. Advanced battery management systems (BMS) and improved thermal management technologies are essential to mitigate these risks. Additionally, ensuring the safety and reliability of batteries under Indonesia's tropical climate, which often features high temperatures and humidity, presents an additional layer of complexity.

Public awareness and understanding of EVs remain low in Indonesia, particularly outside urban areas. Many consumers lack adequate knowledge about the operational benefits of EVs, such as lower maintenance costs and environmental advantages. Moreover, misconceptions persist regarding the practicality of EVs, including concerns about performance, charging time, and durability. This lack of awareness is compounded by limited exposure to EV technology in rural areas, where traditional vehicles dominate. Comprehensive education campaigns are needed to address these gaps and build consumer trust in EV technology.

3. Research Methodology

3.1. Research Design

This study employs a literature review methodology to comprehensively analyze and synthesize the existing body of knowledge on the challenges and opportunities of electric vehicle (EV) adoption in Indonesia. A literature review is particularly suited for this research as it enables the identification of trends, gaps, and patterns within the available academic and industry-focused literature. By evaluating a wide range of studies, reports, and policy documents, this approach ensures a thorough understanding of the factors influencing EV implementation and provides a solid foundation for developing actionable recommendations. The literature review focuses on multiple dimensions of EV adoption, including technical, economic, environmental, and societal aspects. Specifically, the analysis addresses key challenges such as charging infrastructure, grid integration, battery safety, policy frameworks, and public awareness, as well as strategies to overcome these barriers.

3.2. Data Collection

The primary source of data for this study is secondary literature from reputable academic journals, conference proceedings, industry reports, government policy documents, and international publications. The inclusion criteria for the literature are as follows: published within the last 10 years to ensure relevance and contemporaneity; focused on topics related to EV adoption, infrastructure development, energy policies, and sustainability; and emphasizing Indonesia's context while also including comparative studies from other countries to draw lessons and best practices. The data collection process involved systematic searches using keywords such as "electric vehicles in Indonesia", "EV adoption challenges", "charging infrastructure", "battery safety", and "renewable energy integration". Key databases and platforms used include ScienceDirect, IEEE Xplore, Springer, and Google Scholar. Industry reports from organizations such as the International Energy Agency (IEA) and Indonesian government publications were also reviewed for policy-related insights.

3.3. Data Analysis

A thematic analysis approach was used to organize and synthesize the findings from the reviewed literature. The analysis involved the following steps: Categorization: the literature was categorized into key themes, including infrastructure, grid integration, policy, battery safety, and public awareness. Comparison: the study compared findings across different sources to identify common challenges and unique regional insights. Synthesis: thematic findings were synthesized to construct a holistic understanding of the current state of EV adoption in Indonesia and the strategies needed to address existing challenges. Critical Evaluation: each source was critically evaluated for its credibility, methodological rigor, and relevance to the research objectives.

3.4. Scope and Limitations

The scope of this study is limited to a literature-based analysis, which provides valuable insights but does not include primary data collection, such as surveys or interviews. As such, the findings rely on the availability and quality of the existing literature. While the study emphasizes Indonesia's context, lessons from global experiences are incorporated to offer comparative perspectives.

Limitations of this methodology include potential biases in the selected literature due to publication preferences or regional focus and the exclusion of emerging studies not yet published or widely accessible at the time of the review. Despite these limitations, the literature review methodology offers a robust framework for understanding the multifaceted challenges and opportunities in EV adoption.

4. Results

4.1. Security and Future Development of Electric Vehicles in Indonesia

The development and adoption of electric vehicles (EVs) in Indonesia must prioritize security and resilience as critical pillars of its growth. The unique challenges posed by Indonesia's geographical diversity, reliance on fossil fuels, and nascent EV ecosystem demand a forward-looking approach that ensures safety across all aspects of vehicle design, battery management, infrastructure, and regulatory frameworks.

Battery safety remains a paramount concern in the context of EV adoption. Lithium-ion batteries, the cornerstone of current EV technology, are prone to risks such as thermal runaway, which can lead to overheating, fire, or explosions. These risks are amplified in Indonesia's tropical climate, where high temperatures and humidity could accelerate battery degradation. To address this, future EV development must integrate advanced

battery management systems (BMS) that can monitor, regulate, and mitigate risks in real-time. Additionally, research into alternative battery chemistries, such as solid-state batteries, which offer higher stability and lower fire risk, should be prioritized.

The design of EVs for the Indonesian market must also account for the unique challenges posed by road conditions and usage patterns. Indonesia's varied terrain and urban congestion necessitate durable and efficient designs that are resilient to wear and tear. Lightweight materials and aerodynamically optimized structures can improve energy efficiency, while enhanced suspension systems and protective features ensure vehicle longevity and occupant safety in diverse conditions. An EV is equipped with a lithium battery that has been safety tested. The position of battery is under the floor, which you can see in Figure 1.

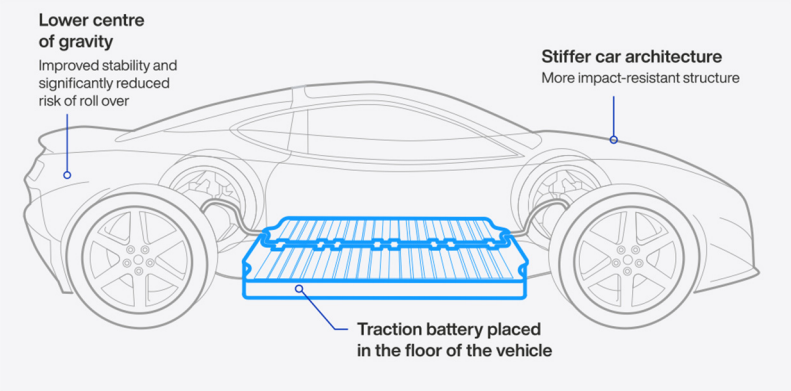


Figure 1. Reinforced EV battery position [49].

Charging infrastructure must evolve to address both user convenience and grid security. The integration of smart charging systems equipped with dynamic load balancing and real-time monitoring can help optimize energy usage and reduce strain on the national grid. Vehicle-to-grid (V2G) technologies, which allow EVs to act as mobile energy storage units, offer additional resilience by stabilizing the grid during peak demand or emergencies. However, the success of such systems hinges on robust cybersecurity measures to prevent vulnerabilities in bi-directional energy flows and data communications.

Policy frameworks must complement technological advancements to foster a safe and sustainable EV ecosystem. Regulations mandating safety standards for battery manufacturing, vehicle assembly, and charging stations are critical. The government should incentivize the development of local testing facilities to ensure compliance with international standards while adapting to Indonesia's unique requirements. Additionally, a regulatory focus on end-of-life battery management, including recycling and disposal protocols, will be essential to mitigate environmental and safety risks associated with battery waste.

Public awareness and education will play a pivotal role in the secure adoption of EVs. Consumer trust can be enhanced through transparent communication about safety features, regular maintenance requirements, and emergency protocols. Collaborative initiatives between government agencies, manufacturers, and educational institutions can disseminate information effectively, fostering a culture of safety and sustainability.

Looking forward, the development of EVs in Indonesia must embrace emerging technologies that enhance security while aligning with global trends. Autonomous driving technologies, when combined with EV platforms, can improve road safety through advanced driver-assistance systems (ADAS). Moreover, incorporating renewable energy sources into the EV ecosystem, such as solar-powered charging stations, will reduce the dependence on fossil fuels and contribute to long-term energy security.

In conclusion, the future of electric vehicles in Indonesia depends on a holistic approach that integrates advanced safety measures, resilient design, smart infrastructure, robust regulations, and public engagement. By addressing these dimensions comprehensively, Indonesia can build a secure and sustainable EV ecosystem that aligns with its environmental goals and enhances the quality of life for its citizens.

4.2. Design Security and Development: From Traditional to Modern Electric Vehicles

The evolution of electric vehicle (EV) design has been a journey marked by continuous innovation to enhance safety, efficiency, and user experience. From the rudimentary designs of early electric cars to the technologically advanced systems in modern EVs, significant progress has been made in addressing safety concerns and adapting to emerging trends. In Indonesia, this evolution provides critical lessons for developing EVs that meet the nation's unique challenges.

Traditional electric vehicles, developed in the late 19th and early 20th centuries, relied on lead-acid batteries. These early EVs were primarily designed for short-distance travel and lacked critical safety features, such as robust battery management systems and crash-resistant vehicle structures. The simplicity of these designs limited their adoption, especially in regions with harsh road conditions like Indonesia's rural areas.

Despite their limitations, these vehicles laid the foundation for modern EV development by introducing the concept of zero-emission transport. However, the absence of thermal management systems often led to battery overheating, highlighting the need for enhanced safety measures in subsequent designs.

The introduction of lithium-ion (Li-ion) batteries marked a turning point in EV design. Li-ion batteries offered higher energy density, longer lifespans, and lower maintenance compared to lead-acid counterparts. However, their adoption introduced new safety challenges, such as thermal runaway and fire hazards. Modern EVs addressed these issues by incorporating advanced battery management systems (BMS) capable of monitoring temperature, voltage, and current to prevent failures.

Innovations such as reinforced battery casings and compartmentalized designs further enhanced safety by isolating potential hazards. These developments were complemented by improvements in vehicle architecture, including crumple zones and side-impact protection, to ensure occupant safety during collisions.

The current generation of EVs is characterized by the integration of smart technologies and advanced driver-assistance systems (ADAS). Features such as automatic emergency braking, lane-keeping assist, and adaptive cruise control have transformed EVs into safer and more intelligent vehicles. Additionally, the use of real-time data monitoring and over-the-air updates allows manufacturers to address safety concerns proactively by deploying software patches and enhancements.

Modern EVs also benefit from advanced materials and design principles aimed at improving aerodynamics and reducing weight without compromising structural integrity. The shift toward solid-state batteries represents another leap forward, offering higher thermal stability and lower fire risk compared to traditional Li-ion batteries.

While global advancements in EV design have set new safety benchmarks, adapting these technologies to Indonesia's unique conditions remains a challenge. The country's tropical climate necessitates enhanced thermal management systems to prevent overheating in high-temperature environments. Additionally, the diverse terrain and inconsistent road quality require durable vehicle designs capable of withstanding wear and tear.

To address these challenges, future EVs in Indonesia must prioritize the following: Customized Battery Systems: batteries optimized for Indonesia's climate, including improved cooling mechanisms and moisture-resistant designs. Rugged Vehicle Designs:

enhanced suspension systems and reinforced undercarriages to navigate uneven roads. Localized Manufacturing: leveraging Indonesia's abundant resources, such as nickel, to produce batteries domestically, reducing costs and improving access.

The next frontier in EV development involves autonomous driving and renewable energy integration. Autonomous EVs are expected to incorporate machine learning and sensor fusion technologies to enhance road safety, while renewable-powered charging stations can reduce reliance on fossil fuels, aligning with Indonesia's sustainability goals.

Additionally, modular designs that allow for battery swapping and upgrades could improve the usability and lifespan of EVs, addressing concerns about long-term value. Collaborative efforts between government agencies, academic institutions, and private manufacturers will be crucial in driving these advancements.

In summary, the evolution of EV design from traditional to modern systems underscores the importance of integrating safety, efficiency, and adaptability. By learning from global advancements and tailoring solutions to local needs, Indonesia can pave the way for a secure and sustainable EV ecosystem (Figure 2).

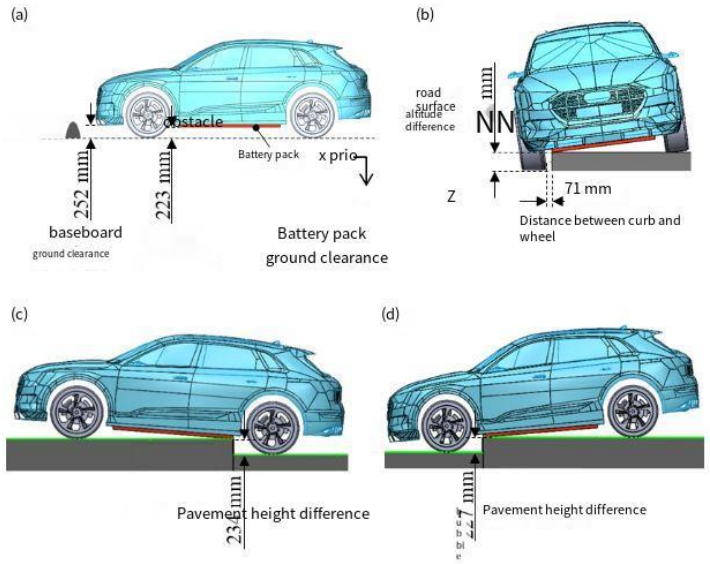


Figure 2. Safety features in electric vehicles (EVs) [50] (**a**) normal position; (**b**) the vertical height of the obstacle is higher than the ground clearance of the battery pack; (**c**) the vehicle passes the curb; and (**d**) the wheel on one side falls into the curb with a height difference.

The safety is a critical aspect of modern electric vehicle (EV) design, encompassing both traditional safety mechanisms and advanced technologies tailored to the unique characteristics of EVs. As EV adoption increases globally and in Indonesia, integrating robust safety features becomes paramount to ensure occupant protection, enhance consumer confidence, and to align with regulatory standards.

Safety belts remain one of the most fundamental and effective safety features in EVs, as in conventional vehicles. They are designed to restrain occupants during sudden deceleration, preventing serious injuries. Modern EVs have improved safety belt designs by incorporating pre-tensioners and load limiters that adapt to the force of impact. These systems ensure that the belts tighten upon collision detection, holding occupants securely in place while minimizing pressure on the chest.

In high-performance EVs, where acceleration forces can be greater than traditional vehicles, safety belts are engineered to provide stability during sharp turns or rapid speed changes. Additionally, advancements in seatbelt sensors integrated with autonomous emergency braking (AEB) systems ensure that belts are pre-tensioned before an imminent crash is detected.

Airbag systems in EVs have evolved to address the specific dynamics of electric vehicles. With battery placement typically in the vehicle floor, the center of gravity in EVs is lower, potentially affecting collision dynamics. Modern airbag systems are calibrated to respond to these unique conditions, ensuring optimal deployment during front, side, and rollover impacts.

Many EVs are now equipped with advanced airbags, including knee airbags, rear-seat airbags, and side curtain airbags, providing comprehensive protection for all passengers. Innovations such as multi-stage deployment allow airbags to adjust inflation levels based on the severity of the collision and the size or position of the occupants.

Tires play a crucial role in EV safety, given the increased weight of electric vehicles due to their batteries. EV-specific tires are designed with stronger sidewalls and higher load ratings to accommodate the additional mass while maintaining optimal grip and stability. Proper tire selection and maintenance are critical to preventing blowouts and ensuring consistent handling, particularly in Indonesia's varied terrain and road conditions.

Traction control systems (TCS) and anti-lock braking systems (ABS) are also optimized for EVs to manage the instantaneous torque delivered by electric motors. These systems help maintain stability during acceleration and braking, reducing the risk of skidding or loss of control, especially on wet or uneven surfaces.

ADAS features have become integral to EV safety, providing real-time monitoring and intervention to prevent accidents. Key ADAS technologies include the following: Autonomous emergency braking (AEB): detects potential collisions and applies brakes automatically to mitigate impact or avoid it altogether. Lane-keeping assist (LKA): alerts drivers when they unintentionally drift out of lanes and actively steers the vehicle back. Blind-spot detection (BSD): monitors areas around the vehicle that are difficult for the driver to see, enhancing situational awareness. In EVs, these systems are often integrated with vehicle telematics and over-the-air updates, enabling continuous improvements in safety performance.

Battery safety is a defining concern for EVs, necessitating specialized systems to prevent risks such as thermal runaway, fires, or explosions. Battery management systems (BMS) monitor parameters such as temperature, voltage, and current, ensuring safe and efficient operation. Additionally, thermal management systems regulate battery temperatures, particularly in high-demand or extreme environmental conditions, like those commonly experienced in Indonesia.

Crash-resistant battery enclosures are another critical safety feature, designed to protect the battery pack during collisions. Materials such as aluminum and high-strength steel are commonly used for these enclosures, ensuring durability and minimizing the risk of leakage or fire.

EV designs emphasize crashworthiness, with reinforced structures to absorb and distribute collision forces effectively. The unique placement of batteries in the vehicle floor adds rigidity to the chassis, contributing to better crash protection. EV manufacturers also design crumple zones and reinforce critical areas such as the pillars and roof to maximize occupant safety during impacts.

Additional features in EVs enhance overall safety. Emergency call systems (eCall) automatically contact emergency services in the event of a severe collision. Reverse cameras and parking sensors assist in maneuvering and help to prevent accidents in confined spaces. Electronic stability control (ESC) helps to maintain vehicle control during sudden maneuvers or adverse road conditions.

As EV technology advances, safety features will continue to evolve. Innovations such as predictive safety systems using artificial intelligence (AI), augmented reality displays for enhanced driver awareness, and biometric monitoring to detect driver fatigue are expected

to redefine safety in EVs. Additionally, regulatory frameworks must evolve to address the unique safety requirements of EVs, ensuring uniform standards for features such as battery safety, crash testing, and advanced driver-assistance systems.

In Indonesia, integrating these advancements with localized solutions—such as tires suited for tropical climates, adaptive safety systems for varied road conditions, and improved public awareness—will be crucial for fostering safe and widespread EV adoption. By prioritizing safety across all components and systems, EVs can set a new benchmark for secure, sustainable transportation in Indonesia.

4.3. Limited Charging Infrastructure

Indonesia's EV market is hindered by an underdeveloped charging infrastructure, which creates a major barrier to consumer adoption. As of now, charging stations are sparsely distributed and primarily concentrated in major urban centers such as Jakarta, Surabaya, and Bali, leaving rural areas and smaller cities underserved. This uneven distribution exacerbates "range anxiety", a concern among potential EV buyers about the availability of charging facilities for long-distance travel.

The lack of fast-charging stations further compounds the problem. Most existing chargers are slow chargers, which can take several hours to fully recharge a vehicle. Fast chargers, capable of recharging batteries within 20–30 min, are essential for reducing downtime and making EVs more practical for everyday use. However, the high installation costs and the need for robust electrical grids limit their widespread deployment.

Additionally, Indonesia's existing electricity grid is not yet optimized to support the increasing energy demand that comes with large-scale EV adoption. Grid reliability issues, particularly in rural and remote areas, pose a challenge for ensuring uninterrupted charging services. Without substantial investment in grid modernization and renewable energy integration, scaling up charging infrastructure will remain difficult.

The high upfront cost of purchasing an EV is another significant challenge for Indonesian consumers. This cost disparity between EVs and internal combustion engine (ICE) vehicles is primarily driven by the expensive lithium-ion batteries that account for up to 40% of an EV's total cost. Although battery prices are declining globally due to economies of scale and advancements in production technologies, the reduction has not yet translated into affordable EV options for the Indonesian market.

Imported EVs, which dominate the Indonesian market, also face additional costs such as import duties and shipping fees, further inflating retail prices. While locally manufactured EVs could address these price issues, Indonesia's domestic manufacturing capabilities are still in their infancy, requiring significant investment and policy support to compete with global producers.

The cost of home charging equipment, including installation of wall-mounted chargers, adds to the overall expense of EV ownership. Consumers also face the challenge of limited financing options tailored for EV purchases, further discouraging adoption among middle- and lower-income groups.

5. Discussion

The adoption of electric vehicles (EVs) in Indonesia represents a critical step toward achieving the nation's sustainability goals and aligning with global efforts to combat climate change. While the market is still in its early stages, the findings of this study highlight both significant challenges and promising opportunities that will shape the future of EV development in the country. This chapter discusses the implications of these findings, integrating insights from technological advancements, market dynamics, and policy frameworks, while identifying actionable strategies to address existing gaps.

A recurring theme in this study is the interplay between infrastructure availability and consumer adoption. Limited charging infrastructure has been identified as one of the major barriers to EV uptake in Indonesia. This creates a "chicken-and-egg" dilemma where low consumer adoption discourages investment in infrastructure, and inadequate infrastructure deters consumers from purchasing EVs. A key point of discussion is the need for simultaneous investments in infrastructure and incentives to stimulate market growth.

Global best practices indicate that a strong public–private partnership is crucial for overcoming this challenge. Governments can play a catalytic role by subsidizing the initial costs of installing charging stations and establishing policies that encourage private sector participation. For Indonesia, targeted investment in urban and intercity fast-charging networks, complemented by renewable energy integration, could accelerate the transition. Additionally, localized solutions, such as battery-swapping stations for two-wheelers, may address the needs of specific segments of the population.

The high cost of EV ownership remains a significant barrier in Indonesia, driven largely by the dependence on imported components such as lithium-ion batteries. Localizing production offers a clear pathway to reducing costs while fostering economic growth. Indonesia's abundant nickel reserves provide a strategic advantage in developing a domestic battery manufacturing industry, which could lower production costs, create jobs, and position the country as a regional hub for EV supply chains.

However, the development of localized production facilities requires substantial investment in technology, skills, and infrastructure. Policies that incentivize domestic and foreign investments, along with public–private partnerships, are essential. Furthermore, collaborations with global EV leaders could accelerate technology transfer and capacity building, ensuring Indonesia remains competitive in the evolving EV landscape.

Technological innovation plays a critical role in overcoming safety concerns and improving the performance of EVs. Advances in battery technology, such as solid-state batteries, offer solutions to challenges like thermal runaway and range limitations, while autonomous driving and IoT integration enhance user safety and convenience.

For Indonesia, prioritizing R&D in these areas is crucial to aligning with global trends and addressing local conditions. For instance, developing batteries optimized for Indonesia's tropical climate and rough terrain can improve both safety and durability. Additionally, implementing advanced driver-assistance systems (ADAS) in EVs could mitigate road safety risks, particularly in urban areas with high traffic density.

Policy frameworks have been instrumental in shaping the EV market globally, and their importance cannot be overstated in the Indonesian context. Current policies, such as Presidential Regulation No. 55/2019, have laid the groundwork for EV adoption through tax incentives, subsidies, and production support. However, their impact has been limited due to fragmented implementation and insufficient focus on infrastructure and public awareness.

A critical area for discussion is the need for integrated and region-specific policies that address the unique challenges of Indonesia's diverse geography. For instance, urban policies could prioritize fast-charging networks and fleet electrification for public transport, while rural initiatives could focus on affordable two- and three-wheel EVs and decentralized renewable energy solutions. Additionally, clear regulations on battery recycling and disposal are essential to address environmental concerns and ensure the sustainability of EV adoption.

Consumer perceptions and behaviors play a pivotal role in driving EV adoption. This study highlights the low awareness and misconceptions about EVs in Indonesia, particularly regarding cost-efficiency, safety, and charging infrastructure. Educational campaigns are essential to address these gaps and build consumer confidence.

Collaborations between government agencies, EV manufacturers, and non-governmental organizations (NGOs) can effectively disseminate information on the benefits of EVs. Demonstration projects, such as pilot programs in urban centers or rural electrification initiatives using EVs, can further showcase the practical advantages and inspire broader adoption.

With around 24 percent of the world's CO_2 emissions coming from the transportation sector, it is one of the biggest sources of air pollution. Because electric vehicles (EVs) do not emit exhaust emissions, they produce fewer dangerous pollutants for the environment and human health, such as carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter ($PM_{2.5}$). Transportation plays a significant role in the air pollution in Jakarta and other urban areas, which surpasses WHO standards, according to the World Bank. The switch to EVs can drastically lower air pollution-related health expenses and haze. Greenhouse gas emissions can be significantly reduced by EVs that run on renewable energy. For example, EV emissions can be up to 70% lower than those of internal combustion engine (ICE) vehicles in nations with cleaner grids. By 2030, the Paris Agreement signatory hopes to reduce greenhouse gas emissions by 29%. Since 85% of the country's energy now comes from fossil fuels, switching to electric vehicles is crucial to reaching this target. Making the switch to electric vehicles (EVs) lessens reliance on oil, preserving natural resources and encouraging sustainable energy use. Furthermore, programs like recycling EV batteries aid in addressing waste and resource depletion issues.

By switching to EVs, energy security is improved by lowering dependency on imported oil. For example, EV adoption in the U.S. resulted in fuel cost savings of over $12 billion in 2020. The nation imports more than $17 billion worth of fuel every year. Promoting domestically made EVs and renewable energy can help Indonesia lower its energy import costs and strengthen its economy. Operating costs for EVs are lower than those for ICE cars. Because EVs have fewer moving parts, they require less maintenance than gasoline, and electricity is more affordable. Over the course of the vehicle's life, buyers can save thousands of dollars. The manufacturing of batteries and infrastructure for charging EVs has generated millions of employment. For instance, Tesla's Gigafactories are significant employment centers. Being a significant manufacturer of nickel, a crucial component of EV batteries, Indonesia has the ability to control the EV supply chain. Economic growth can be stimulated by initiatives such as the $1.1 billion battery plant in Karawang that Hyundai and LG invested in.

Innovation in battery technology, including solid-state and lithium-ion batteries, which are also used in renewable energy storage, is accelerated by EV development. This invention is advantageous to industries other than transportation. EVs are frequently equipped with cutting-edge technologies such as smart grid systems, Internet of Things (IoT) connection, and autonomous driving. These developments facilitate effective urban transportation and energy conservation. The United States, China, and the European Union are making significant investments in electric vehicle (EV) technology in an effort to become leaders in the green economy. For instance, China is the world's EV center, having sold over 6.8 million EVs in 2022. By 2030, the Indonesian government wants to see 2.5 million electric vehicles on the road. In order to increase domestic capabilities and draw in investments, policies such as tax cuts, subsidies, and local production requirements are implemented.

With more than 80% of new car sales in 2022 being electric, Norway is the world leader in EV adoption. This achievement is the result of a mix of incentives and policies. EVs in Norway are more affordable than conventional cars because they are not subject to value-added tax (VAT) or purchase taxes. Benefits of EVs include reduced or free access to ferries, toll highways, and parking in cities. Drivers' range anxiety has decreased as a result of investments in charging infrastructure, particularly in urban and rural locations.

Financial assistance reduces the initial cost of electric vehicles. By 2025, public fleets and taxis must switch to electric cars. By discouraging the use of ICE vehicles, high prices on gasoline and diesel vehicles hasten the adoption of EVs. Strong safety regulations, such as required crash tests and fire-resistant battery certifications, are enforced for EVs in Norway. Campaigns for public awareness also teach people how to charge and operate EVs safely.

A superpower in adoption and manufacturing, China has a strong local EV industry backed by strategic policies, and it accounts for over 50% of worldwide EV sales. The cost barrier for EV purchasers is lowered by substantial government subsidies. Because they are correlated with vehicle performance, subsidies promote the creation of superior vehicles. To achieve regulatory quotas, manufacturers are required to produce a minimum percentage of electric vehicles (EVs) under the "New Energy Vehicle (NEV) credit program. By completely electrifying their public bus networks, cities like Shenzhen have decreased their emissions. With more than 5 million public and private charging stations set up by 2023, China is the leader in EV charging infrastructure. The government provides funding for the construction of high-speed chargers along highways and in cities. China ensures that EV batteries are safe in harsh environments by enforcing stringent battery-quality inspections and thermal-runaway-prevention rules. To reduce dangers, the nation has installed fire suppression systems in EV buses and public EV charges.

Significant EV adoption has occurred in the US, especially in areas like California, which sets the standard for infrastructure development and policy innovation in the nation. Under the Inflation Reduction Act of 2022, the US government offers tax credits for EV purchases of up to $7500. Additionally, this act encourages domestic EV manufacturing. Additional subsidies are provided by states such as California, which lowers the cost of EV ownership. Additionally, automakers are required to sell a minimum quantity of zero-emission vehicles under California's zero-emission vehicle (ZEV) regulation. A total of $7.5 billion will be used to construct 500,000 EV chargers by 2030 as part of the Biden administration's bipartisan infrastructure law. Successful partnerships between the public and private sectors are exemplified by initiatives like Tesla's Supercharger network, which improves the experience of EV drivers

Strict crash safety regulations for EVs are enforced by the National Highway Traffic Safety Administration (NHTSA). Manufacturers of electric vehicles are required to adhere to stringent battery safety standards, which include mechanical shock and heat testing. Considering all-inclusive incentive plans like China and Norway, Indonesia might provide a combination of tax breaks, subsidies, and toll advantages to entice consumers to purchase EVs.

In order to accommodate Indonesia's increasing motorcycle usage, direct subsidies can concentrate on public fleets and two-wheelers. Indonesia might prioritize the installation of fast chargers along major highways and other charging stations, just like China has performed. Infrastructure development can be accelerated through public–private partnerships by utilizing private-sector knowledge. Similarly to China, Indonesia might leverage its plentiful nickel resources by providing incentives for domestic EV and battery manufacture.

Long-term sustainability can be improved and environmental issues can be addressed by policies that encourage battery recycling.

At the moment, Indonesia does not have a sufficient infrastructure for EV charging. Less than 600 public charging stations exist nationally as of 2023, which is not enough to accommodate the demands of the expanding EV market. Rural areas are underserved by the concentration of charging infrastructure in urban locations such as Jakarta and Bali. Potential purchasers' range anxiety is made worse by this unequal distribution. Especially in rural regions, Indonesia's electrical grid has frequent outages. The grid may become

much more stressed as EV infrastructure grows, requiring major modifications to keep up with demand. Although Indonesia has a lot of potential for renewable energy, more than 85% of its electricity is currently produced using coal, which lessens the environmental benefits of EV adoption unless the energy mix changes to include cleaner sources. Although regulations like Presidential Regulation No. 55/2019 encourage the adoption of EVs, investors and consumers are left in the dark due to the absence of comprehensive implementation instructions and regional differences in policy enforcement. Low-income users and the market leader, motorcycles, are under supported by the current tax incentives and subsidies, which largely benefit high-end EVs. EVs are more costly than conventional cars since a sizable amount of their parts, such as batteries, are still imported. Local uptake and affordability are hampered by this. Compared to internal combustion engine (ICE) vehicles, electric vehicles (EVs) are thought to be more costly because of their high initial prices. This impression is made worse by a lack of knowledge about long-term savings. A large number of Indonesians are ignorant of the financial and environmental advantages of electric vehicles. Additionally, little is known about the criteria for maintenance and billing procedures. Motorcycles are a popular choice in Indonesia, where they make up more than 80% of all vehicles on the road. For EV adoption to be widely appealing, this market must be served.

As of 2023, Indonesia has less than 600 public charging stations, most of which were found in major cities like Jakarta, Bali, and Surabaya. Rural and less developed areas are underserved as a result of this unequal distribution. Concerns around charging availability, especially for long-distance trips, put off a lot of prospective customers. This problem is made worse by the lack of highway fast-charging stations. Adoption is made more difficult by the fact that different EV manufacturers employ different charging standards, which can lead to issues with vehicles and charging stations. Power outages are common in Indonesia's grid, particularly in rural areas. Because of this, it is difficult to guarantee dependable charging for EV consumers. Without major improvements, the current grid infrastructure may not be able to manage the increasing demand for electricity brought on by the widespread adoption of EVs. Coal and other fossil fuels provide more than 85% of Indonesia's electricity. The environmental advantages of EVs are compromised in the absence of a switch to renewable energy.

Despite the government's introduction of helpful policies, such as Presidential Regulation No. 55/2019, stakeholders are confused by the absence of precise rules and coordination between the national and regional administrations. There are significant regional differences in the way policies are implemented, with some places advancing more quickly than others. National adoption is slowed by this discrepancy. Higher-end EV vehicles are the main beneficiaries of current incentives like tax breaks and subsidies. This reduces the number of reasonably priced options available to middle- and lower-class consumers, who make up the majority of Indonesia's market. Compared to internal combustion engine (ICE) vehicles, EVs are more expensive due to the importation of many EV components, particularly batteries. There are no thorough laws governing battery disposal, recycling, or EV safety in Indonesia. Adoption may be discouraged by the safety and environmental dangers this presents. The long-term financial and environmental advantages of electric vehicles are not well known among many Indonesians. The demand is hampered by this ignorance. There is less of a need for cleaner alternatives because the general population is frequently ignorant of the connection between traditional vehicle emissions and health problems brought on by air pollution. More than 80% of the cars on Indonesian roadways are motorcycles. Despite the growing popularity of electric motorbikes, most buyers still favor conventional gasoline-powered motorcycles because of their perceived dependability and familiarity. A lot of Indonesians have concerns about the dependability and perfor-

mance of EVs, particularly in difficult situations like steep terrain or lengthy journeys. One of the primary deterrents to EVs is still their initial cost. Many customers value lower upfront prices even when operating costs are lower.

6. Conclusions

Electric vehicles (EVs) offer a transformative opportunity for Indonesia to transition toward a sustainable transportation system, reducing carbon emissions and reliance on fossil fuels. This literature review highlights that while EVs provide significant environmental and economic benefits, safety considerations are paramount to building consumer trust and ensuring widespread adoption. Battery safety, structural integrity, and advanced driver-assistance systems (ADAS) are critical components of modern EVs, addressing unique risks such as thermal runaway and collision dynamics specific to electric powertrains. For Indonesia, integrating safety features optimized for tropical climates and diverse road conditions is essential for promoting EV adoption.

The limited charging infrastructure, high upfront costs, and low public awareness remain significant barriers to EV market growth in Indonesia. However, opportunities abound in leveraging the country's natural resources, particularly nickel for battery production, and focusing on localized manufacturing to reduce costs. Innovations in safety technologies, such as reinforced battery enclosures and predictive safety systems, further enhance the appeal of EVs by addressing consumer concerns about reliability and accident prevention. Expanding policies to incentivize safety-focused R&D and manufacturing could position Indonesia as a leader in safe and sustainable EV production.

Policy frameworks, such as Presidential Regulation No. 55/2019, have laid the foundation for EV adoption in Indonesia, but greater emphasis on safety regulations, battery recycling protocols, and public education campaigns is needed. Collaborating with global EV leaders to implement best practices in safety testing and standards can ensure that Indonesia's EVs meet international benchmarks. Moreover, scaling public transportation electrification with a focus on safety features can contribute significantly to urban emission reductions while demonstrating the reliability of EVs.

7. Future Research

Future research should prioritize battery safety technologies, such as advanced thermal management systems (e.g., phase change materials and liquid cooling) and crash-resistant designs (e.g., reinforced battery enclosures) tailored to Indonesia's tropical climate. Investigating the lifecycle impacts of batteries, from production to disposal, can address environmental and safety concerns, guiding the development of sustainable recycling systems and end-of-life management protocols. Additionally, studies on advanced driver-assistance systems (ADAS) and their integration with EVs in Indonesia's unique traffic and road conditions could provide valuable insights into enhancing road safety.

Exploring the economic feasibility of integrating renewable energy sources, such as solar-powered charging stations, with safety-focused charging infrastructure would align with Indonesia's broader sustainability goals. Research on the electrification of public transportation systems, including buses and commuter trains, should emphasize safety measures for passengers and operational reliability. By focusing on these areas, future studies can provide actionable strategies to advance EV adoption while ensuring safety remains a central pillar of Indonesia's transition to a sustainable transportation ecosystem.

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