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Research article

Drivers and barriers of eco-innovation in electric vehicle diffusion: Evidence from Indonesia

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ABSTRACT

Electric vehicles (EVs) are critical to achieving global decarbonization targets, yet their adoption in emerging economies remains limited. Indonesia is an emerging economy in Southeast Asia with a vehicle population of more than 164 million. However, public interest in adopting EVs remains low, with only 322,325. This study explores the drivers and barriers of eco-innovation (EI) in EV diffusion in Indonesia through qualitative interviews with 61 stakeholders, including energy companies, automotive manufacturers, and infrastructure providers. The findings highlight that fiscal and non-fiscal incentives, such as subsidies and tax exemptions, have encouraged EV adoption but suffer from inconsistent implementation. Collaboration among manufacturers, green suppliers, and research institutions emerges as key drivers, fostering technological innovation through knowledge spillovers. Early adopters, including urban users and ride-hailing services, demonstrate the importance of green market sensing in shaping demand. Major barriers include limited charging infrastructure, high upfront costs, and low public awareness. Additionally, we find that circular economic practices, such as battery recycling and repurpose energy storage, offer sustainability benefits but require stronger policy support. This research extends eco-innovation and innovation diffusion theories by contextualizing them for emerging economies, addressing socio-economic and regulatory barriers. We conclude by providing insights for policymakers and industry leaders.

1. Introduction

One of the pivotal initiatives to achieve net-zero emission targets in transportation is the transition from internal combustion engine vehicles (ICEVs) to electric vehicles (EVs). EVs have diffused globally. However, the trend of adopting EVs as cleaner transportation in Indonesia has been slower than in major regions. Despite promising growth from 2022 to 2024, the proportion of EVs, less than 0.2 % of Indonesia's total vehicle population, indicates that EV adoption in Indonesia is still limited compared to the ICEVs. This study, building on the eco-innovation (EI) literature, examines how EI drivers and barriers influence EV diffusion in Indonesia. EI plays a crucial role in sustainable development by preserving the environment and optimizing resource utilization (Orjuela-Ramirez et al., 2023). Firms implement EI in various technical and non-technical ways, including products, services, manufacturing processes, and business models (Janahi et al., 2021). The implementation of EI is influenced by various drivers and barriers that firms encounter, particularly due to the dual externalities it involves—namely, knowledge spillovers and environmental externalities (Orjuela-Ramirez et al., 2023; Garcia et al., 2019).

First, knowledge spillovers occur when firms that invest in research and development (R&D) activities do not fully appropriate the returns on their investment, as their innovation may benefit other firms (Audretsch and Belitski, 2022; Demirel and Kesidou, 2019). While knowledge spillovers can promote the diffusion of green technologies, they also lead firms to underinvest in EI (Barrena-Martínez et al., 2020; Grimaldi et al., 2021).

Second, firms implement EI to mitigate the negative environmental

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externalities of business operations, such as carbon emissions and environmental pollution. However, the neoclassical approach often treats environmental issues as externalities, leaving society to bear the costs (Piluso, 2024). As a result, firms often underinvest in EI unless governments offer incentives or subsidies to make EIs more competitive in the market.

Prior research has largely examined the drivers and barriers of EI in advanced economies (Audretsch and Belitski, 2022; Bocken and Geradts, 2020; Demirel and Kesidou, 2019; Piluso, 2024). However, more recent research in emerging countries have highlighted the roles of regulation (Sasongko et al., 2024; Setiawan et al., 2022), finance (Sasongko et al., 2024), technology (Fernández et al., 2021; Han et al., 2019), market conditions (Mohamad and Songthaveephol, 2020; Tarei et al., 2021; Yu et al., 2018), and environmental concerns (Al-Shami and Rashid, 2022; Filiou et al., 2023). Yet, comprehensive research on the drivers and barriers of EI specifically related to the diffusion of EV in emerging economies is still limited.

Our study seeks to contribute to this literature by exploring EI drivers and barriers in the context of EV diffusion in emerging economies. EV play a critical role in global decarbonization efforts. As emerging economies push toward low-carbon transportation technologies, it is important to understand how firms in this context acquire technological capabilities, foster collaborative innovation, and overcome persistent EI barriers. Given the global urgency to meet net-zero emission (NZE) targets, examining drivers and barriers of EV in emerging markets will offer critical insights into understanding the diffusion of affordable and clean energy on a global scale.

This paper addresses the above research gaps by posing the following questions: First, what factors contribute to the slow diffusion of EVs in emerging economies despite their large vehicle populations? Second, how do energy companies in emerging economies acquire technological capabilities—through in-house R&D or by knowledge spillovers? Third, how is collaborative innovation between automotive manufacturers and infrastructure providers conceived to address the technical challenges of EV diffusion? Finally, how can stakeholders in emerging economies overcome the main EI barriers to EV diffusion, including high upfront purchasing prices and lack of infrastructure? We answer these questions by employing a qualitative approach, conducting semi-structured interviews with 61 multi-level participants from automotive manufacturers, energy companies, and infrastructure providers in Indonesia.

Our conceptual framework integrates key theoretical perspectives. First, we consider the role of long-term green regulations in driving the diffusion of EI (Filiou et al., 2023; Setiawan et al., 2022). Second, we consider whether firms acquire technological capabilities, either through in-house R&D or by leveraging external knowledge via knowledge spillovers (Lee et al., 2021; Mohamad and Songthaveephol, 2020; Demirel and Kesidou, 2019). Third, green market sensing capabilities provide insights into how firms identify market needs and adapt their EI strategies (Cano et al., 2018; Larbi-Siaw et al., 2022). Finally, cost reduction strategies and sustainable ecosystems (Bhattacharyya and Thakre, 2021; Sasongko et al., 2022) offer a lens to understand collaborative approaches for addressing financial and infrastructural barriers.

This study makes several theoretical contributions to the literature on EI and diffusion of innovation (DOI). First, this research extends EI frameworks to emerging economies, especially Indonesia. Previous research on EI has predominantly focused on developed economies, yet the diffusion of EIs differs significantly in emerging markets due to differences in institutional, infrastructural, and consumer dynamics (Demirel and Kesidou, 2019; Orjuela-Ramirez et al., 2023). We bridge that gap by applying and contextualizing EI frameworks to an emerging economy, revealing unique barriers that arise at each stage in the diffusion of EI such as inefficient subsidy distribution and limited infrastructure availability. These findings refine eco-innovation theories by highlighting the critical role of socio-economic conditions and regulatory inconsistencies in shaping innovation diffusion in less mature markets.

Second, this study enriches our understanding of knowledge spillovers and their impact on EI. It demonstrates how collaborative networks involving automotive manufacturers, research institutions, and infrastructure providers foster the acquisition of technological capabilities in Indonesia. This aligns with and extends the literature on collaborative eco-innovation (Audretsch and Belitski, 2022; Garcia et al., 2019), offering empirical evidence of how such collaborations operate in resource-constrained contexts.

Third, we integrate green market sensing into diffusion of innovation theory. We employ the concept of green market sensing, emphasizing the importance of early adopters, such as urban users and ride-hailing services, in driving demand. By exploring how firms adapt business models to local consumer behavior, the paper extends their relevance to eco-innovations in nascent markets. In doing so, the paper sheds light into our understanding of cultural transition in emerging markets, from existing energy utilization to cleaner alternatives (Li et al., 2024; Sun et al., 2019).

Fourth, our study links EV adoption to circular economy principles, such as battery recycling and secondary applications for energy storage. This novel perspective integrates lifecycle sustainability into technology diffusion theories, expanding on frameworks that traditionally focus on upfront adoption and market penetration without considering post-use implications (Harper et al., 2019; Martinez-Laserna et al., 2018).

Finally, we contribute to a nuanced understanding of technological adoption pathways in constrained contexts, complementing existing studies on incremental and radical innovation adoption in emerging economies (Lee et al., 2021; Mohamad and Songthaveephol, 2020). Specifically, unlike much of the literature that treats hybrid electric vehicles (HEVs) and EVs as separate diffusion trajectories, this study identifies HEVs as transitional solutions in markets with limited charging infrastructure. This insight contributes to a nuanced understanding of technology adoption pathways in constrained contexts, complementing existing studies on incremental and radical innovation adoption (De Jesus and Mendonça, 2018).

2. Literature review

Increasing awareness of decarbonization has tightened environmental regulations, encouraging EI activities. EI begins with generating and mobilizing ideas, followed by screening and evaluating their potential for compliance with environmental regulations and revenue generation (Orjuela-Ramirez et al., 2023). Selected EI projects are then developed through experimentation and development, which leads to commercialization and subsequent diffusion (Janahi et al., 2021). The diffusion process typically requires further adaptation and ongoing experimentation and in turn customer acceptance.

The transport sector accounts for the third highest share of global carbon dioxide (CO_2) emissions, contributing to 22.96 % of total emissions, equivalent to 7.98 gigatons of CO_2. Transportation remains heavily dependent on oil products, which constitute 91 % of its energy sources —only a 3.5 % decrease from the early 1970s (IEA, 2023a). Many countries including emerging economies are promoting the development of low-emission fuels to meet NZE targets. Among these EIs, the diffusion of EVs has emerged as an alternative affordable and clean fuel for transportation.

The Diffusion of Innovation (DOI) theory, proposed by E.M. Rogers in his book "Diffusion of Innovations," emphasizes the significance of persuading individuals to accept new ideas, concepts, and products through media, particularly concerning innovation adoption (Bening et al., 2023). Recent literature has examined the DOI theory in relation to the diffusion of EVs in emerging countries, exploring the issue at macro and micro levels (Li et al., 2024).

At the macro level, the application of the DOI theory focuses on analyzing the overall diffusion trend at the societal level and the influencing factors. This level of examination highlights the prominent role of the government in determining the national EV diffusion policy

strategy by increasing interest and willingness to purchase among lower—and middle-class groups. The government's capabilities also determine industry investment in innovation diffusion and supporting infrastructures (Li et al., 2024; Champahom et al., 2024).

At the micro level, the DOI theory application emphasizes the specific adoption behaviors of individual consumers regarding new energy vehicles. Several factors influence consumer decisions to switch to EVs, including product performance, purchase price, operating and maintenance costs, service levels, psychological factors, consumer behavior, government policies, infrastructure availability, and other related elements (Gumasing, 2025; Li et al., 2024).

Furthermore, recent studies have explored the internal and external drivers and barriers to the diffusion of EVs in various emerging economies. Prior research in several countries, such as Brazil (Cano et al., 2018), Chile (Fernández et al., 2021), China (Deng et al., 2024), Ghana (Atombo et al., 2024), India (Kautish et al., 2024), Indonesia (Sasongko et al., 2024), Malaysia (Reddy et al., 2024), Pakistan (Shahid et al., 2022), Thailand (Mohamad and Songthaveephol, 2020), and Vietnam (Ninh, 2021) highlights the crucial role that both drivers and barriers play in shaping the adoption of EVs. In this context, the depletion of crude oil reserves and fluctuations in oil prices resulting by global crises are encouraging consumers to switch to EVs (Tarei et al., 2021). EVs offer advantages compared to ICEs, such as lower long-term operational and maintenance costs (Novizayanti et al., 2021; Shahid et al., 2022; Atombo et al., 2024), reduced GHGs emission (Kautish et al., 2024; Deng et al., 2024; Atombo et al., 2024), and increasingly higher affordability due to technological advancements, such as higher battery density and declining battery prices (Fernández et al., 2021; Han et al., 2019).

Governments have also encouraged the EV ecosystem's growth by fostering the utilization of renewable energy sources in electricity production (Filiou et al., 2023; Shahid et al., 2022; IEA, 2023b) and implementing incentive policies to stimulate consumer interest in switching to EVs (Sasongko et al., 2024; Setiawan et al., 2022). In addition, promotional campaigns tend to communicate the benefits of EVs to the public (Mohamad and Songthaveephol, 2020; Tarei et al., 2021).

However, the diffusion of EVs, especially in emerging countries, lags behind developed countries. The high upfront purchase price of EVs remains a significant deterrent for many consumers (Huang et al., 2021; Kautish et al., 2024; Sasongko et al., 2022; Atombo et al., 2024; Ayetor et al., 2023). Inadequate charging infrastructure (Bhattacharyya and Thakre, 2021; Grütter and Kim, 2019) such as limited availability of charging stations, particularly for long-distance daily travel, discourages EV adoption (Ayetor et al., 2023). High costs associated with installing standardized charging points is a challenge for infrastructure providers (Bhattacharyya and Thakre, 2021; Grütter and Kim, 2019). Furthermore, consumers demand improved EV performance, including safety features, increased mileage, shorter charging times, and improved top speeds (Deng et al., 2024; Ninh, 2021).

The diffusion of EVs in emerging economies has encountered ineffective implementation of regulations and poor coordination between central and local governments (Bhattacharyya and Thakre, 2021; Reddy et al., 2024). Finally, it is important to note that the reliance on fossil-fuel-based power plants for charging stations and battery manufacturing undermines the goal of reducing GHG emissions through EV adoption (Deng et al., 2024; Shahid et al., 2022). Thus, it is important to also increase the share of renewable energy in power generation to address this issue (Pandyaswargo and Maghfiroh, 2021; Filiou et al., 2023; Shahid et al., 2022). Table 1 summarizes the drivers and barriers to EV diffusion in emerging countries.

Table 1
Drivers and barriers to EV diffusion in emerging countries.

EI Drivers and Barriers on EV Diffusion		References	Observed Countries
Drivers	Environmental regulations and incentive policies implementation	Sasongko et al. (2024)	Indonesia
		Setiawan et al. (2022)	Indonesia
		Ayetor et al. (2023)	African countries
		Atombo et al. (2024)	Ghana
		Kautish et al. (2024)	India
		Cano et al. (2018)	Brazil
	Demand for more affordable long-term operational, lower maintenance costs, and lower emission compared to ICE	Tarei et al. (2021)	India
		Novizayanti et al. (2021)	Indonesia
		Shahid et al. (2022)	Pakistan
		Atombo et al. (2024)	Ghana
		Kautish et al. (2024)	India
		Deng et al. (2024)	China
		Ayetor et al. (2023)	African countries
		Reddy et al. (2024)	Malaysia
	Increasing density and declining prices of batteries	Fernández et al. (2021)	Chile
		Han et al. (2019)	China
	Promotional campaigns	Mohamad and Songthaveephol (2020)	Thailand
		Reddy et al. (2024)	Malaysia
		Fernández et al. (2021)	Chile
	Enhance the utilization of renewable energy sources in electricity production	Filiou et al. (2023)	China
		Shahid et al. (2022)	Pakistan
		Maghfiroh et al. (2021)	Indonesia
Barriers	Ineffective implementation of regulations and lack of coordination between central and local governments	Bhattacharyya and Thakre (2021)	India
		Reddy et al. (2024)	Malaysia
	High upfront purchase prices	Huang et al. (2021)	China
		Kautish et al. (2024)	India
		Sasongko et al. (2022)	Indonesia
		Atombo et al. (2024)	Ghana
		Ayetor et al. (2023)	African countries
	Inadequate availability and high investment cost charging infrastructure	Bhattacharyya and Thakre (2021)	India
		Grütter and Kim (2019)	Thailand
		Ayetor et al. (2023)	African countries
		Atombo et al. (2024)	Ghana
		Setiawan et al. (2022)	Indonesia
	Technological and performance risks, thus consumers demanding on improved EV performance	Deng et al. (2024)	China
		Ninh (2021)	Vietnam
		Putera et al. (2025)	Indonesia
		Reddy et al. (2024)	Malaysia
		Tarei et al. (2021)	India
	Reliance on fossil power plant	Deng et al. (2024)	China
		Shahid et al. (2022)	Pakistan
		Tarei et al. (2021)	India
		Setiawan et al. (2022)	Indonesia

Source: Authors

3. Methodology

3.1. Research context

We analyzed the drivers and barriers of eco-friendly fuel in emerging economies, with a focus on the diffusion EVs in Indonesia. Despite receiving regulatory support, including incentives and subsidy schemes, the diffusion of EVs in Indonesia has been slower compared to other Southeast Asian countries. The socio-technical context of our research has influenced EI activities in the case of the diffusion of EV in Indonesia. Energy firms and automotive manufacturers were encouraged to maintain business continuity through eco-friendly fuel. At the same time,

financial considerations played a critical role, including firms' commitments to advancing technology and consumers' concerns regarding upfront purchase prices, as well as operational and maintenance costs.

3.2. Data collection

This study employs a qualitative methodology to provide an in-depth exploration and holistic understanding (Taylor et al., 2016) of the research phenomenon, namely EI activities in the case of the diffusion of EV. The qualitative approach enables the exploration and redefinition of concepts for future studies (Hojnik and Ruzzier, 2016). However, it is important to note that qualitative methods can be influenced by participant subjectivity and do not produce generalizations about observed social phenomena (Creswell and Clark, 2017; Stockemer, 2018).

3.2.1. Primary data collection

Primary data were gathered through multi-level interviews with various stakeholders actively contributing to the EV ecosystem in Indonesia (Blake et al., 2021; Heaphy and Einarsdottir, 2013). Semi-structured interviews were conducted to examine three categories of data: EI activities in EV diffusion, EI drivers, and barriers faced by micro-actors in EV diffusion. The first category focused on EI activities in EV diffusion that aimed at understanding interviewees' general perceptions of EVs, the timeline for initiating EV development or distribution, the ongoing development of related products or services, and the impact of EV diffusion on their companies. The list of main questions, mostly open-ended, serves as a guide; the interview guidelines can be found in Annex 1.

The second category examined the drivers of EI in EV diffusion. This category included exploring the main driving factors, regulatory support, incentives and subsidies, technological capabilities, consumer environmental awareness, market responses, the effects of oil price fluctuations, and other enabling factors. The third category of questions identified key barriers to EV diffusion. Furthermore, this section analyzed the challenges posed by high investment costs and risks, infrastructure availability and needs, difficulties in mastering technology, EV purchase prices, socio-economic issues, unclear or conflicting policies, environmental concerns, and other barriers.

The study utilized stratified snowball sampling to ensure the adequate representation of various stakeholder groups in Indonesia's EV ecosystem. The approach for selecting potential participants encompasses e-mail, telephone, and LinkedIn's social media platform. Potential participants were given one week to respond to their invitation to participate or decline. Response times varied among participants, ranging from two days to three weeks. Online interviews took place from February 2023 to November 2023.

The Indonesian EV ecosystem includes several interrelated subsystems, as shown in Fig. 1, consist of.

1. *EV innovation subsystem*: This subsystem drives the EV ecosystem through EI collaboration among EV manufacturers, battery suppliers, component suppliers, application developers, and telematics providers.
2. *EV infrastructure subsystem*: These are essential for providing energy to charge EVs. This subsystem distributes electricity from power plants through the distribution network to charging point operators and battery swap system (BSS) integrators.
3. *EV adopter's subsystem:* This group includes key consumers using EVs for mobility. It comprises individual consumers, public and private transport providers (such as taxis and ride-hailing services), and corporate customers.
4. *Regulators and strategic partners subsystem:* Governments at various levels are responsible for creating and enforcing regulations. Research institutions, industry associations, and environmental organizations also serve as strategic partners, assisting the government in formulating policies that promote the sustainability of the EV ecosystem.

This study's sample selection focused on micro-actors in firms in the *EV innovation subsystem* and *EV infrastructure subsystem* because they are actively involved in implementing EI in EV diffusion. Other stakeholder subsystems, such as *EV adopter's subsystem* and *regulators and strategic partners subsystem* were not included in the scope of data collection through interviews. However, we gathered and analyzed secondary data to represent the roles and perspectives of these additional stakeholders.

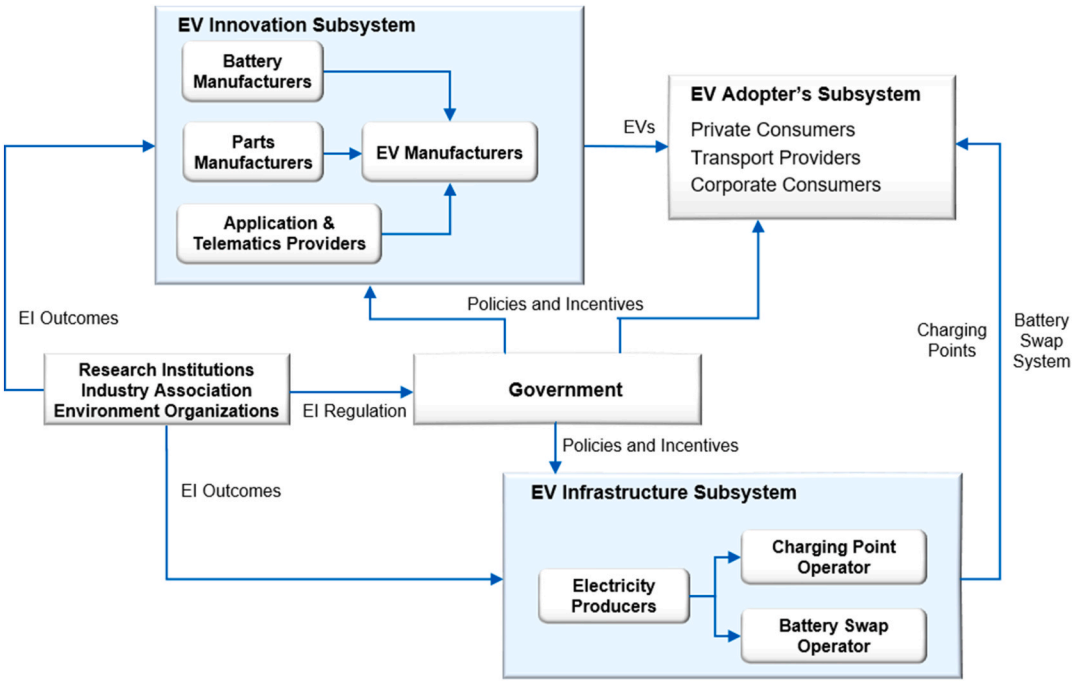


Fig. 1. Ei ecosystem in Indonesian on EV diffusion *Source*: Authors.

Specifically, the samples were selected by analyzing various categories of firms within the EV innovation subsystem including EV manufacturers for both two-wheelers and four-wheelers and suppliers of batteries, green components, and application providers. EI implementation in EV innovation subsystem faces challenges such as meeting consumer performance requirements, ensuring battery producer sustainability, guaranteeing component reliability, providing accessible agent networks, and offering effective after-sales services.

The EV infrastructure subsystem comprises energy producers, charging point operators, and BSS integrators. These subsystems are crucial for facilitating EV market penetration. The emergence of business opportunities to provide energy for EV charging has prompted energy producers to collaborate with charging point operators and BSS providers, thereby expanding EV infrastructures. The study focused on firms mandated by PLN, the state-owned company managing electricity in Indonesia, which plays a critical role in EV diffusion. PLN is involved in power generation, distribution networks, and enabling infrastructure such as charging stations and battery swap systems (BSS).

A total of 61 micro-level actors from 32 companies participated in the interviews, representing different segments of the EV ecosystem. These included: 12 energy generation companies (36.36 %), 4 infrastructure network deployment companies (12.12 %), 7 two-wheeler manufacturers (21.21 %), 8 four-wheeler manufacturers (24.24 %), 2 green suppliers (6.06 %), such as EV batteries and spare parts providers. Table 2 outlines the classification of interviewees based on company type.

Semi-structured interviews targeted micro-level stakeholders across organizational levels: (i) Top management: To examine long-term business strategies and investment in EI activities. (ii) Mid-level management: To evaluate capabilities related to responding to environmental policies, internal coordination on innovative systems, and green market sensing. (iii) Staff in engineering, R&D, production, maintenance, and marketing roles: To assess manufacturing capabilities, challenges in adopting green technology, green market sensing capabilities, and after-sales services.

Specifically, the sample includes micro-level stakeholders based on the following organizational position levels: eleven individuals in top-level management (18.03 %), eighteen in mid-level management (29.51 %), and thirty-two at the staff level (52.46 %). The percentages reflect the hierarchical structure, showing a decrease in the number of participants as position levels increase. Among staff-level participants, the sample includes eleven engineers (18.03 %), ten professionals in operations and maintenance (16.39 %), six in business and marketing (9.84 %), and five of R&D (8.20 %). The smaller proportion of R&D staff can be attributed to the limited number of companies in Indonesia with dedicated R&D departments. Typically, innovation development activities are distributed across various departments, particularly in engineering, operations and maintenance, as well as business and marketing.

All interviews were conducted in Indonesian using Zoom or Microsoft Teams and recorded digitally. Transcriptions were subsequently translated into English for coding and thematic analysis using NVivo software. NVivo facilitated theme tracking across interview transcripts and determined when data saturation was achieved, signifying no emergence of new themes. Table 3 summarizes participant characteristics by position level.

3.2.2. Secondary data collection

We also collected secondary data regarding the diffusion of EVs from other stakeholders, such as the *EV adopter's subsystem and the regulators and strategic partners subsystem* in Indonesia. This information was sourced from various materials, including firm's annual reports, firm websites, industry association reports, official government policy websites, newspapers, and academic journals.

To ensure validity and mitigate researcher and participant biases, we employed data triangulation by cross-validating interview findings with secondary data. This approach enhances the robustness and credibility of qualitative research, as demonstrated in prior studies (Creswell and Poth, 2018).

3.3. Data analysis

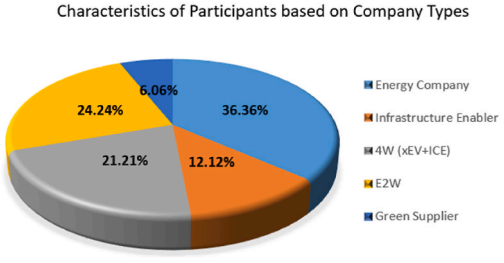
We utilized an iterative inductive approach to analyze the interview transcript data. We also collected secondary data from various government policies, newspapers, and academic journals, that primarily include customer surveys. We also examined firms' annual reports and websites to identify EV diffusion strategies in Indonesia. We then triangulated primary data using the secondary data to verify and crosscheck the information obtained from the interviews and confirm the accuracy of the timeline. This approach allows dynamic refinement across the stages of data collection, analysis, and the identification of potential participants for further interviews (Corley and Gioia, 2004; Gomes et al., 2023). Fig. 2 presents the construction of the data structure in this study.

The iterative data analysis process involves three stages: identifying first-order concepts, synthesizing second-order themes, and constructing aggregate dimensions (Magnani and Gioia, 2023). During the first stage of our analysis, we thoroughly read all primary data transcripts and notes that were collected. This initial analysis identified similarities and differences in the main themes that influence EV diffusion in Indonesia. This step gives us a comprehensive understanding, which is then classified into 'first-order codes' (Iatridis et al., 2022). We then analyzed secondary data, focusing on government policies, company annual reports, surveys, and news articles, to conceptualize first-order codes by clarifying interviewees' perspectives (Grøgaard et al., 2022).

In the second stage, we used techniques of systematic combining to synthesize common themes from the first-order codes. We cross-referenced emerging themes from the primary data with company reports, public records, and previously published academic literature.

Table 2
Characteristics of Participants based on Company Types.

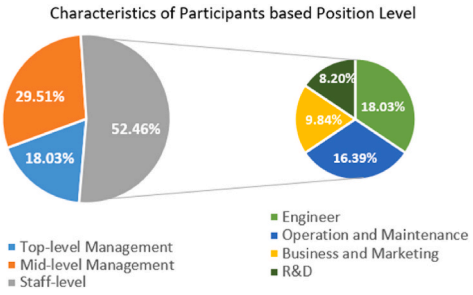
Company Type	Freq.	Pct.	Pie Chart
Energy Company	12	36.36 %	
Infrastructure Enabler	4	12.12 %	
Four-wheelers Manufacturer	7	21.21 %	
Two-wheelers Manufacturer	8	24.24 %	
Green Supplier	2	6.06 %	
Total	33	100 %	



Source: Authors

Table 3
Characteristics of Participants based on Position Level.

Position Level	Staff Freq.	Staff Pct.	Freq	Pct.	Pie Chart
Top-level Management			11	18.03 %	
Mid-level Management			18	29.51 %	
Staff Level			32	52.46 %	
• Engineer	11	18.03 %			
• Operation and Maintenance	10	16.39 %			
• Business and Marketing	6	9.84 %			
• R&D	5	8.20 %			
Total			61	100 %	



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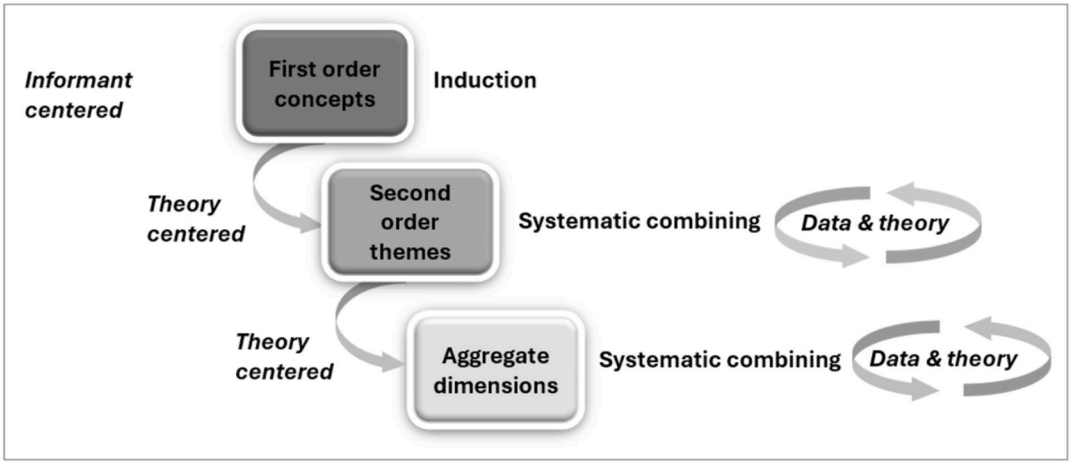

Fig. 2. Construction process of the data structure *Source*: Magnani and Gioia (2023).

Furthermore, secondary data verified the emerging themes by enhancing credibility and contextual enrichment. This approach bridges theory with empirical findings to produce second-order codes (Magnani and Gioia, 2023). This iteration generated 'second-order codes', including regulatory support, implementation of incentives and subsidy schemes, financial considerations, technological capabilities, external collaboration, market acceptance, infrastructure availability, sectoral competition, and supply sustainability.

The third stage focused on probing overarching dimensions from the second-order themes. Then, validation and triangulation with secondary data were conducted to obtain solid theoretical insights. These aggregate dimensions become the basis for constructing a coherent data structure (Iatridis et al., 2022; Gioia et al., 2013). We identified five aggregated dimensions: regulatory, financial, technological, market, and environmental. These dimensions form the basis for understanding the drivers and barriers of EI within the EV ecosystem in Indonesia (Fig. 4).

4. Findings

4.1. Eco-innovation diffusion of EV in Indonesia

The Indonesian government has initiated the innovation of environmentally friendly alternative fuels. This EI was motivated by "government policy aimed at reducing emissions, fuel subsidies, and imports" (Interviewee 12, Mid-Level Management). EVs have gained the government's attention despite the fact that "in Indonesia, the adoption of EVs is still relatively slow" (Interviewee 1, R&D Staff). The development of EVs was influenced by government policies that prioritize biofuels. One interviewee noted that this is "further encouraged by the government through the mandatory use of biodiesel" (Interviewee 2, R&D Staff). Additionally, "there is the management of palm oil funds" (Interviewee 2, R&D Staff), which are the source of incentive schemes for the biodiesel industry.

From 2017 to 2019, all EVs introduced to the Indonesian market were imported in a completely built-up form. The research on EVs in Indonesia began with electric motorcycles (EMCs), which "the EMC vehicle was initially initiated by university partners. In 2017, we joined or collaborated with the university" (Interviewee 10, Engineer). One respondent stated regarding locally manufactured EMCs that "we are selling them to retail starting in 2020" (Interviewee 10, Engineer). As public interest grew, some manufacturers began increasing their production capacity and introducing new products to meet consumer demands.

According to secondary data, in 2017, the Indonesian market saw the emergence of 32-unit EMCs, marking the initial stages of EV diffusion. The growth of EV sales in Indonesia from 2022 to 2024 shows a positive trend. Sales of EMCs grew, reaching 5486 units in 2021. This number surged to 85,838 units in 2023 and reached 160,578 units in 2024. In 2019, several manufacturers launched hybrid electric vehicles (HEVs), selling 787 units, along with 85 battery electric four-wheelers (E4Ws). HEV sales increased dramatically, reaching 67,340 units in 2023 and 127,243 units in 2024. In the E4W category, sales grew from 22,003 units in 2023 to 34,504 units in 2024 (Deloitte and Foundry, 2023;

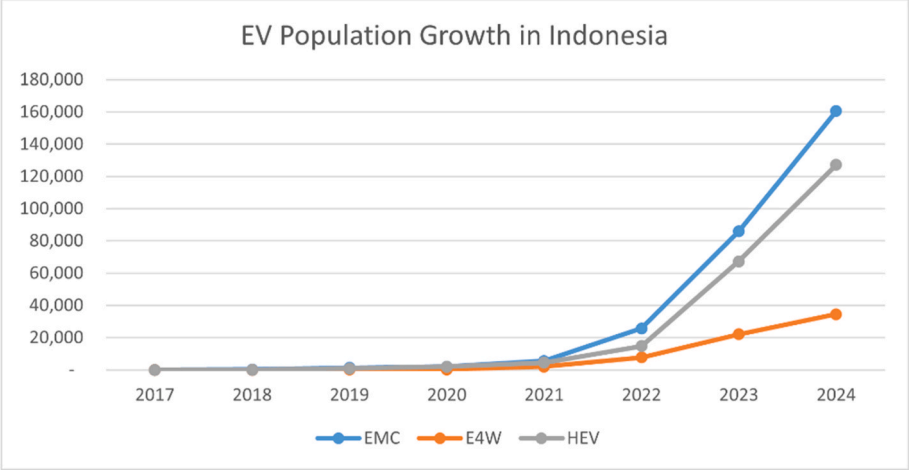

Fig. 3. EV population growth in Indonesia (Deloitte and Foundry, 2023; Times, 2024; Tempo, 2025).

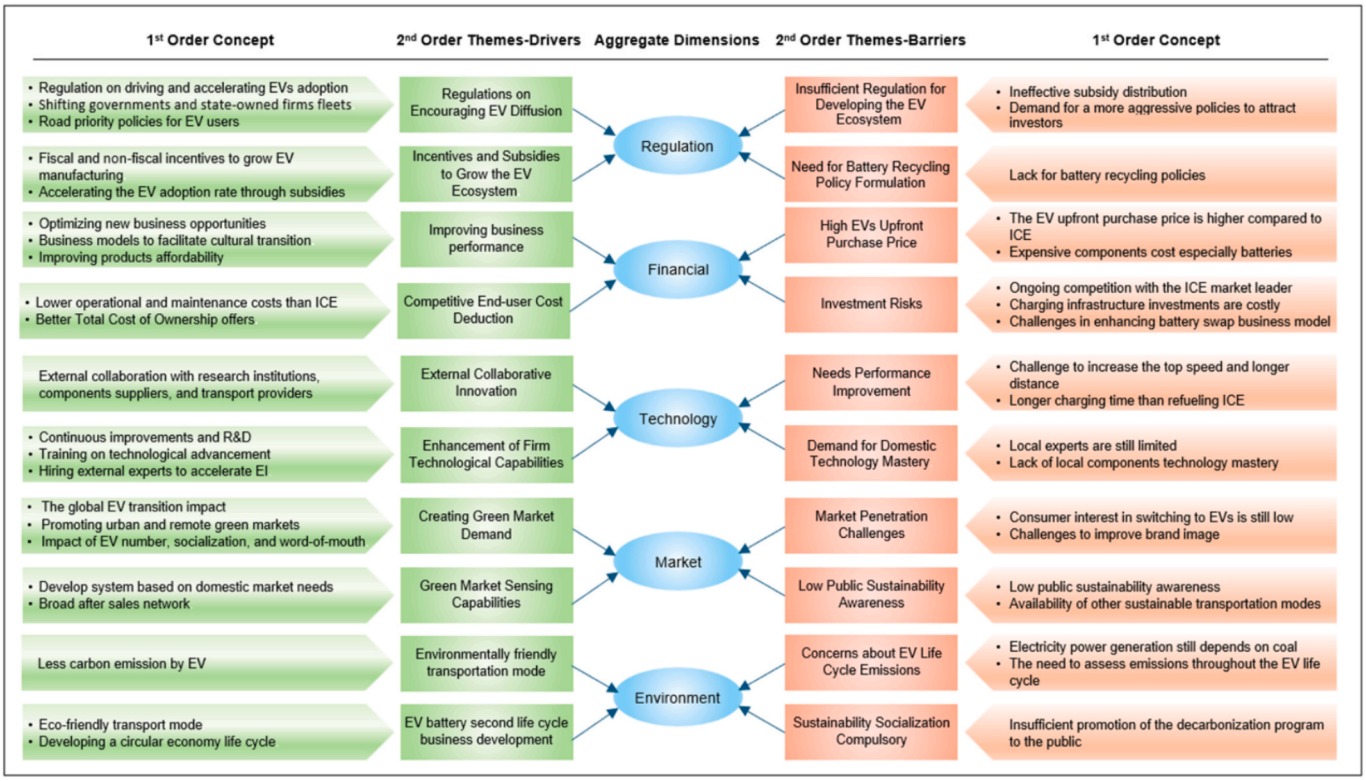

Fig. 4. Ei drivers and barriers in diffusing Indonesian EV
Source: Authors.

Times, 2024; Tempo, 2025). Fig. 3 displays the growth of the EV population in Indonesia.

Our analysis identified the drivers and barriers micro-level actors face in this diffusion process. These include regulatory, financial, technological, market, and environmental aspects (Fig. 4). Table S1 shows the data structure for EI drivers in Indonesian EV diffusion, while Table S2 outlines the EI barriers.

4.2. EI drivers for diffusing EVs in Indonesia

4.2.1. Regulatory drivers

The primary driver for EV diffusion in Indonesia is regulatory support as stated by one respondent: "the government has issued presidential regulations [to introduce the EV]" (Respondent 10, Engineer). Presidential Regulation No. 55/2019 marked a milestone for EV adoption. Moreover, the government intensified the diffusion of EVs by implementing "Presidential Instruction number 7 of 2022, which mandated the use of EVs in state-owned companies and regional government fleet vehicles" (Respondent 4, Top-level Management). Furthermore, the government introduced policies that prioritize EV users on highways and in parking areas.

Respondents highlighted the role of fiscal and non-fiscal incentives, such as tax exemptions, lower luxury goods sales tax rates, and the odd-even vehicle number policies, encouraging EV adoption:

> "Regulations like tax exemptions, one percent of luxury goods sales tax, and also the odd-even vehicle number [policy], which

encourages consumers to switch to EVs." (Interviewee 60, Mid-Level Management)

Subsidies have further stimulated public interest in EVs, with one respondent noting: "support from the government, which implements the subsidies" (Respondent 61, Engineer).

Information from secondary sources corroborates that the implementation of a series of regulations and incentives by the government fostered the growth of the EV ecosystem in Indonesia (Setiawan et al. (2022). Political support for accelerating the diffusion of EVs began with Presidential Regulation No. 19/2019, marking the start of the electrification era (Sasongko et al., 2024). This regulatory support culminated in incentives and subsidy schemes through Government Regulation No. 74/2021 to the Minister of Finance Regulation No. August 2024 (Kompas, 2024).

4.2.2. Financial drivers

Financial incentives and the improvement in the affordability of EVs have enhanced business performance. Subsidized EV prices have made them competitive, as one responded noted: "[EVs] can go head-to-head [with conventional vehicles]" (Respondent 5, Mid-level Management). The Indonesian government's focus on using its mineral reserves for EV batteries has further strengthened financial incentives. One respondent highlighted that the government's prioritization of EV is evident in its approach to "downstream raw materials" (Respondent 4, Top-Level Management).

Another important EI driver is the value proposition offered by EVs, where "after using an EV, it feels like the operational costs are significantly reduced" (Respondent 34, Top-Level Management) and "the maintenance costs will be low" (Respondent 41, Business and Marketing Analyst). Another respondent also stated: "the total cost of ownership of ride-hailing drivers will also decrease" (Respondent 1, R&D). These findings are consistent with secondary sources showing that electricity prices for home charging and charging stations were lower than fuel oil costs. Likewise, the maintenance cost of EVs were lower than that of conventional vehicles (Sasongko et al., 2024).

4.2.3. Technology drivers

Our study revealed that the diffusion of EVs in Indonesia was influenced by extensive collaborative research among automotive manufacturers and strategic partners, including research institutions, green suppliers, and transportation providers. Respondent 10 emphasized the role of the collaboration between automotive manufacturers and research institutions:

> "The EMC was initially initiated by… conducted collaborative research with university partners and produced a prototype… we refined it further following the standardization … we carried out in such industries at the end of 2019." (Respondent 10, Engineer)

Automotive companies "also collaborate with several brands or suppliers that are sufficient for green energy conversion" (Respondent 40, Technical Trainer). Besides targeting individual consumers, the EV adoption growth was also "dominated by online ride-hailing. Many [EMC brands] are collaborating with online ride-hailing" (Respondent 5, Mid-level Management). Furthermore, a strategic alliance was formed to develop "the EV ecosystem from upstream to downstream together with … major EV producers, such as Korea or China." (Respondent 4, Top-level Management)

Automotive manufacturers continuously enhance their technological capabilities to meet consumer needs, as stated by Respondent 34:

> "We will never stop innovating … [So], with so many swap stations, range anxiety should be the main problem with this EMC." (Respondent 34, Top-level Management)

Technological capabilities were also enhanced through: "carrying out training" (Respondent 40, Operation and Maintenance), "recruiting experienced staff from other companies … and knowledge transfer from local suppliers" (Respondent 61, Engineer).

4.2.4. Market drivers

The global EV market trend and early adopters in Indonesia, particularly urban users and ride-hailing services, have stimulated domestic demand. As respondent 34 noted: "EVs are starting to become a lifestyle for Indonesian people. EVs are the real trend in the world" (Respondent 34, Top-level Management). Early adopters are EMC users "who are still [riding around] in the city or who understand [EV] technology" (Respondent 41, Business and Marketing Analyst).

Demand is also driven by market segments in remote areas, as one responded stated, especially those areas far away from gas stations:

> "In fact, our biggest sales are outside Java. The electricity network infrastructure is sometimes more adequate [than the gas stations]. So, they prefer to buy an EMC rather than petrol, maybe because the distance to a gas station is far away" (Respondent 23, Mid-level Management).

Social media and user communities have further accelerated market growth through word-of-mouth promotion:

> "… EMCs have their user group … fans of certain brands have their specific groups … They will make modifications to test the mileage … Indirectly, each of these groups also contributes to promoting the EMC to the public via social media, and then in stages directly." (Respondent 61, Engineer)

The momentum in the demand growth of EV adoption is sustained by green market sensing capabilities. Our study revealed the EI business model was developed to facilitate the Indonesian consumer behavior:

> "Yes, we built our system ourselves according to the needs of the Indonesian people. Our habit differs from other companies… abroad. It was brought [and] used in Indonesia, where behaviorally the market may be very different … We only pay per kilometer of road." (Respondent 34, Top-level Management)

Furthermore, growing demand for EVs is driven by "service centers" (Respondent 61, Engineer) as "it is easy for consumers to get spare parts or a place for maintenance" (Respondent 41, Business and Marketing). This perception was echoed in an industry report by PLN (2023), which noted that as charging infrastructure expanded, energy companies partnered with EV dealers and infrastructure providers such as charging point operators and BSS providers.

4.2.5. Environmental drivers

Increasing environmental awareness has driven the early adoption of EVs, particularly for their reduced carbon emissions and quieter operation:

> "Furthermore, most consumers are satisfied with EMCs, as they are less tired and do not feel vibrations while riding." (Respondent 34, Top-Level Management)

The circular economy has emerged as a priority, as one respondent highlighted:

> "We understand that the [battery] materials have several utilization levels. The first is that it is used for EVs. After five to seven years of normal use, its performance will decrease. It will be recycled again or used to make derivative products to [utilize as] battery energy storage systems (BESS)" (Respondent 10, Engineer).

The focus is on repurposing EV batteries for secondary applications like uninterruptible power supplies (UPS) and streetlights: "use second life batteries as UPS" (Respondent 34, Top-level Management) "[and] streetlight, … In other countries, EV batteries can be repurposed for power banks and laptops" (Respondent 10, Engineer). This aligns with secondary sources that highlight "… the use of solar photovoltaic energy

for charging public street lighting" (Tempo, 2023).

4.3. EI barriers to diffusing EVs in Indonesia

4.3.1. Regulatory barriers

Regulation has played a pivotal role in introducing EVs to Indonesian consumers, but ineffective implementation has hindered their adoption. One respondent expressed concern about the lack of clarity in the initial stages of EV purchase subsidies distribution:

> "Yes, many people are already interested [in buying EVs]. By using subsidies or incentives from the government, we are still waiting for procedural certainty from the government. However, we cannot execute it in the field at this time. The government also issues several requirements. Not all people can enjoy these subsidies or incentives either. (Respondent 37, Mid-level Management)

The deployment of subsidies remains limited by customers' socio-economic conditions:

> "The latest [subsidy scheme] still has limitations, such as household electrical power not exceeding 900 Wh. If the government removes these restrictions, the demand for EVs may increase. " (Respondent 61, Engineer)

These findings are in line with secondary sources indicating that public interest in EVs was primarily driven by upper-middle-income groups, which are currently ineligible for subsidies (Detiknews (2023). As a result, there has been public demand to expand the subsidy scheme. In addition, Jawa Pos (2024) reported that while public interest in purchasing HEVs is growing as a step toward EVs, the government still has not provided subsidies to accelerate the HEV transition.

Respondents emphasized that "a more aggressive policy is still needed. Because … countries like Thailand implement special policies … to compete to attract investors" (Respondent 4, Top-level Management). Also, as interest in EVs grows, respondents stressed that "the regulations regarding battery waste processing may need to be re-emphasized" (Respondent 60, Mid-level Management).

4.3.2. Financial barriers

A key barrier in the diffusion of EVs in Indonesia is that "the price is still high" (Respondent 1, R&D). The high upfront purchase price of EVs can be attributed to expensive components:

> "30 per cent of the components are quite expensive. There are three core components: controller, battery, and BLDC[1] [motor dynamo] … There has been no local [price] reduction." (Respondent 41, Business Analyst and Marketing)

Our findings indicate that another barrier is the competition between EVs with market leaders of conventional vehicles that are presently transitioning to HEVs:

> "The biggest challenge was when the two big brands [ICE] entered [the EMC market] … Competitors control the supply and chain of all the big markets …. They will gradually go to hybrid first … There are many things to consider, the first of which is perhaps the spare parts … with a high turnover … " (Respondent 41, Business Analyst and Marketing)

A manufacturer pointed out that subsidies for lower-cost e-bikes create market overlap with traditional motorcycles:

> "Well, that could potentially overlap the market for motorcycles because for IDR 10 million, for example, the subsidy is IDR 7 million, so it is only IDR 3 million. Meanwhile, our e-bike in the range from IDR 5 million to IDR 7 million." (Interviewee 41, Business Analyst and Marketing)

Meanwhile, infrastructure enablers have not been able to match the demand for the deployment of charging infrastructure because "it requires high voltage and high charging investment too" (Respondent 5, Mid-level Management). Furthermore,

> "The future [challenge] is more about the business model; if I look at Taiwan, the penetration is much higher … with swapping batteries … By purchasing kilowatt-hours of power for several months. And [consumers] do not need to invest in battery; purchase the motorcycle, and the risks are all there." (Respondent 5, Mid-Level Management)

4.3.3. Technology barriers

Our findings highlight technological limitations of EVs, particularly their performance compared to ICE vehicles, serve as a barrier to diffusion. "Some people may desire a faster EMC [than the existing top speed], while others prefer extended travel distances" (Respondent 34, Top-level Management).

Another technological barrier to the diffusion of EVs is lengthy charging time: "charging takes a long time. If you need to [travel] long distances, you need to charge for 4–5 h before usage" (Respondent 5, Mid-level Management). Some respondents considered the challenge of reducing charging time by achieving battery interchangeability. "The government could standardize battery connectors. So, it can be plug-and-play with other batteries" (Interviewee 61, Engineer).

Our findings also show a lack of local expertise in EV technology, which deters the diffusion of EVs and increases dependence on high-priced imports. "There are abundant experts outside. But in Indonesia, it is still limited because it has not yet been industrialized for EVs" (Respondent 4, Top-level Management). According to one respondent, the inadequate grasp of local technology has impacted EV prices:

> "There are currently no local [components], only imported [ones]. Prices may be reduced further in the future if this technology is mastered. " (Respondent 5, Mid-level Management)

4.3.4. Market barriers

Our findings highlight market barriers such as delayed market penetration and low consumer awareness. Several respondents mentioned that "Indonesia's entry into the EV market happened a bit late" (Respondent 34, Top-level Management). One respondent confirmed the delay in the diffusion of EVs in Indonesia:

> " Acceptance in the Indonesian market was somewhat lower. It only [grew] after Elon Musk with Tesla and introducing more EVs in Indonesia." (Respondent 5, Mid-Level Management)

Some manufacturers face challenges with brand positioning:

> "Our brand is at the top of customers' minds, identical to electric bicycles. So, some of our product lines, such as EMCs, may struggle to gain an image in the customers' minds." (Respondent 41, Business Analyst and Marketing)

EV market penetration also is challenging because "most of society is unconcerned about sustainability issues. Most Indonesians" (Respondent 1, R&D). Sasongko et al. (2024) elaborated that low public awareness of EVs is due to insufficient comprehensive socialization regarding their benefits. Those aware of sustainability have alternatives to EVs, "as evidenced by the discourses … They also have options like cycling or taking public transportation" (Respondent 1, R&D).

[1] Brushless Direct Current (BLDC) motors are synchronous motors powered by direct current (DC) electric power sources. Electronic controllers are utilized to direct DC power to motor coils that generate a magnetic field spinning efficiently in space, accompanied by a permanent magnetic rotor (Yedamale, 2003).

4.3.5. Environmental barriers

The findings point out that decarbonization using EVs has gained attention, yet environmental concerns remain. The main environmental issue is caused by the dominance of coal as the primary source for electricity generation in Indonesia:

> "In Indonesia, coal is [the source of energy] for almost sixty per cent of electricity generation … [Meanwhile,] the realization of renewable [sources] by 2023 is just halfway to the target" (Respondent 5, Mid-level Management).

This issue is also documented in PLN's 2022 annual report (PLN, 2023), which highlights that although, the plan to phase out coal-based power plants is scheduled to begin in 2025, environmental concerns persist. Respondents also noted: "the manufacturing of lithium batteries itself produces emissions as well. Thus, the entire life cycle needs to be assessed" (Respondent 5, Mid-level Management). Moreover, the underlying environmental barrier to EV diffusion is the necessity for increased public education about sustainability. The following statement illustrates this:

> "We need to educate [the public] and advocate for the use of EVs to highlight their beneficial impacts on preserving the earth. EVs represent greener energy, are more environmentally friendly, quieter, [and offer other advantages]." (Respondent 10, Engineer)

5. Discussion

The diffusion of EVs in Indonesia remains slow, with a market share of only 0.2 %. Despite the introduction of EVs in the national automotive market in 2017 and the country's high vehicle ownership rate of over 163 million units, adoption has been sluggish. Our findings highlight the prolonged process required for the Indonesian government to formulate EV policies within its green energy initiatives. This delay in regulatory support reflects the strong influence of advocacy networks favoring other forms of energy EI, particularly biofuels, amidst the technological disruptions brought by EVs. The government prioritized biofuels over EVs in the initial stage of alternative vehicle fuel diversification because biofuels utilized the existing oil infrastructure, had abundant feedstocks from palm oil, and required less technical adjustments for existing ICEVs. Our study contributes to the literature on government policy-making by examining its role in prioritizing new energy innovations, which in turn influences financial, technological, market, and environmental support mechanisms (Reddy et al., 2024).

Our study also indicates that global trends toward EV adoption have been influenced by digital media, particularly news coverage and social media platforms. Between 2017 and 2019, these platforms encouraged groups of innovators and early adopters—often part of brand enthusiast communities—to explore EVs. These early adopters shared their experiences regarding performance, benefits, and challenges, reinforcing the socialization process essential to market penetration. Prior studies have established the importance of word-of-mouth communication and social media effects in accelerating EV adoption in emerging economies (Mohamad and Songthaveephol, 2020; Tarei et al., 2021). Our findings extend this literature by emphasizing the role of green market sensing in shaping consumer demand and fostering the diffusion of new green technologies.

Eco-innovation depends on the financial incentives available to industries investing in green energy (Agrawal et al., 2024; Larbi-Siaw et al., 2022). The emergence of EI is viable only when it can compete with existing products in the market. Our research finds that key energy companies—particularly PLN—and automotive manufacturers have identified new business opportunities in EV-related markets. Infrastructure enablers have begun developing charging stations to meet emerging demand, especially in urban centers. Moreover, collaboration networks have been established not only for technological absorption but also to advocate for supportive regulations and incentives (Sasongko et al., 2022; Setiawan et al., 2022). These regulatory initiatives were first introduced in 2019, laying the foundation for subsequent policy interventions.

Technological mastery is a critical driver of EI sustainability. Industries must either develop in-house R&D capabilities or leverage knowledge spillovers to remain competitive (Fernández et al., 2021; Janahi et al., 2022). Our findings suggest that Indonesia's EV sector requires manufacturers to engage in collaborative networks involving research institutions, green suppliers, infrastructure enablers, and government agencies. Knowledge spillovers from established EV markets, including the US, EU, China, Japan, and South Korea, have facilitated technology acquisition. Initially, Indonesia's EV market was dominated by foreign brands, but domestic EMC manufacturers have gradually entered the market since 2020. However, key components such as batteries, motors, and controllers are still primarily imported.

The literature on EI underscores the importance of incentive policies and subsidy schemes in fostering the growth of EV ecosystems, particularly in emerging economies (Kautish et al., 2024; Sasongko et al., 2024). In 2022, the Indonesian government introduced limited subsidy programs to support EV adoption. However, our study identified key challenges in subsidy disbursement, including administrative delays and lack of coordination, which hindered the government's ambitious EV growth targets. These implementation challenges have caused potential buyers to postpone their purchases. Moreover, budgetary constraints have led to stringent eligibility criteria, restricting subsidies to low-income consumers. Our findings contribute to the growing body of research on the impact of policy inefficiencies and institutional coordination on the diffusion of EI in the context of emerging economies (Bhattacharyya and Thakre, 2021; Reddy et al., 2024).

Consumer preferences are also shaping the EV market, particularly in the domestic EMC segment. Recent studies indicate that Indonesian consumers prioritize increased mileage, higher top speeds, improved charging infrastructure, and reduced charging times (Balijepalli et al., 2023; Sasongko et al., 2022). Standardizing battery connectors, particularly for domestic EMCs, could further enhance battery-swapping networks (Tu et al., 2019). These technological improvements are vital for expanding the EV market beyond urban centers. Our findings indicate that EV manufacturers have strengthened their green market sensing capabilities by building direct relationships with consumers, incorporating feedback into product development, and identifying niche markets—particularly in remote areas where fuel stations are scarce.

During the early adoption phase, increased public acceptance of EVs has motivated companies to introduce new models tailored to local market preferences. Industries have accelerated technology absorption through specialized training programs and by recruiting experienced personnel from established EV firms. Our findings align with literature on the significance of technology acquisition and development in driving EI diffusion (Fernández et al., 2021; Janahi et al., 2022). However, a key technological barrier remains: Indonesia has a limited number of local experts proficient in EV technologies, with most knowledge concentrated in key R&D hubs.

Consumer research highlights the high purchase price as a major barrier to EV adoption in developing countries (Kautish et al., 2024; Sasongko et al., 2022). Our findings suggest that Indonesia's EV adoption remained minimal from 2017 to 2021, but sales began to rise in 2022 following improved subsidy coordination. Early adopters increasingly viewed subsidies as a mechanism to offset high purchase costs. Additionally, information on lower electricity costs relative to fuel has made EVs more financially attractive. The total cost of ownership has become an essential factor in purchasing decisions, as EVs require less maintenance than ICEVs. These findings extend prior studies emphasizing the role of financial considerations in consumer decision-making, particularly in emerging economies.

Lastly, business model innovation plays a crucial role in the transition from ICEVs to EVs (Li et al., 2024; Sun et al., 2019). Indonesian consumers are accustomed to monthly operational and maintenance

costs associated with ICEVs. Thus, new business models, such as battery-swapping services with subscription-based pricing, have gained traction (Balijepalli et al., 2023). However, our findings suggest that Indonesia's business models differ from those in developed markets such as Taiwan and Italy, where time-based subscription plans dominate (IEA, 2023b). Future research should explore how localized business models can further support EV diffusion in Indonesia.

6. Conclusions

Prior literature has emphasized the importance of the diffusion of green technology innovations in emerging economies. Yet, little attention has been paid to the factors that influence affordable and clean energy provision in the transportation sector in emerging economies. Even less attention has been paid to the EI drivers and barriers in the diffusion of EVs in Indonesia. In this study, we adopted a qualitative methodology, analyzing primary data inputs from 61 multi-level stakeholders and secondary data triangulation to address critical gaps in understanding the socio-technical and economic dynamics influencing EI adoption in contexts outside developed markets. We examine the drivers and barriers of EI that impact the trajectory of EV growth in Indonesia based on the diffusion of innovation theory. We contribute to the debate in EI studies on EV diffusion in emerging economies, focusing on the influence of regulatory, financial, technological, market, and environmental factors.

Our findings reveal that the government's policy to prioritize biofuels as the primary alternative vehicle fuel has slowed the pace of EV diffusion in Indonesia. Additionally, our findings highlight the critical role of fiscal and non-fiscal mechanisms in fostering EV diffusion. Notably, tax exemptions and subsidies stimulate consumers to overcome high EV purchase prices. Non-fiscal policies have encouraged the urban public, such as road privileges for EV users and the replacement of official fleets and Jakarta's public buses with EVs. Although our results indicate that the government is committed to fostering the growth of the EV ecosystem, scaling up EV adoption in Indonesia to meet roadmap targets is challenged by budgetary constraints relating to the demand for expanded subsidies. The literature shows that some emerging economies provide regulatory support to encourage the transition to HEVs, helping to address the issue of insufficient charging points. Our findings indicate a growing interest among the Indonesian public in purchasing HEVs, more than three times that of E4Ws. However, fiscal and non-fiscal support for accelerating HEV growth in Indonesia remains limited. Further regulatory formulation and intervention are required, as the existing literature on regulatory push-pull dynamics underscores the need for tailored interventions to address the unique challenges in emerging economies, underlying the interplay between incentives and infrastructure in shaping market dynamics.

Our research supports the view that knowledge spillovers and collaborative innovation networks generate positive technological externalities that can facilitate the uptake of new green knowledge and thus improve firms' technological mastery. As a new energy type, the adoption process of EV technology in Indonesia requires the absorption of knowledge spillovers, especially from major EV-producing countries. Collaboration networks have linked automotive manufacturers with green suppliers, infrastructure enablers, and research institutions. Technology transfer, along with human resource training and recruiting experienced personnel, has enhanced the capabilities in mastering technology. This improvement has allowed companies to develop products that meet consumer needs. Furthermore, we contribute to the body of literature on the capabilities required for green market sensing, which are essential for fostering a sustainable EV market. The development of EI through products, services, and business models tailored to the energy purchasing behavior of Indonesian public energy purchasing culture has facilitated the transition to EVs. In addition, distribution and after-sales networks have been expanded to reach niche markets in remote areas, particularly those far from gas stations. Our findings also confirm developing countries' financial challenges concerning the investment needed to expand charging points and BSS networks.

Crucially, our contribution confirms recent studies highlighting the importance of public awareness regarding decarbonization through EVs (Kautish et al., 2024; Sasongko et al., 2024). While the government has been promoting EV programs as a form of green energy, these initiatives have not yet reached all segments of society. Our findings extend recent researches Filiou et al. (2023) and Shahid et al. (2022) indicating that emissions during the entire lifecycle of EVs will only decrease if non-renewable energy (NRE) sources are utilized effectively. Currently, coal remains the dominant source of electricity generation that powers EVs, and the development of potential NRE sources is still not optimized. Our study contributes to the existing body of literature on developing a circular economy by utilizing retired EV batteries for second-life cycle applications in stationary energy storage systems and recycling to recover valuable materials.

6.1. Policy implications

Accelerating EV diffusion in Indonesia requires cohesive policy measures to address current barriers and build a sustainable ecosystem. First, we suggest that governments in emerging economies pay attention to regulatory consistency. For instance, the Indonesian government could strengthen fiscal and non-fiscal incentives, including transparent subsidy distribution and procedural efficiency, to enhance consumer affordability. Additionally, targeted grant and loan programs for logistics, public transport, and ride-hailing operators, alongside decarbonization zoning policies (IEA, 2023b), can accelerate EV adoption. Policies like low-emission zones in urban centers can further encourage EV adoption (Bhattacharyya and Thakre, 2021; Sasongko et al., 2024).

Second, emerging economies should support stakeholders' collaboration. In the case of Indonesia, fostering synergy among automotive manufacturers, energy providers, and infrastructure enablers will expand charging networks and develop battery-swapping systems. Collaboration is critical to overcoming infrastructural challenges (Mohamad and Songthaveephol, 2020).

Third, governments in emerging economies should promote hybrid adoption as a bridge to EVs in regions with limited charging infrastructure, due to these vehicles' lower dependency on charging networks (König et al., 2021).

Fourth, emerging economies should pay attention to circular economic practices. The Indonesian case shows that integration of battery recycling and second-life applications (e.g., energy storage systems) into policies minimizes lifecycle emissions ((Harper et al., 2019; Martinez-Laserna et al., 2018).

Finally, public awareness campaigns are necessary. Educating consumers on EV benefits, such as reduced operational costs and environmental impacts, can further drive adoption and build trust (Sasongko et al., 2024).

6.2. Limitations and future research

This study has limitations that present opportunities for future research. While we focus on EVs, alternative eco-friendly technologies, such as biofuels and rail-based electrification, warrant investigation. Comparing their drivers and barriers with those of EVs could identify optimal pathways for sustainable transportation (De Jesus and Mendonça, 2018). Moreover, future research could employ quantitative approaches to validate the identified drivers and barriers. This would provide a broader generalizability of findings and aid policymakers in prioritizing interventions (Creswell and Clark, 2017). Finally, cross-country comparisons between Indonesia and other emerging economies can uncover context-specific strategies. This could involve examining policy effectiveness in nations like India or Malaysia, where EV adoption faces similar socioeconomic and infrastructural challenges (Bhattacharyya and Thakre, 2021; Reddy et al., 2024).

CRediT authorship contribution statement

Ferry Fathoni: Writing – original draft, Validation, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Effie Kesidou:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Conceptualization. **Muhammad Mufti Rifansha:** Writing – review & editing, Formal analysis. **Avif Tiftazani:** Writing – review & editing, Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ferry Fathoni reports financial support was provided by PT Pertamina (Persero). Ferry Fathoni reports a relationship with PT Pertamina (Persero) that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2025.126021.

Data availability

Data will be made available on request.

References

Agrawal, R., Agrawal, S., Samadhiya, A., Kumar, A., Luthra, S., Jain, V., 2024. Adoption of green finance and green innovation for achieving circularity: an exploratory review and future directions. Geosci. Front. 15 (4), p101669. https://doi.org/10.1016/j.gsf.2023.101669.

Al-Shami, S., Rashid, N., 2022. A holistic model of dynamic capabilities and environment management system towards eco-product innovation and sustainability in automobile firms. J. Bus. Ind. Market. 37 (2), 402–416. https://doi.org/10.1108/JBIM-04-2020-0217.

Atombo, C., Pappoe, G., Akple, M.S., Adzah, D., 2024. Evaluating the adoption of electric vehicles: insights from Ghana. Afr. Tranp. Stud. 2, p100007. https://doi.org/10.1016/j.aftran.2024.100007.

Audretsch, D.B., Belitski, M., 2022. The knowledge spillover of innovation. Ind. Corp. Change 31 (6), 1329–1357. https://doi.org/10.1093/icc/dtac035.

Ayetor, G.K., Mashele, J., Mbonigaba, I., 2023. The progress toward the transition to electromobility in Africa. Renew. Sustain. Energy Rev. 183, p113533. https://doi.org/10.1016/j.rser.2023.113533.

Balijepalli, C., Shepherd, S., Crastes Dit Sourd, R., Farda, M., Praesha, T., Lubis, H.A.-R., 2023. Preferences for electric motorcycle adoption in Bandung, Indonesia. Urban Plann. Transp. Res. 11 (1), p2238033. https://doi.org/10.1080/21650020.2023.2238033.

Barrena-Martínez, J., Cricelli, L., Ferrándiz, E., Greco, M., Grimaldi, M., 2020. Joint forces: towards an integration of intellectual capital theory and the open innovation paradigm. J. Bus. Res. 112, 261–270. https://doi.org/10.1016/j.jbusres.2019.10.029.

Bening, S.A., Dachyar, M., Pratama, N.R., Park, J., Chang, Y., 2023. E-commerce technologies adoption strategy selection in Indonesian SMEs using the decision-makers, technological, organizational and environmental (DTOE) framework. Sustainability 15 (12), p9361. https://doi.org/10.3390/su15129361.

Bhattacharyya, S.S., Thakre, S., 2021. Exploring the factors influencing electric vehicle adoption: an empirical investigation in the emerging economy context of India. Foresight 23 (3), 311–326. https://doi.org/10.1108/FS-04-2020-0037. Cambridge.

Blake, S., Janssens, A., Ewing, J., Barlow, A., 2021. Reflections on joint and individual interviews with couples: a multi-level interview mode. Int. J. Qual. Methods 20, p16094069211016733. https://doi.org/10.1177/16094069211016733.

Bocken, N.M.P., Geradts, T.H.J., 2020. Barriers and drivers to sustainable business model innovation: organization design and dynamic capabilities. Long. Range Plan. 53 (4), p101950. https://doi.org/10.1016/j.lrp.2019.101950.

Cano, Z.P., Banham, D., Ye, S., Hintennach, A., Lu, J., Fowler, M., Chen, Z., 2018. Batteries and fuel cells for emerging electric vehicle markets. Nat. Energy 3 (4), 279–289. https://doi.org/10.1038/s41560-018-0108-1.

Champahom, T., Se, C., Laphrom, W., Jomnonkwao, S., Karoonsoontawong, A., Ratanavaraha, V., 2024. Modeling user intentions for electric vehicle adoption in Thailand: incorporating multilayer preference heterogeneity. Logistics 8 (3), p83. https://doi.org/10.3390/logistics8030083.

Corley, K.G., Gioia, D.A., 2004. Identity ambiguity and change in the wake of a corporate spin-off. Administrative Science Quarterly 49 (2), 173–208. https://doi.org/10.2307/4131471.

Creswell, J.W., Clark, V.L.P., 2017. Designing and Conducting Mixed Methods Research, third ed. Sage Publications, Inc, Los Angeles.

Creswell, J.W., Poth, C.N., 2018. Qualitative Inquiry and Research Design: Choosing Among Five Approaches, fourth ed. Sage Publications, Los Angeles.

De Jesus, A., Mendonça, S., 2018. Lost in transition? drivers and barriers in the eco-innovation road to the circular economy. Ecol. Econ. 145, 75–89. https://doi.org/10.1016/j.ecolecon.2017.08.001.

Deloitte and Foundry, 2023. An electric revolution: the rise of Indonesia's e-motorcycle [Online]. https://drive.google.com/file/d/1f6O51-CjkojJ3skhL8zDVTsMUMHfXJvB/view. (Accessed 11 February 2024).

Demirel, P., Kesidou, E., 2019. Sustainability-oriented capabilities for eco-innovation: meeting the regulatory, technology, and market demands. Bus. Strat. Environ. 28 (5), 847–857. https://doi.org/10.1002/bse.2286.

Deng, C., Qian, Y., Song, X., Xie, M., Duan, H., Shen, P., Qiao, Q., 2024. Are electric vehicles really the optimal option for the transportation sector in China to approach pollution reduction and carbon neutrality goals? J. Environ. Manag. 356, p120648. https://doi.org/10.1016/j.jenvman.2024.120648.

Fernández, S., Torrecillas, C., Labra, R.E., 2021. Drivers of eco-innovation in developing countries: the case of Chilean firms. Technol. Forecast. Soc. Change 170, p120902. https://doi.org/10.1016/j.techfore.2021.120902.

Filiou, D., Kesidou, E., Wu, L., 2023. Are smart cities green? The role of environmental and digital policies for Eco-innovation in China. World Dev. 165, p106212. https://doi.org/10.1016/j.worlddev.2023.106212.

Garcia, R., Wigger, K., Hermann, R.R., 2019. Challenges of creating and capturing value in open eco-innovation: evidence from the maritime industry in Denmark. J. Clean. Prod. 220, 642–654. https://doi.org/10.1016/j.jclepro.2019.02.027.

Gioia, D.A., Corley, K.G., Hamilton, A.L., 2013. Seeking qualitative rigor in inductive research: notes on the Gioia methodology. Organ. Res. Methods 16 (1), 15–31. https://doi.org/10.1177/1094428112452151.

Gomes, L.A.V., Vasconcellos, L., Hamza, K.M., 2023. in qualitative research. RAUSP Management Journal 58 (3), 190–196.

Grimaldi, M., Greco, M., Cricelli, L., 2021. A framework of intellectual property protection strategies and open innovation. J. Bus. Res. 123, 156–164. https://doi.org/10.1016/j.jbusres.2020.09.043.

Grøgaard, B., Colman, H.L., Stensaker, I.G., 2022. Legitimizing, leveraging, and launching: developing dynamic capabilities in the MNE. J. Int. Bus. Stud. 53 (4), 636–656. https://doi.org/10.1057/s41267-019-00245-5.

Grütter, J.M., Kim, K.-J., 2019. E-mobility options for ADB developing member countries [Online]. https://doi.org/10.22617/WPS190075-2. (Accessed 23 August 2020).

Gumasing, M.J.J., 2025. Exploring factors influencing E-bike adoption among Filipino commuters: an integrated diffusion of innovation and technology acceptance model. https://doi.org/10.3390/wevj16020113.

Han, X., Lu, L., Zheng, Y., Feng, X., Li, Z., Li, J., Ouyang, M., 2019. A review on the key issues of the lithium ion battery degradation among the whole life cycle. ETransportation 1, p100005. https://doi.org/10.1016/j.etran.2019.100005.

Harper, G., Sommerville, R., Kendrick, E., Driscoll, L., Slater, P., Stolkin, R., Walton, A., Christensen, P., Heidrich, O., Lambert, S., Abbott, A., Ryder, K., Gaines, L., Anderson, P., 2019. Recycling lithium-ion batteries from electric vehicles. Nature 575 (7781), 75–86. https://doi.org/10.1038/s41586-019-1682-5.

Heaphy, B., Einarsdottir, A., 2013. Scripting civil partnerships: interviewing couples together and apart. Qual. Res. 13 (1), 53–70. https://doi.org/10.1177/1468794112454997.

Hojnik, J., Ruzzier, M., 2016. Drivers of and barriers to eco-innovation: a case study. Int. J. Sustain. Econ. 8 (4), 273–294. https://doi.org/10.1504/IJSE.2016.079433.

Huang, X., Lin, Y., Zhou, F., Lim, M.K., Chen, S., 2021. Agent-based modelling for market acceptance of electric vehicles: evidence from China. Sustain. Prod. Consum. 28, 206–217. https://doi.org/10.1016/j.spc.2021.04.007.

Iatridis, K., Gond, J.-P., Kesidou, E., 2022. How meaningfulness and professional identity interact in emerging professions: the case of corporate social responsibility consultants. Organ. Stud. 43 (9), 1401–1423. https://doi.org/10.1177/01708406211035506.

IDN Times, 2024. *Number of electric vehicles in Indonesia reaches 85 thousand!* [Online]. https://www.idntimes.com/automotive/motorbike/dwi-agustiar/jumlah-kendaraan-listrik-di-indonesia-tembus-85-ribu. (Accessed 9 February 2024).

IEA, 2023a. *CO2* emissions *in 2022* [Online]. https://iea.blob.core.windows.net/assets/3c8fa115-35c4-4474-b237-1b00424c8844/CO2Emissionsin2022.pdf. (Accessed 18 March 2024).

IEA, 2023b. Global EV outlook 2023 [Online]. https://iea.blob.core.windows.net/assets/dacf14d2-eabc-498a-8263-9f97fd5dc327/GEVO2023.pdf. (Accessed 21 January 2024).

Janahi, N.A., Durugbo, C.M., Al-Jayyousi, O.R., 2021. Eco-innovation strategy in manufacturing: a systematic review. Clean. Eng. Technol. 5, p100343. https://doi.org/10.1016/j.clet.2021.100343.

Janahi, N.A., Durugbo, C.M., Al-Jayyousi, O.R., 2022. Exploring network strategies for eco-innovation in manufacturing from a triple helix perspective. Clean. Logist. Supply CHain 4, p100035. https://doi.org/10.1016/j.clscn.2022.100035.

Kautish, P., Lavuri, R., Roubaud, D., Grebinevych, O., 2024. Electric vehicles' choice behaviour: an emerging market scenario. J. Environ. Manag. 354, p120250. https://doi.org/10.1016/j.jenvman.2024.120250.

Kompas, 2024. A series of regulations and incentives for electric vehicles in Indonesia [Online]. https://otomotif.kompas.com/read/2024/07/25/120200515/sederet-aturan-dan-insentif-buat-mobil-listrik-di-indonesia?page=all. (Accessed 22 February 2025).

König, A., Nicoletti, L., Schröder, D., Wolff, S., Waclaw, A., Lienkamp, M., 2021. An overview of parameter and cost for battery electric vehicles. https://doi.org/10.3390/wevj12010021.

Larbi-Siaw, O., Xuhua, H., Owusu, E., Owusu-Agyeman, A., Fulgence, B.E., Frimpong, S. A., 2022. Eco-innovation, sustainable business performance and market turbulence moderation in emerging economies. Technol. Soc. 68, p101899. https://doi.org/10.1016/j.techsoc.2022.101899.

Pos, Jawa, 2024. *Hybrid* cars *in Indonesia are growing rapidly, the government is still reluctant to provide subsidies* [Online]. https://www.jawapos.com/otomotif/013715888/mobil-hybrid-di-indonesia-tumbuh-subur-pemerintah-masih-enggan-beri-subsidi. (Accessed 9 February 2024).

Lee, J.-D., Lee, K., Meissner, D., Radosevic, S., Vonortas, N.S., 2021. The Challenges of Technology and Economic Catch-Up in Emerging Economies. Oxford University Press, Oxford [Online]. https://library.oapen.org/bitstream/id/01ecf7e5-d2d8-49c1-9b20-ec196d434efa/9780192896049.pdf. (Accessed 16 September 2022).

Li, Z., Cui, R., Shen, Z., 2024. How can the government effectively promote consumers' green purchasing behavior?—based on the diffusion study of new energy vehicles in China. https://doi.org/10.3390/wevj15100437.

Maghfiroh, M.F.N., Pandyaswargo, A.H., Onoda, H., 2021. Current readiness status of electric vehicles in Indonesia: multistakeholder perceptions. Sustainability 13 (23), p13177. https://doi.org/10.3390/su132313177.

Magnani, G., Gioia, D., 2023. Using the Gioia methodology in international business and entrepreneurship research. Int. Bus. Rev. 32 (2), p102097. https://doi.org/10.1016/j.ibusrev.2022.102097.

Martinez-Laserna, E., Gandiaga, I., Sarasketa-Zabala, E., Badeda, J., Stroe, D.I., Swierczynski, M., Goikoetxea, A., 2018. Battery second life: hype, hope or reality? a critical review of the state of the art. Renew. Sustain. Energy Rev. 93, 701–718. https://doi.org/10.1016/j.rser.2018.04.035.

Mohamad, M., Songthaveephol, V., 2020. Clash of titans: the challenges of socio-technical transitions in the electrical vehicle technologies – the case study of Thai automotive industry. Technol. Forecast. Soc. Change 153, p119772. https://doi.org/10.1016/j.techfore.2019.119772.

Ninh, N.G., 2021. Resistance to change and purchase intention of electric vehicles: empirical evidence from Vietnam. Asian J. Bus. Res. 11 (2). https://doi.org/10.14707/ajbr.210108.

Novizayanti, D., Prasetio, E.A., Siallagan, M., Santosa, S.P., 2021. Agent-based modeling framework for electric vehicle adoption transition in Indonesia. https://doi.org/10.3390/wevj12020073.

Orjuela-Ramirez, G., Zuluaga-Jimenez, J.C., Urbano, D., 2023. Drivers of eco-innovation: the role of appropriability strategies and complementary assets. Sci. Publ. Pol. 51 (2), 309–323. https://doi.org/10.1093/scipol/scad072.

Detiknews, 2023. Enthusiasts of subsidized electric motorbikes are booming, but [Online]. https://oto.detik.com/motor/d-6737932/peminat-motor-listrik-subsidi-membludak-tapi. (Accessed 12 June 2023).

Tempo, 2023. Viar research on the utilization of used electric vehicle batteries [Online]. https://otomotif.tempo.co/read/1246050/viar-riset-pemanfaatan-baterai-bekas-kendaraan-listrik. (Accessed 12 February 2024).

Pandyaswargo, A.H., Maghfiroh, M.F.N., 2021. The current state of EV readiness in Indonesia: assessing the industrial sector's perspective with J-TRA methodology. In: 2021 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM). IEEE, pp. 361–366. https://doi.org/10.1109/IEEM50564.2021.9672889.

Piluso, N., 2024. Is corporate social responsibility effective in improving environmental quality? Literature review. Environ. Econ. 15 (2), 1–11. https://doi.org/10.21511/ee.15(2).2024.01.

PLN, 2023. 2022 Annual Report. [Online]. [Accessed 22 February 2025]. Available from: https://web.pln.co.id/statics/uploads/2023/06/Laporan-Tahunan-2022_Final_3005_Med-Res.pdf.

Putera, D.A., Fajri, N., Alda, T., 2025. Advancing Electric Vehicle Safety and Adoption in Indonesia: Insights from Global and Local Perspectives. Engineering Proceedings 84 (1), 52. In: https://doi.org/10.3390/engproc2025084052.

Reddy, V.J., Hariram, N.P., Maity, R., Ghazali, M.F., Kumarasamy, S., 2024. Sustainable vehicles for decarbonizing the transport sector: a comparison of biofuel, electric, fuel cell and solar-powered vehicles. https://doi.org/10.3390/wevj15030093.

Sasongko, T.W., Ciptomulyono, U., Wirjodirdjo, B., Prastawa, A., 2022. Electric vehicle adoption factors and an ecosystem conceptual model. In: 3rd Asia Pacific International Conference on Industrial Engineering and Operations Management, 13-15 September 2022. IEOM Society International, Johor Bahru, Malaysia, pp. 1986–1997. https://doi.org/10.46254/AP03.20220336.

Sasongko, T.W., Ciptomulyono, U., Wirjodirdjo, B., Prastawa, A., 2024. Identification of electric vehicle adoption and production factors based on an ecosystem perspective in Indonesia. Cogent Bus. Manag. 11 (1), p2332497. https://doi.org/10.1080/23311975.2024.2332497.

Setiawan, A.D., Zahari, T.N., Purba, F.J., Moeis, A.O., Hidayatno, A., 2022. Investigating policies on increasing the adoption of electric vehicles in Indonesia. J. Clean. Prod. 380, p135097. https://doi.org/10.1016/j.jclepro.2022.135097.

Shahid, M., Ullah, K., Imran, K., Masroor, N., Sajid, M.B., 2022. Economic and environmental analysis of green transport penetration in Pakistan. Energy Policy 166, p113040. https://doi.org/10.1016/j.enpol.2022.113040.

Stockemer, D., 2018. Quantitative Methods for the Social Sciences: A Practical Introduction with Examples in SPSS and Stata. Springer, Cham, Switzerland.

Sun, B., Sun, X., Tsang, D.H., Whitt, W., 2019. Optimal battery purchasing and charging strategy at electric vehicle battery swap stations. Eur. J. Oper. Res. 279 (2), 524–539. https://doi.org/10.1016/j.ejor.2019.06.019.

Tarei, P.K., Chand, P., Gupta, H., 2021. Barriers to the adoption of electric vehicles: evidence from India. J. Clean. Prod. 291, p125847. https://doi.org/10.1016/j.jclepro.2021.125847.

Taylor, S.J., Bogdan, R., DeVault, M.L., 2016. Introduction to Qualitative Research Methods: A Guidebook and Resource, fourth ed. John Wiley & Sons, New Jersey.

Tempo, 2025. *Outlook 2025:* awaiting *the Development of electric vehicle infrastructure* [Online]. https://www.tempo.co/ekonomi/outlook-2025-menanti-perkembangan-infrastruktur-kendaraan-listrik-1196867. (Accessed 14 February 2025).

Tu, H., Feng, H., Srdic, S., Lukic, S., 2019. Extreme fast charging of electric vehicles: a technology overview. IEEE Trans. Transp. 5 (4), 861–878. https://doi.org/10.1109/TTE.2019.2958709.

Yedamale, P., 2003. Brushless DC (BLDC) motor fundamentals. Microchip Technology Inc 20 (1), 3–15.

Yu, J., Yang, P., Zhang, K., Wang, F., Miao, L., 2018. Evaluating the effect of policies and the development of charging infrastructure on electric vehicle diffusion in China. Sustainability 10 (10), p3394. https://doi.org/10.3390/su10103394.