Charging Forward: Unlocking The Acceleration of Electric Vehicles (EVs) Adoption In Indonesia

Theresia Bhekti Putranti[a*] and Aidan Sliwkowski[a]

[a] System Dynamics Group, Department of Geography, University of Bergen P. O. Box 7802, 5020 Bergen, Norway

[*] Correspondence: Theresia.Putranti@student.uib.no

Abstract

Driven by rapid urbanization, increasing transportation demand, and concerns over carbon emissions, electric vehicles (EVs) have emerged as one of the promising solutions to reduce pollution in Indonesia. Despite rising awareness, EV adoption remains limited due to inadequate charging infrastructure, high purchase cost, and behavioral barriers. This study seeks to analyze the dynamic interaction among multi-drivers influencing early EV adoption in Indonesia, focusing on charging infrastructure, vehicle purchase price, social/peer influence, and environmental concern. A System Dynamics approach, incorporating Bass Diffusion in the model, is employed to develop a stock-flow framework that captures interdependencies and feedback mechanisms among the drivers: infrastructure availability, EV purchase price, social imitation, and environmental concern. The model is then used to explore policy recommendations that could accelerate EV adoption.

Baseline simulations show that while EV adoption grows exponentially, it remains far below government targets, primarily constrained by the high EV purchase prices and limited charging infrastructure. Policy simulations reveal that infrastructure expansion alone is insufficient to address affordability barriers, while price subsidies alone do not directly resolve infrastructural gaps. In contrast, integrated policy, combining EV price subsidies and charging station expansion, substantially improves EV adoptions. The findings underscore the need for Indonesia to pursue integrated policy that balances short-term incentives with long-term commitments. Coordinated efforts between government agencies, private sector, and utility providers are essential to address systemic adoption barriers. Future research should refine the model by incorporating deaveraged behavioral dynamics, consumer segmentation, technological variables (e.g., vehicle range, type), operational costs, and production constraints to improve policy relevance and model realism.

Keywords: Electric Vehicle, Technology Adoption, Infrastructure, Innovation, Policy Analysis, System Dynamics, Bass Diffusion

1. Introduction

1.1 Problem Identification

Indonesia's economic growth, like many developing countries, has been coinciding with rapid urbanization and increasing transportation demand. As the 11th largest greenhouse gas (GHG) emitter globally (World Population Review, 2022), the country's transportation sector accounts for approximately 21% of total emissions, mainly from land transport. With urbanization continuing to rise, now encompassing over 60% of the population, and transportation demand escalating, pollution concerns are intensifying, challenging Indonesia's ambition of reducing emissions by 32% by 2030 and reaching net-zero emissions by 2060.

In response to these environmental concerns, the Indonesian government has initiated a transition agenda toward a more environmental-friendly transportation with electric vehicles (EVs). This transition embodies Indonesia's strategic effort to reduce carbon emissions, decrease reliance on oil import, and generate economic returns as one of nickel producer country (AC Ventures & AEML, 2023). Presidential Regulation No. 55 in 2019 established a national EV acceleration program, targeting 2 million EVs by 2025 and 15 million by 2030. The government has taken the lead in promoting EVs by introducing electric public buses and taxis, as well as showcasing the initiatives through the B20/G20 event in 2021-2022.

However, five years after the policy's introduction, EV adoption remains low, accounting for less than 1% penetration of Indonesia's automobile market. Current projections estimate only 250 thousand EV by the end of 2024 (Bakrie-Brothers, 2024) and 3 million EVs by 2030. This is certainly far from the government's target of 2 million EVs by 2025 and 15 million by 2030. Without significant intervention, the adoption trajectory is likely to remain below target, slowing Indonesia's journey to be one of key players in EV global market.

Several interconnected factors contribute to the slow adoption of EVs in Indonesia. First, limited charging infrastructure discourages potential adoption due to "range anxiety," the fear of driving EV and running out of power without any accessible charging options. Simultaneously, low EV penetration disincentivizes investment in infrastructure. There were only 600 public charging stations available as of 2023, falling far short of the 6,300-target set for 2025. Second, EV prices remain significantly higher compared to internal combustion engine (ICE) vehicles, driven by limited adoption and insufficient government subsidies. Third, while public awareness of EVs is generally positive regarding environment and fuel efficiency, low EVs penetration and presence weaken peer imitation effects that typically drive wider diffusion. Finally, government policy or support plays a critical role (Lonan et al., 2020), however many strategies remain unaware of or unenforced, forming doubt on their effectiveness in achieving EV targets (Watson Farley and Williams, 2024).

This study aims to provide a system-wide analysis of the interacting drivers (infrastructure availability, pricing, imitation, and environmental concern) influencing EVs adoption trends. Understanding these interdependencies and feedback mechanism is critical for designing policies that not only accelerate EV adoption but also offers insight to help policy makers and industry stakeholder to develop targeted, high impact strategies that are cost-efficient and operable.

1.2 Reference Mode of Behavior

This research investigates how Indonesia can accelerate EV adoption while addressing systemic barriers that hinder the progress. To support the analysis, several behavior modes are identified. The primary reference modes, as grounds for the analysis, are the time series behavior of Total Vehicle, Transportation Emission, EV Adopted (Number of EVs), and Charging Stations. These trends encompass both historical data (2019-2023), compiled from various official sources, and projected trends (2024–2040), which are extrapolated using the moving compound annual growth rate (CAGR) over the past decade to generate future estimates.

As shown in Figure 1, urban population continue to grow steadily, as forecasted by Statistics Indonesia and the United Nations (Worldometers & Statistics Indonesia, 2023). This trend mirrors with the increasing number of vehicles due to urban mobility and rising transportation emission.

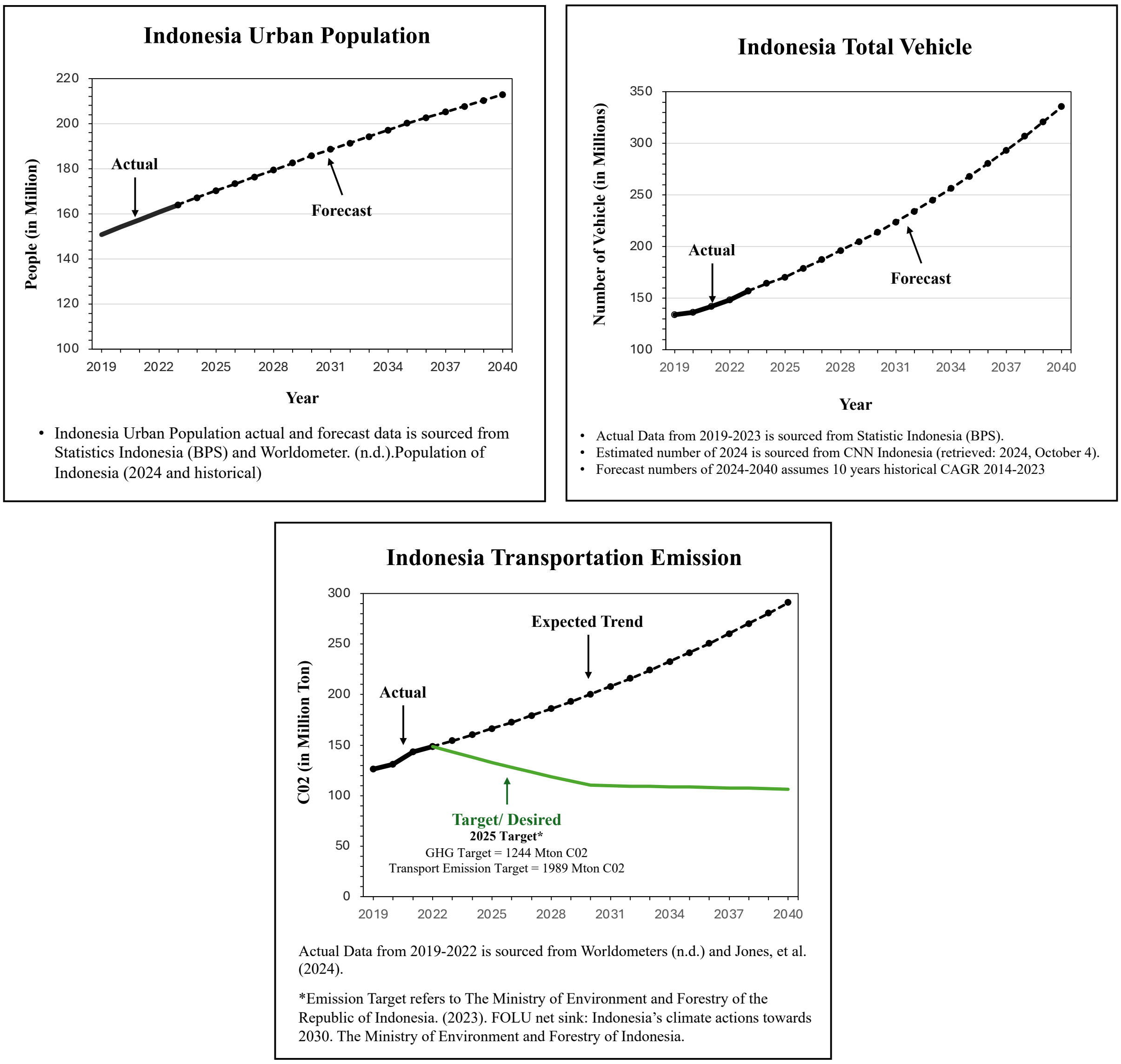

Figure 1: Reference Modes of (a) Indonesia Urban Population, (b)Total Vehicle, (c) Transportation Emission

Figure 1c further illustrates Indonesia's desire to reduce transportation emission, aligned with the goal of reducing GHG emissions from 2,100 million Ton in 2022 to 1,244 million Ton of CO_2 by 2030 and 540 million Ton by 2050. Although a specific target for transportation emissions has not been explicitly defined, the trend is estimated based on sector's proportional contribution to total national emissions. While EV adoption is expected to play a key role in achieving these reductions (Ministry of Environment and Forestry, 2023), current adoption trajectories suggest a significant shortfall relative to these goals.

Through Presidential Regulation No. 55, government has set the desired number of EVs and Charging Stations in Indonesia, which is translated in the target/desire behavior line in Figure 2. However, current low EV adoption suggests that the expected trend is significantly lower than target. Similarly, using current trend indicates that the number of charging stations is unlikely to meet the government's targets.

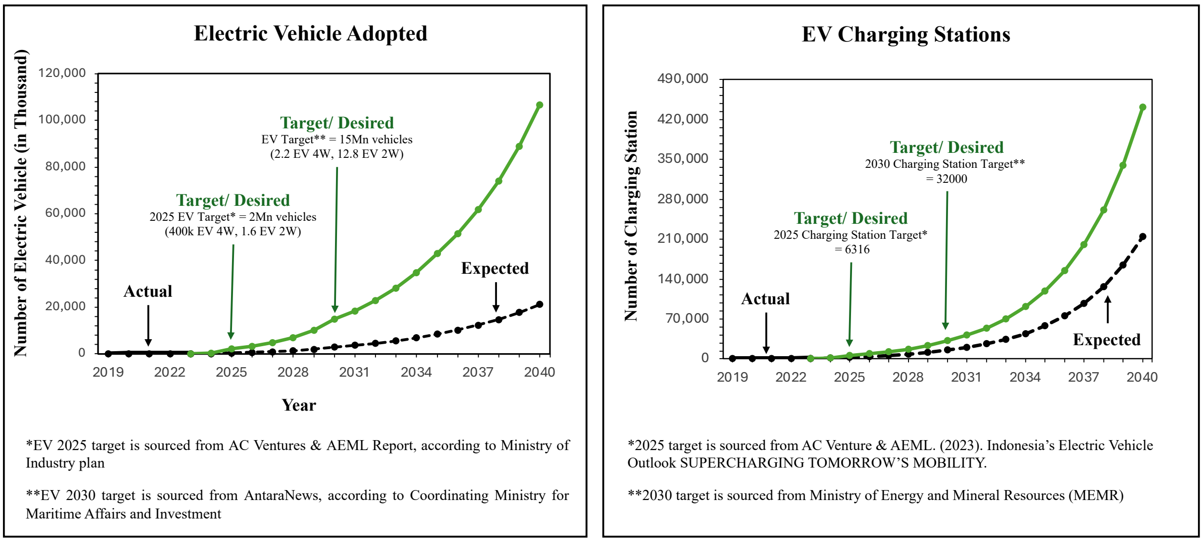

Figure 2: Reference Modes of (a) Indonesia Electric Vehicle Adopted, (b) EV Charging Stations

2. Literature Review

2.1 Key Drivers Influencing EV Adoptions

Indonesia, with its rapid urbanization and increasing transportation demand due to high volume of mobility, faces growing environmental concerns due to fossil fuel dependency (Idris et al., 2024). Transportation sector remains one of primary contributors to carbon emissions, leading to high GHG emissions in Indonesia (Nabila & Aritenang, 2024). According to the Institute for Essential Services Reform (IESR, 2022), Indonesia's road transport emissions have increasingly risen because of urban expansion and number of internal combustion engine (ICE) vehicles. In this context, electric vehicles (EVs) offer a solution for lowering carbon emissions and fossil fuel consumption (IEA, 2020). Studies suggest that widespread EV adoption could reduce urban air pollution, leading to improved public health outcomes and lower healthcare costs (Sukarno et al., 2016).

EVs adoption is influenced by the interplay of multi-drivers, including economic, infrastructural, and environmental considerations. Research has found that environmental awareness plays a role in shaping consumer awareness and attitudes toward EV adoption (Lin & Wu, 2018). Nevertheless, infrastructural challenge, such as limited charging stations, and high initial cost (purchase price), remain significant barriers in developing countries and early-stage EV market, like Indonesia (Lazuardy et al., 2024). Range anxiety, the concern of insufficient driving range due to lack of charging stations, remains to be a barrier to adoption and highly influence consumer willingness to adopt EVs (Jochem et al., 2018). Pricing dynamics is undeniably playing a fundamental role in EV adoption, particularly in developing market with early stage of EV adoption. While EVs have higher purchase (upfront) costs compared to internal combustion engine (ICE) vehicles, their long-term operational costs are relatively lower due to reduced fuel (Hardman et al., 2017).

2.2 The Role of Social/Peer Influence in EV Adoption

Social imitation refers to the tendency of individuals to adopt new technologies based on behaviors and actions of their peers. In the context of EV adoption, decisions are not driven solely by rational economic choices but also by social influences that shape consumer perceptions and preferences (Lonan & Ardi, 2020). Social imitation can accelerate EV adoption by growing network effects, where an increasing number of users creates a reinforcing cycle of adoption. Studies have shown that early adopters play a role in setting trends and reducing the perceived risks associated with new technologies (Lin & Wu, 2018).

This dynamic is particularly relevant in Indonesia, where vehicle ownership is also influenced by societal norms and peer comparisons (Novizayanti et al., 2021). Given that public perception of EVs is still developing in Indonesia, social influence from key influencers and industry leaders can trigger consumer interest to adopt EVs (Lazuardy et al., 2024).

2.3 Policy Intervention For EV Adoption

Indonesia has introduced some policy measures to encourage EV adoption, including tax exemptions and infrastructure investments (AC Ventures & AEML, 2023). Studies from other markets demonstrate that financial incentives, such as purchase price subsidies and tax reductions, have been able to stimulate consumer demand for EVs (Zhang et al., 2018). Infrastructure development is another critical domain of policy intervention. The availability of charging stations is a major driver of EV adoption (Lazuardy et al., 2024). In response, Indonesia’s state-owned electricity company, PLN, has been actively expanding charging infrastructure, with 624 stations built as of 2024 (Antara News, 2024). However, further expansion in infrastructure is still required to ensure widespread accessibility.

Beyond financial and infrastructure support, policies that integrate mass marketing campaigns and social public awareness initiatives can amplify the impact of EV promotion (Novizayanti et al., 2021). Mass campaigns and awareness can help normalize EV ownership and shape public perception, reinforcing both social influence and economic motivations. Thus, a coordinated collaboration approach between economic incentives, infrastructure investment, regulatory support, and social influence is essential to driving systemic change in the transportation (EVs) sector.

3. Dynamic Hypothesis

The Dynamic Hypothesis of this study is represented through following Causal Loop Diagram (CLD), which is driven by problem statement, grounded by empirical literatures, and reflects a simplified version of stock-flow diagram (SFD) model. It captures the feedback mechanism and key variables influencing EV adoption. This conceptual framework supports exploratory analysis of various policy scenarios and helps identify leverage points for accelerating EV adoption in Indonesia.

While the model treats electric vehicles (EVs) as a single category, it acknowledges the dominance of two-wheeled EVs (~80%) of total EV adoption, compared to about 20% for four-wheeled EVs. Although this segmentation is not explicitly modeled in this study due to its simplified scope, it is recognized as an important contextual factor that could influence policy effectiveness. Nonetheless, the current study aims to offer a foundational system-level understanding of adoption behavior and policy impacts, which can serve as a basis for more segmented analyses in subsequent work.

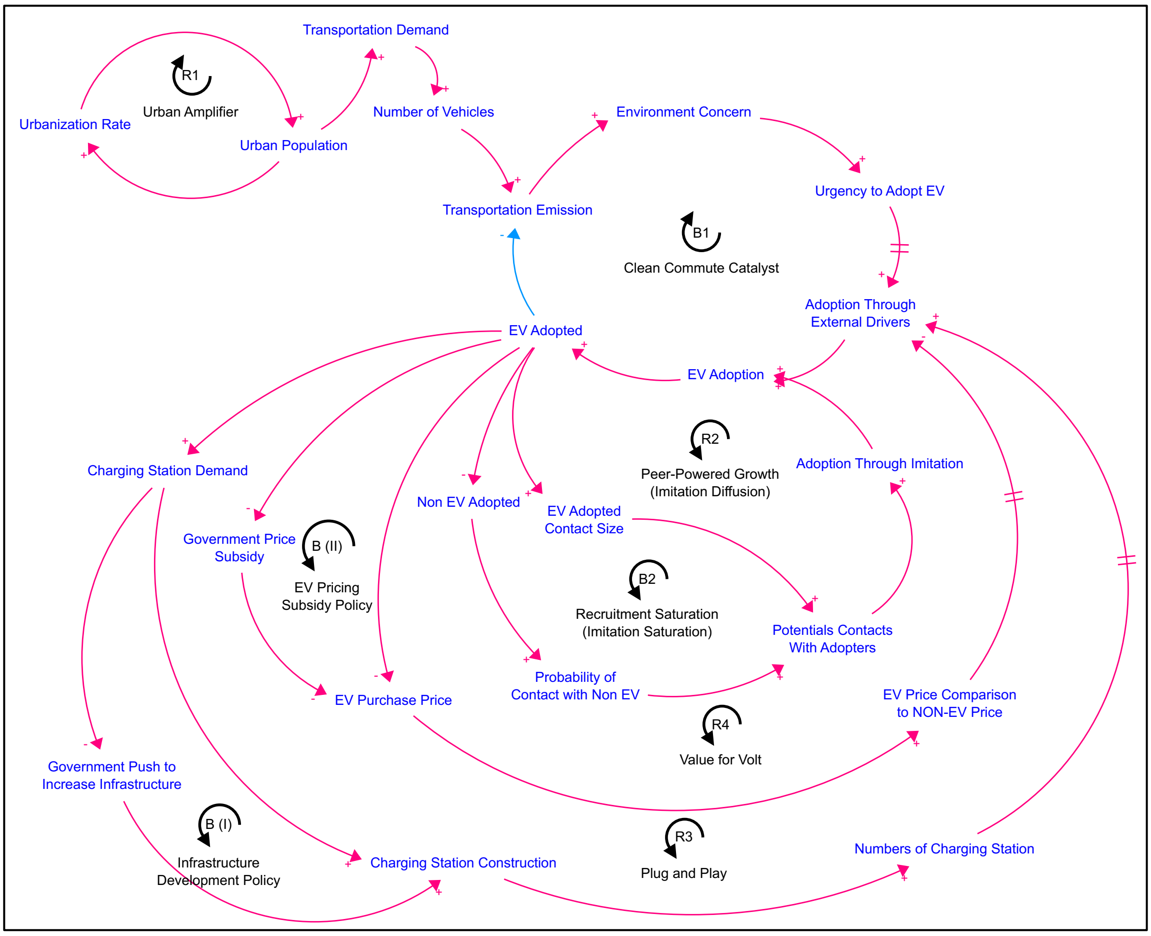

Figure 3: Causal Loop Diagram for EV Adoption in Indonesia

1. Urban Amplifier (R1)

This loop describes the self-reinforcing nature of urbanization. Increased urbanization generates a feedback effect in which a greater urban population drives more urban growth due to more opportunities and resources in cities, attracting more migrants (Glaeser et al., 1992;

Henderson & Venables, 2009). In turn, increased urbanization raises transportation demand, contributing to higher emissions. While not the primary focus of this study, urbanization serves as a background condition that amplifies the relevance and urgency of EV adoption.

2. Clean Commute Catalyst (B1) - Environment-Concern Driver

This loop describes how growing environmental concern contributes to EV adoption. As numbers of ICE vehicles increase, so do pollution and emissions. Over time, the worsening environmental quality raises public concern, further motivating EV adoption. The delay in action is influenced by the time it takes for individuals to be informed and feel the effects of environmental degradation. Research shows that increased environmental concern correlates with higher EV adoption rates (Axsen et al., 2016). Additionally, EVs can reduce CO_2 emissions by up to 30% compared to ICE vehicles in Indonesia (IEA, 2020). The loop an important, though less dominant, pathway for adoption in the Indonesian context.

Even among environmentally conscious consumers, concerns persist regarding the EVs' carbon footprint, for example from battery disposal. Currently, the model does not explicitly incorporate and discuss the battery lifecycle emission. Instead, the loop emphasizes the broader perception of environmental benefit as a motivator for EV adoption.

3. Plug and Play Loop (R2) - Infrastructure Driver

This loop describes the positive feedback between charging infrastructure and EV adoption. As more charging stations are constructed, EV ownership becomes increasingly appealing, leading to greater adoption. Rising EV adoption, in turn, creates higher demand for charging stations, incentivizing further infrastructure development. Lazuardy et al. (2024) emphasize in their study that the availability of charging stations is a significant driver of EV adoption in Indonesia. Similarly, Lin and Wu (2018) highlight the direct correlation between charging infrastructure and EV purchase intentions in China. However, infrastructure deployment is subject to time delays caused by financial constraints, regulatory approvals, and logistical hurdles. The goal of this loop is to increase EV Adoption through expanding infrastructure availability. A balancing loop, Infrastructure Development Policy (BI), acts as a corrective mechanism: when infrastructure lags behind adoption, the government intervenes to accelerate charging station deployment. However, as more charging stations are built, the need for government support on infrastructure expansion then reduces.

4. Value for Volt Loop (R3) : EV Pricing Driver

This loop captures the interaction between EV adoption and EV affordability. As more consumers adopt EVs, prices tend to decrease due to economies of scale, manufacturing advancements, and increased competition. Lower EV prices enhance their affordability and attractiveness, encouraging further adoption, more. This virtuous cycle is well-documented (Nykvist & Sprei, 2015; Breetz et al., 2018). The model incorporates a variable, Effect of EV Price Ratio to Non-EV Adoption, to represent and account for relative price sensitivity. A balancing loop, EV Pricing Subsidy (BII), reflects government interventions: when adoption is low due to high prices, subsidies are introduced to stimulate uptake. As adoption accelerates and market maturity increases, these subsidies may be scaled back.

5. Peer-Powered Growth Loop (R4)

This loop captures the role of peer/social influence in accelerating EV adoption. As individuals observe peers adopting EVs, they are more likely to follow suit, driven by social comparison, trust in the experiences of early adopters. Each adopter increases the visibility of EVs in their social network, resulting in a positive feedback loop where increasing number of EV adopters amplifies peer influence, leading to exponential adoption growth. Zhang et al. (2018) found that social networks play a crucial role in EV adoption, particularly in urban areas where visibility of EVs is high. Similarly, Rogers' Diffusion of Innovations Theory (1962) emphasizes that social influence is a key driver in the adoption process, particularly during the early stages. While this loop is currently modeled through a fixed imitation coefficient as part of the Bass Diffusion structure, behavioral realism could be improved in the future research by endogenizing the imitation driver.

6. Recruitment Saturation (B2)

This loop describes how the EV adoption eventually reaches a saturation point in the market, primarily driven by diminishing numbers of potential adopters from the pool of Non-EV users. As EV adoption grows, the stock of EV Adopted increases and Non-EV decreases. Lower Non-EVs reduce the pool of potential adopters who can be influenced through imitation. Consequently, the rate of adoption through social influence slows down, creating a natural limit to the diffusion of EVs within the market.

4. Methodology

Studies on EV Adoption in Indonesia are not new. Lonan and Ardi (2020) discovered in their study that EV adoption in Indonesia is highly reliant on charging infrastructure, and they emphasized the role of government subsidies in making EVs affordable for consumers' purchase power. Novizayanti et al. (2021) used Agent-Based Modelling (ABM) to analyze consumers behavior towards EV adoption and found that adopting cleaner transportation mode is influenced more by vehicle utilities (price, range, spare part) with only a few adopting EV because of emission concerns.

This study, thus, seeks to complement previous research by offering a more holistic and system-oriented perspective. Rather than analyzing the drivers or policy in isolation, this study accounts the interaction of multiple interdependent drivers, infrastructure, pricing, imitation, and environmental concerns, dynamically. Hence, this research employs System Dynamics (SD) modeling in combination with Bass' Diffusion framework. System Dynamics is well-suited for analyzing complex model, multi-interacting drivers and feedback loops that influence adoption rate over time, while addressing Indonesia-specific challenges towards EV. The Bass Diffusion model is integrated to capture imitation-driven adoption. This is especially relevant in Indonesia, where social contagion effects, such as word-of-mouth influence or demonstration effects, plays significantly impact toward innovation adoption. By combining these methodologies, this study not only identifies the systemic barriers but also explores how social imitation effect interacts with other drivers to accelerate or prevent diffusion.

While the model offers insights into systemic interacting-drivers influencing EV adoption in Indonesia, several limitations must be acknowledged. First, the model treats EVs as a single category and does not distinguish between two-wheeled and four-wheeled vehicles. Second, although economic factors such as price are captured through a variable representing the effect of EV-to-non-EV price ratio, the model does not explicitly simulate demand elasticity or consumer segmentation. Third, the imitation driver in the Bass Diffusion framework is simplified based on fixed contact rates rather than endogenously linking to factors such as EV visibility or media exposure. Lastly, environmental considerations in the model focus on vehicle-level emissions and do not account for carbon footprint, particularly those related to battery disposal. These limitations are recognized and suggested for future research or model refinement.

4.1 Model Validation

Parameter assumptions in this model are grounded in empirical literature, primarily from studies on EV adoption in Indonesia and China. Key references include Lonan and Ardi (2020), Novizayanti et al. (2021), Lin and Wu (2018), and Zhang et al. (2018), alongside a variety of statistical and data sources. The key parameters' value, such as Reference Environmental Concern-Driver Fraction, Reference Pricing Driver Fraction, Reference Infrastructure Driver Fraction and Imitation fraction, are set to the midpoint of ranges identified in these literatures. Historical data up to 2023 are derived from reported national statistics, while projections for 2024–2040 are based on decadal moving compound annual growth rates (CAGR). The projections serve only as starting references to inform base trajectories, not as fixed growth paths. Additionally, the model incorporates feedback mechanisms, such as imitation saturation (Recruitment Saturation loop), pricing effect (Value-for-Volt loop), and infrastructure reinforcement (Plug-and-Play loop), which allow for nonlinear behavior and dynamics. These feedback loops are designed to moderate exponential growth over time, especially as the adopter base matures and infrastructural or behavioral constraints emerge.

Model calibration was performed using two approaches: (1) Stella's Calibration Optimization to fit the model against historical data trends, and (2) hand calibration to reflect expected trends of the key indicators.

Due to the project's scope, data availability, and time resource, the model focuses on four key EV adoption drivers (infrastructure, price, peer/ social influence, and environmental concern). It excludes drivers like vehicle capacity (range, spare parts, battery), distance, and production constraints. Additionally, it assumes no increase in urban road length, with vehicle growth aligned to government projections, and presumes that EV adoption fully replaces NON-EVs, leading to a corresponding decline in NON-EV.

4.1.1 Model Validation Test

Parameter Confirmation Test: The parameters in this model align with real-world meaning and the values are backed by literature, variety of data source, or credible news sources. The descriptions are provided in the Model Documentation (Appendix B in separate file).

Dimensional Consistency Test: All the parameters and variables have consistent and appropriate unit, and the equations are mathematically valid. This is confirmed by Stella Software.

Extreme Condition Test: Extreme values are assigned to selected parameters and under extreme condition value, the model doesn't produce unexpected behavior.

Integration Test: This test is performed to determine whether the model simulation results are sensitive to the choice of time step or numerical integration method in the model setting (Sterman, 2000). The test is conducted by comparing result from Euler and RK2 at different DTs (1/8, 1/16, 1/32, 1/64, 1/128). RK2 and DT 1/16 are then chosen as the integration errors are removed.

4.1.2. Sensitivity Test Analysis

Local Behavior Sensitivity Test: Local sensitivity test was performed to examine how uncertainty in individual parameters affect key performance indicators (KPIs), specifically EV Adopted (stock), EV Adoption (flow), and numbers of Charging Stations. Each uncertain parameter was tested through 1,000 sensitivity-runs, using uniform distribution random and Sobol Sequence sampling method.

Results indicate that parameters related to Social Contagion Driver exhibit behavioral sensitivity. This suggest that social exposure is crucial in shaping the diffusion of EV in Indonesia. Likewise, the initial number of charging station per vehicle shows behavioral sensitivity, highlighting that early infrastructure availability can strongly influence adoption over time. Meanwhile, most other parameters are found to be numerically sensitive. It indicates that while changes in these parameters' value affect the KPI, they do not fundamentally introduce systemic change in behavior trend.

Table 1: Overview of Local Sensitivity Test

PARAMETERS				
Sector	**Variable**	**BASELINE**	**RANGE**	**Sensitivity**
Total Vehicle Projection	Urban Change Fractional Rate	0.02	0.0125 - 0.05	Numerically Sensitive
	Avg Vehicle per Person Change Rate	0.025	0.018 - 0.05	Numerically Sensitive
	Baseline Avg Vehicle per person	0.9	0.5 - 1.5	Numerically Sensitive
Environmental Concern Driver	Avg Emission per Vehicle	0.97	0.5 - 1.5	Numerically Sensitive
	Reference Environmental Concern-Driver Fraction	0.1	0.005 - 1	Numerically Sensitive
Pricing Driver	Avg Baseline EV Purchase Price	35,000,000	15Mn - 60Mn	Numerically Sensitive
	Avg Price per Non EV	15,000,000	10Mn - 30Mn	Numerically Sensitive
	Reference Pricing Driver Fraction	0.291173	0.1 - 1	Numerically Sensitive
Infrastructure Driver	Initial Avg CS per Vehicle	0.0244	0.01 - 0.06	Behaviourally Sensitive
	Change in CS per Vehicle	0.42	0 - 0.75	Numerically Sensitive
	Construction Time	1.5	0.5 - 2.5	Numerically Sensitive
	Sensitivity of Adoption To Infrastructure Attractiveness	1.00154	0.1 - 2	Numerically Sensitive
	Reference Infrastructure Driver Fraction	0.282251	0.1 - 1	Numerically Sensitive
	Fraction of Potential Adopting	0.6	0.05 - 0.99	Numerically Sensitive
Social Contagion Driver	Imitation fraction	0.108	0.01 - 0.5	Behaviourally Sensitive
	Initial Contact Size Rate	10.3489	20-Feb	Behaviourally Sensitive
	Change in Contact Size Rate	0.750804433	0.5 - 0.9	Behaviourally Sensitive

Global Behavior Sensitivity Test: Global sensitivity was performed on the base-run model simulation, using combined variations across all uncertain parameters. Using Sobol Sequence sampling method and through 5,000 runs, the simulation produced confidence intervals ranging from 75% to 95%, aiming to provide insights into the robustness and variability of key system behaviors in the EV Adoption Model before implementing policy.

Figure 4 presents the result of the global sensitivity test. Result indicates that while early EV adoption and infrastructure deployment are relatively predictable, long-term trends are highly sensitive to policy stability, market conditions, and social contagion effects. Charging station grows rapidly until 2030, then relatively stabilizes, though long-term uncertainty persists due to potential policy and market shifts. EV adoption follows an exponential trend with low uncertainty in the short-term but high variability after 2035, indicating that consumer behavior, policy incentives, and infrastructure availability will play critical roles.

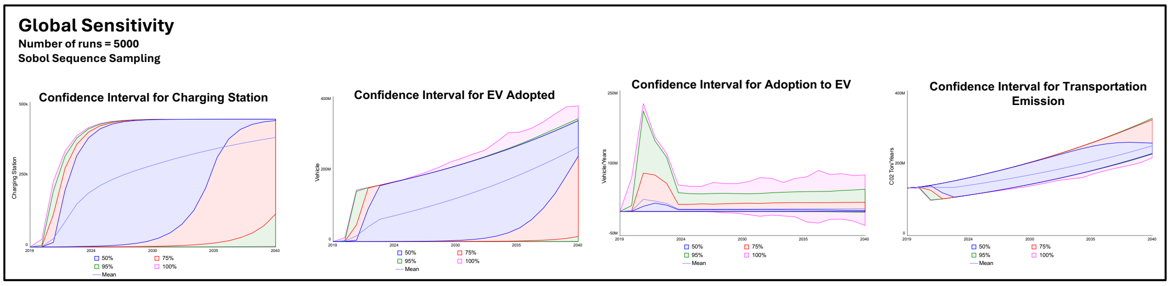

Figure 4: Confidence Intervals Graph from Global Sensitivity Test

5. Analysis

5.1 Base Run Simulation

The base-run (or baseline) simulation, presented by Figure 5, produces exponential growth in both number of EVs Adopted and Charging Stations, driven by reinforcing feedback loop from external (price, infrastructure, environmental concern) and social contagion drivers. While Charging Station produces similar exponential growth behavior, the corresponding increase in EV Adopted is delayed due to the time required for individuals to assess infrastructure readiness and make purchase decision. In contrast, NON-EV exhibits a linear growth trend, reflecting continuous increasing population and transport demand, as well as continued dominance of fossil-fuel vehicles and consumers' habit. Hence, Transportation Emission (CO2) trend remains driven by NON-EVs.

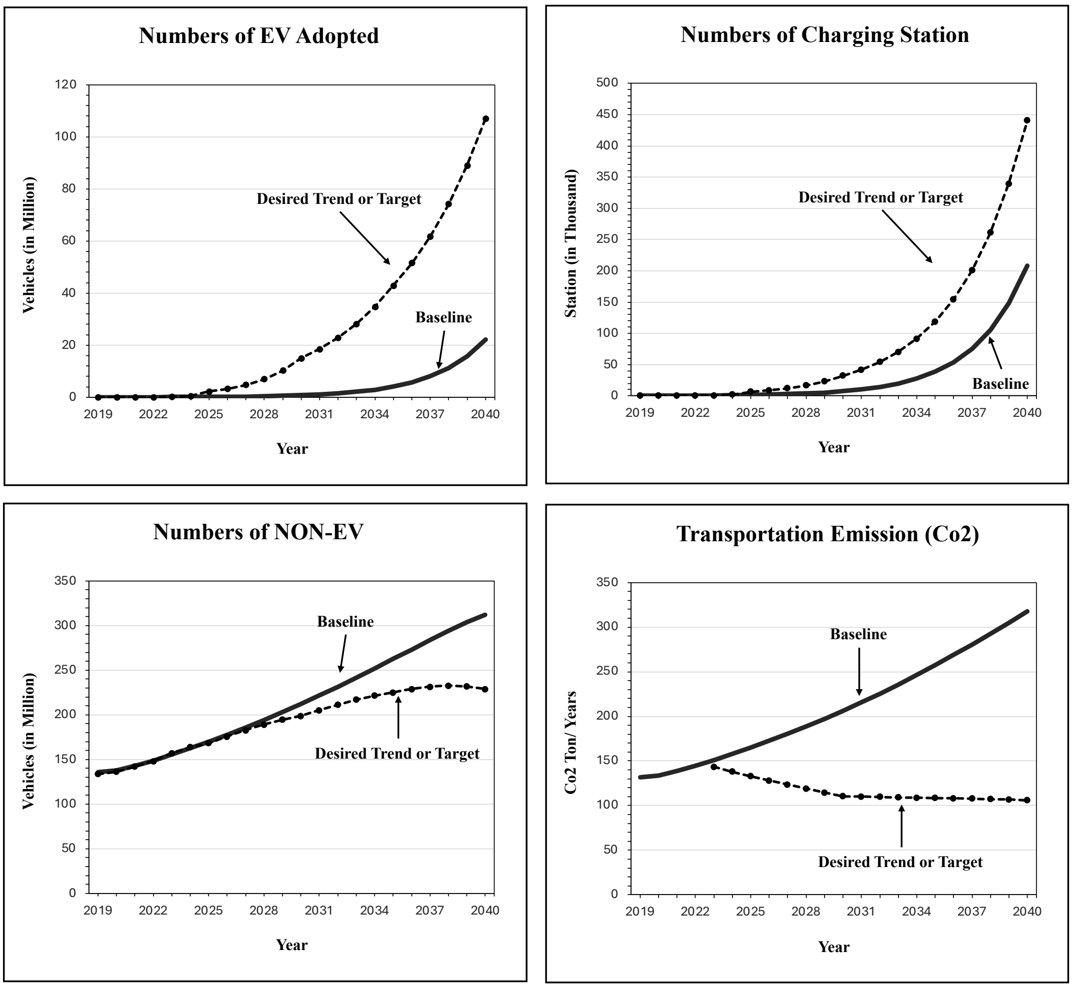

Figure 5: Baseline Behavior of Key Performance Indicators

<u>Year: 2019 – 2023</u>

During the first 5-6 years of Indonesia's EV Acceleration Program, both EV adoption and charging station numbers remained low. A noticeable shift began in 2021, when EV adoption started to accelerate, fueled by Peer-Powered Growth Loop (R2). This loop is particularly strong in early-stage market, where uncertainty about the new technology is high, emphasizing the role of peer influence or mass awareness in accelerating EV adoption. During this period, each EV user is assumed interacted with 10.3 contacts annually. Given the higher prevalence of NON-EVs in the population, probability of contact with NON-EVs owners was correspondingly higher, increasing the likelihood of adoption through the Imitation Driver. This dynamic aligned with real-world development, reflecting aggressive initiatives from Indonesian government to provide e-fleet taxi/busses trial (2020–2021), national campaigns at big events such as the B20/G20 Event (2021–2022), and directive encouragement to use EV in government operations (2022–2023) (AC Ventures and AEML, July 2023). Collectively, these efforts significantly enhanced public awareness.

As EV adoption grew, demand for Charging Stations (CS) increased, activating two loops: CS (Charging Station) Capacity Balancing (B3) and Plug-and-Play (R3). B3 loop represents a balancing mechanism, where CS development is adjusted to reduce the infrastructure gap. In parallel, increasing deployed CS makes EV more attractive to adopt, hence strengthen the R3 loop. In this early phase, the growth of EVs and Charging Stations were significant though from a low base, underscoring the critical need to scaling up CS construction to meet EV demand and sustain long-term adoption growth.

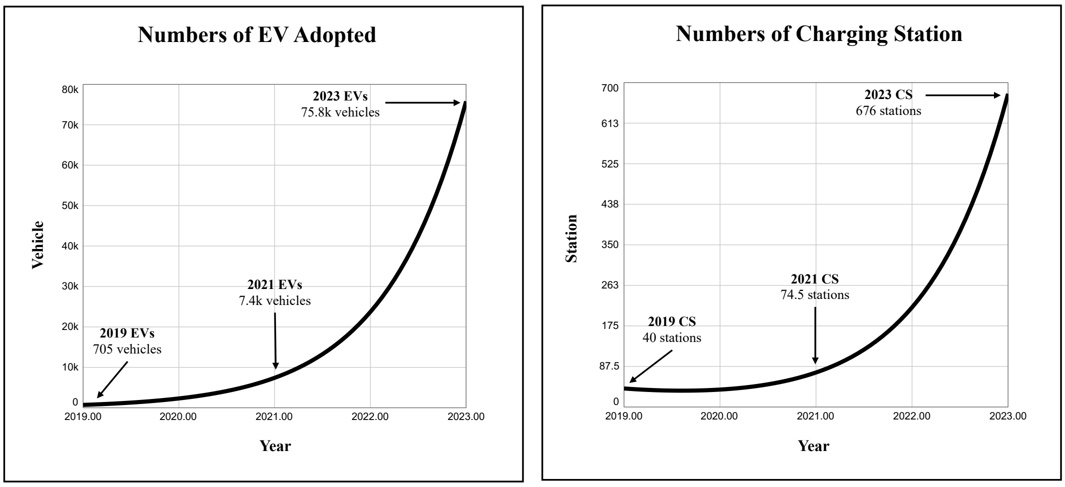

Figure 6: Baseline Behavior in 2019-2023

Year: 2023 – 2030

After 2023, the growth of EV adoption and charging station (CS) construction slows down. Following the earlier aggressive initiatives, public communication efforts by the government have ceased. Since 2022, the government has shifted its focus towards finding infrastructure investments and regulatory adjustments, while private sector players have yet to launch substantial marketing campaigns (Modern Diplomacy, 2024; AEI, 2024). Consequently, EV awareness now grows organically, relies more on interpersonal influence, with potential adopters learning about EVs primarily through their direct social network.

Given the relatively small EV penetration rate, the assumed contact rate now will not match the broader impact of mass advertising by government, declining from 10.3 in 2023 to 2.6 per year. This model is a simplification of Bass Diffusion model; hence STEP function is used to represent the structural change in information dissemination. Figure 7 illustrate that, during this period, Peer-Powered Growth (R2) and CS Capacity Balancing (B3) loops work in tandem. R2 loop, which initially drove EV adoption, slightly weakens due to lower contact size, slowing EV adoption and demand for charging stations. Nevertheless, charging station construction continues, albeit at a slower pace.

Time Delay in CS infrastructure projects (estimated at 1.5 years) is attributable to planning and execution phases, managed by the Ministry of Transportation and the State Electricity Company (PLN). As a result, despite reduced contact size, the demand for charging station is still accumulating for construction. This dynamic explains why CS growth from 2023 to 2030 slows to half its earlier rate, while EV adoption declines to one-fifth of its prior pace. Simultaneously, B3 loop ensures charging station construction aligns with the demand, preventing overinvestment.

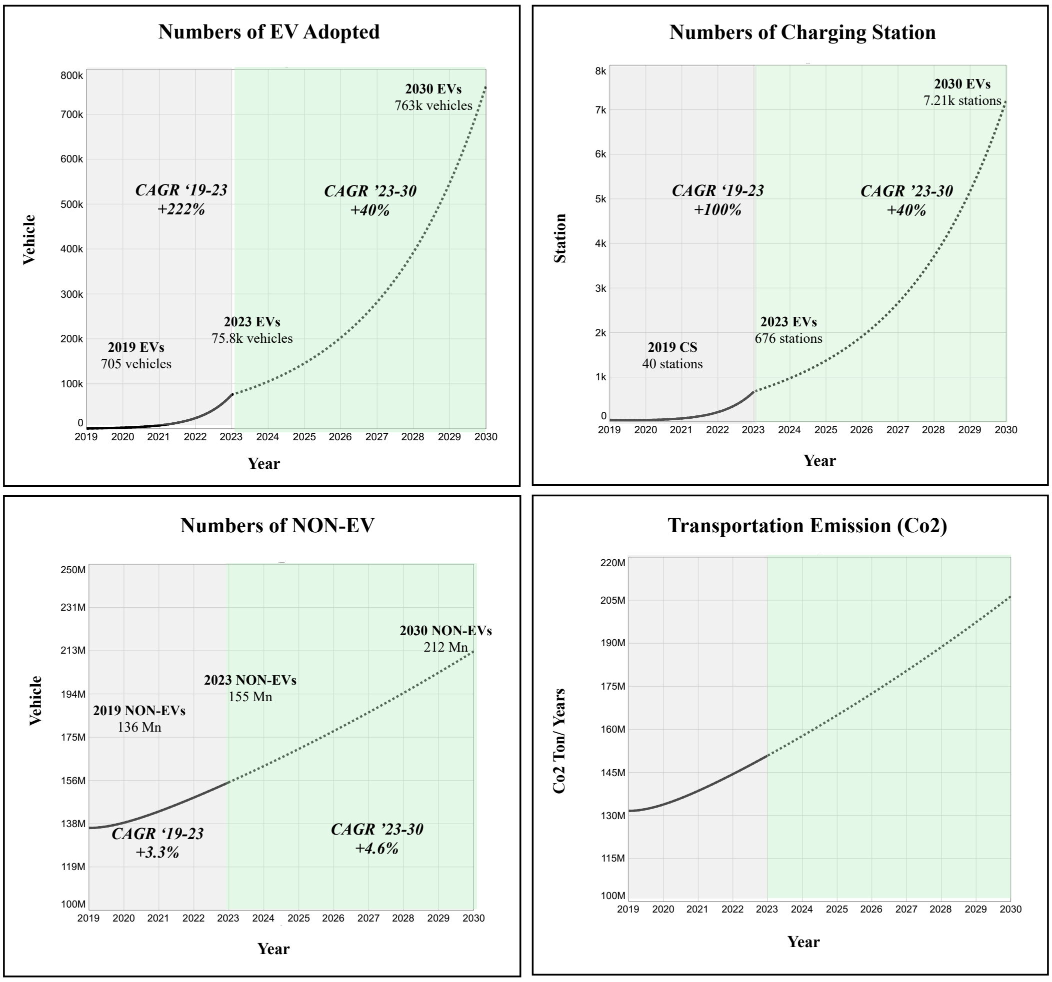

Figure 7: Baseline Behavior in 2019-2030

As EV adoption slows, the number of NON-EVs continues to increase, strengthening the Recruitment Saturation Balancing Loop (B2). Unfortunately, the persistence of NON-EVs on the road increases transportation emissions, contradicting governmental goals for EV adoption. This underscores the need for interventions to achieve the desired transition. With more Non-EVs on the road, Probability of Contact With potential adopters rise, leading to opportunity to re-accelerate adoption, provided timely interventions such as targeted subsidies, infrastructure development, or renewed awareness campaigns are introduced.

<u>Year: 2030 – 2040</u>

In the final decade of simulation, the system behavior is primarily determined by infrastructure drivers, which are Plug and Play Loop (R3) and CS Balancing Loop (B3). Continued charging station development strengthens R3, facilitating EV adoption through infrastructure drivers. Simultaneously, B3 continues to align charging station development with growing demand, gradually narrowing the gap between actual and CS target/ demand. However, despite low EV penetration rate (<1%), Indonesia shows early signs of recruitment saturation due to limited infrastructure, less affordability, and a slow pace of adoption beyond urban elites. As EV adoption increases, the Clean Commute Catalyst Loop (R5) strengthens gradually, showcasing the potential of EVs in gradually reducing transportation emissions between 2030 and 2040.

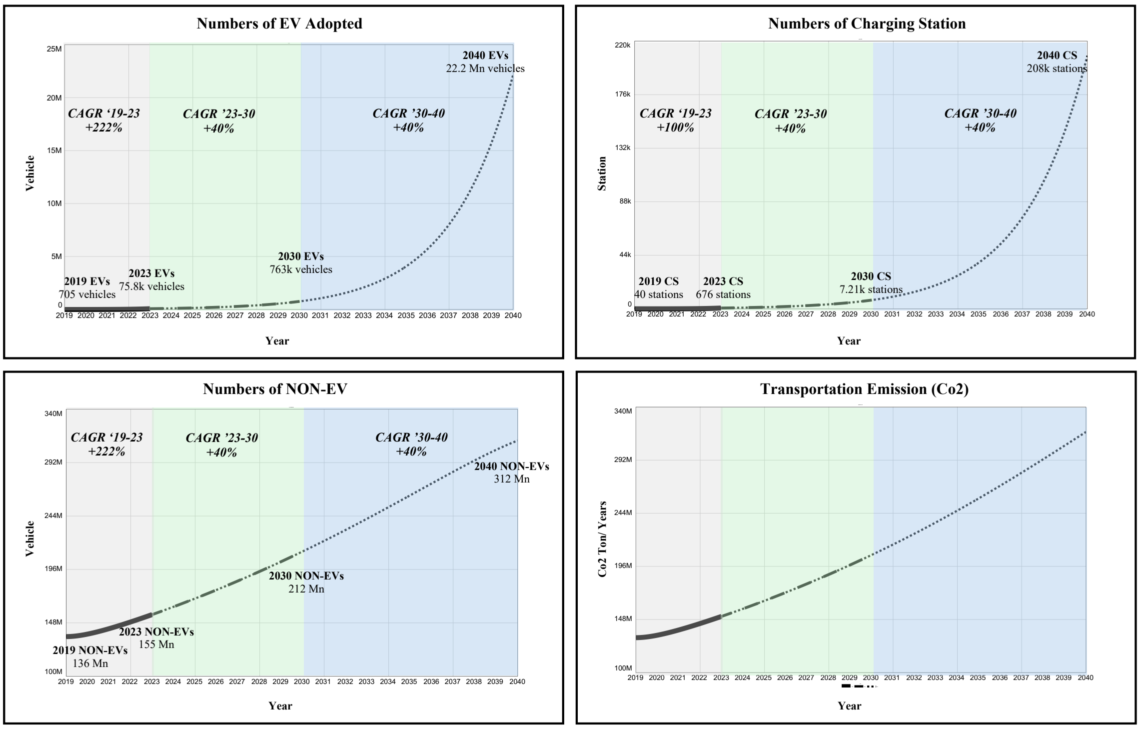

Figure 8: Baseline Behavior in 2019-2040

The base-run simulation reveals that Environmental-Concern Driver (Clean Commute Catalyst – R5) has minimal influence on adoption rate. In parallel, Pricing Drivers (Value for Volt loop – R4) is currently exert marginal impact, attributed to the significantly higher price of EVs compared to fossil-fuel vehicles (Non-EVs) in Indonesia, which limits affordability to only upper-income consumers. Novizayanti et al. (2021) highlighted in their study that pricing is the second most critical drivers in vehicle purchases, underscoring the need for affordability to drive adoption. Without substantial government interventions to make EVs accessible, pricing remains a barrier. Moreover, their study found that only 6% of respondents adopted EVs for their sustainability benefit, indicating niche appeal of EVs in Indonesia from environmental concerns compared to practical considerations such as affordability and quality. These findings help explain why the model exhibits the slower-than-desired exponential growth in EV adoption and charging station deployment (see Figure 5). The adoption rate remains dominated by imitation driver among a narrow group of early adopters and the limited charging infrastructure.

Although the government has introduced fiscal incentives, EV price tax, to stimulate EV purchases, these measures have largely benefited high-end vehicle segments, leaving mass-market penetration unaddressed (Jakarta Post, 2023). Without more inclusive policies and infrastructure expansion, the transition to widespread EV adoption remains limited.

5.2 Policy Analysis

Understanding the feedback loops is essential for identifying leverage points where policy intervention can generate significant impact. When designing policies to accelerate EV adoption, it is important to establish evaluation criteria, including effectiveness, efficiency, and operability. Effectiveness is measured by how close the number of EVs adopted after implementing policy aligns with the government's goal. Efficiency considers the cost-effectiveness of policy implementation and its impact on increasing adoption. Operability assesses the feasibility and practical execution of the policy. Given the scope of this project, policy analysis will primarily be assessed from effectiveness metric while efficiency and operability will be discussed qualitatively.

According to base-run simulation, Peer-Powered Growth Loop (R2) and Infrastructure Driver loops (B3 and R3) are the dominant drivers on EV adoption in Indonesia. Therefore, strengthening R2 loop by doubling the contact size rate from 2.6 to 5.2 annually (2023–2040) could significantly accelerate adoption through imitation. Contact size rate represents the number of potential EV adopters who encounter existing adopters annually. In practice, this policy could involve engaging influencers, public figures, community leaders, hosting EV experience events or running public campaigns emphasizing EV benefits. A historical of is the Indonesia's government use of EVs during the 2022 G20 Summit, which temporarily increased public visibility and interest (Jakarta Post, 2022). As illustrated in Figure 9, such interventions improve both EV adoption rates and charging station expansion, potentially surpassing baseline targets.

However, this strategy faces several challenges. Encouraging influencers to endorse EV may require significant and consistent upfront efforts, i.e. providing vehicles or incentives for the influencers, which neither the government nor private companies is currently prioritizing, and it often results in short-term spikes in adoption without sustained growth.

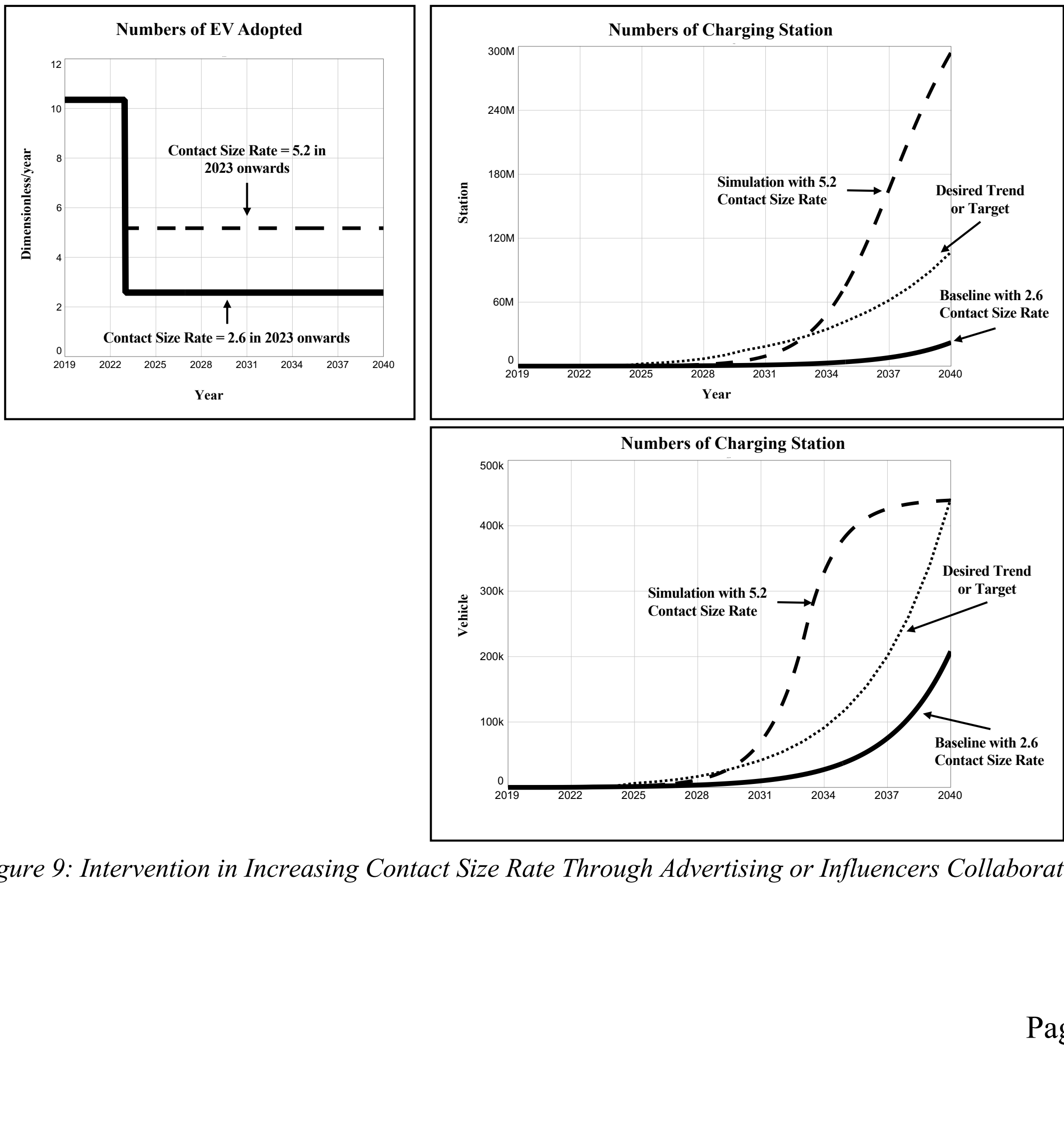

Figure 9: Intervention in Increasing Contact Size Rate Through Advertising or Influencers Collaboration

To ensure exponential adoption, two policies are introduced: (1) accelerating the construction of charging station, (2) providing price subsidies tailored to Indonesia's purchasing power.

Policy 1: Infrastructure (Charging Station) Acceleration

Indonesia's current Charging Station (CS)-to-EV ratio stands at approximately 1:70, significantly lower than that matured EV markets such as Norway, where the ratio stands at 1:25. This indicates the gap between infrastructure availability and the EV adoption in Indonesia. Therefore, the Infrastructure Acceleration Policy aims to directly strengthen the Infrastructure Driver, enhancing the attractiveness of EV ownership and influencing faster adoption. Two scenarios are then simulated within Infrastructure Acceleration policy:

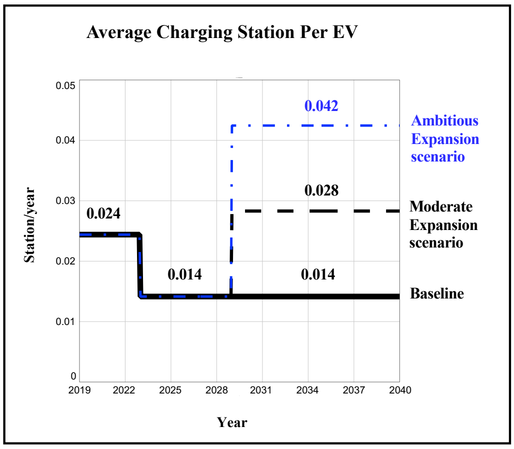

Figure 10: Average Charging Station per EV with and without policy

(a) Moderate Expansion: Doubling CS-to-EV (2x than baseline) by collaborating with private sectors to build charging stations in commercial parking spaces like shopping malls and business complexes.

(b) Ambitious Expansion: Tripling CS-to-EV (3x than baseline) by expanding moderate expansion effort with financial incentives for private firms, e.g. Pertamina and Shell, to grow charging station alongside their petrol stations.

The policy is integrated into the model by introducing two parameters: 'Gov't Push on CS Improvement', which serves as multiplication of how many times the charging station will be accelerated, and 'CS Push Policy Start Time', set at 2029, ensuring adequate time for stakeholder engagement, investments, and infrastructure planning.

As illustrated in Figure 11, both policy scenarios (moderate and ambitious expansion) yield positive impacts on charging station growth. Higher CS-to-EV ratio stimulates demand for charging station, triggering B3 loop (CS-Capacity Balancing) to construct more stations. Increasing number of CS strengthens R3 loop (Plug and Play), enhancing the accessibility and appeal of EV ownership, and contributing to increased adoption through the infrastructure drivers. Under the ambitious scenario, Indonesia is projected to meet its government's charging infrastructure targets by 2035. However, despite significant improvement in charging stations, number of EV Adopted remains modest and below the government's target. A major limiting factor is the higher cost of EVs, which is 2-3x more expensive than NON-EV, making EV largely inaccessible to middle and lower-income consumers and limiting the impact of infrastructure improvements. This finding is consistent with Lonan & Ardi (2020), which emphasizes that charging infrastructure development is a critical yet insufficient factor for EV adoption in Indonesia.

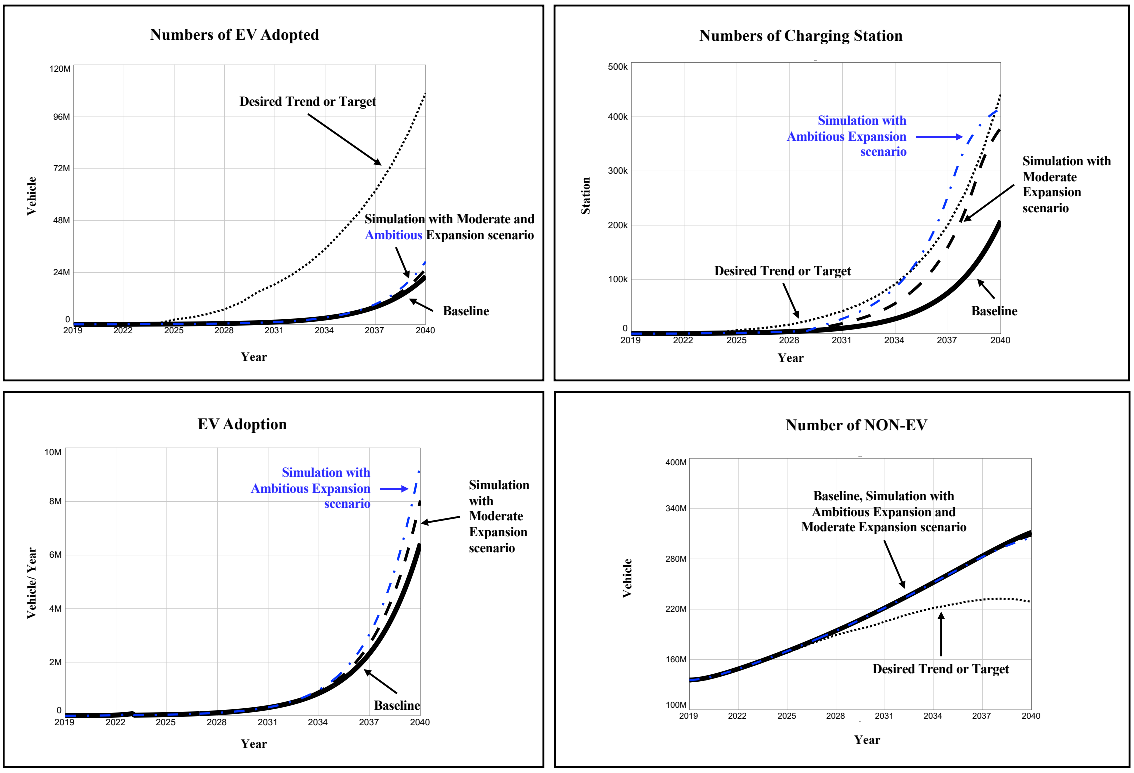

Figure 11: Policy Simulation Result – Infrastructure (Charging Station) Acceleration

Policy 2: Purchase Price Subsidy

While accelerating charging infrastructure addresses supply-side barriers to EV adoption, high upfront cost (EV purchase price) remains a barrier, particularly for middle and lower-income consumers. To address this, Policy 2 introduces purchase price subsidies, aiming to improve affordability and stimulate EV demand. The policy is tested under three scenarios:

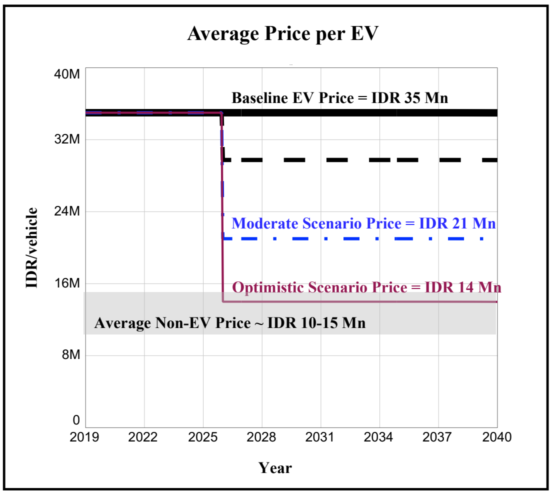

Figure 12: Average Price per EV with and without policy

(a) Current Implemented Scenario: Removing EV Price tax (15% price reduction).

(b) Moderate Scenario: Tax removal +25% subsidy (40% total price reduction).

(c) Optimistic Scenario: Tax removal +45% subsidy (60% total price reduction).

The policy is integrated in the model by introducing two parameters: ‘Government Price Subsidy’, varying according to the three scenarios, and ‘Subsidy Policy Start Time’, set at 2026, reflecting the policy implementation scenario.

Reducing EV Price relative to internal combustion engine (ICE or Non-EV) vehicles activates Price Driver, increasing appeal and consumer willingness to adopt EV. This policy strengthens Value for Volt loop (R4). As adoption increases, demand for charging stations also grows, activating the CS Capacity Balancing Loop (B3) and prompting further infrastructure expansion and reinforcing Plug and Play Loop (R3).

However, as shown in Figure 13, simulation results reveal that modest price subsidy/ reduction is insufficient to accelerate EV adoption. The first two scenario (Tax Removal and Moderate scenarios) have limited impact as EVs remain costlier than Non-EVs, discouraging adoption. Only the Optimistic scenario is able to produce notable increase in EV Adoption, as it effectively equalizes EV and Non-EV purchase price, removing the affordability challenge.

Nonetheless, policy on price reduction alone is not enough to meet government target on EV adoption. While subsidy improves affordability, it alone does not directly address charging infrastructure availability, which limiting for long-term and sustainable adoption. EV adoption remains modest unless subsidies are substantial. The first two scenarios show limited impact as EVs remain costlier than non-EVs, discouraging adoption. Only Optimistic Scenario (60% total price reduction) results in visible EV Adopted increase by equalizing EV and Non-EV prices. Nonetheless, only reducing the price will not fully solve the infrastructure issue, hence it still does not meet target.

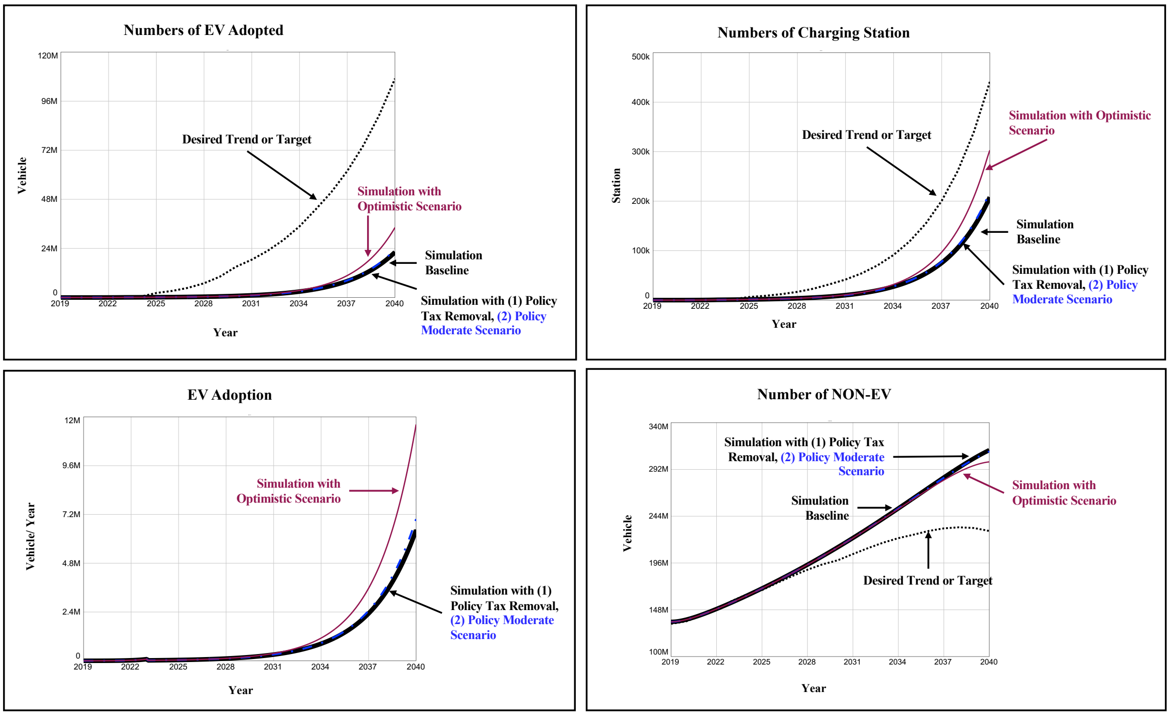

Figure 13: Policy Simulation Result – Purchase Price Subsidy

Integrated Policies

Neither infrastructure (charging station) expansion nor price subsidies alone can fully address the systemic barriers to EV adoption in Indonesia. To develop a more optimal and comprehensive strategies for EV acceleration, this study simulates set of combined policy scenarios.

(a) Scenario 1: Optimistic Price Subsidy + Ambitious Infrastructure Expansion

The first combined scenario combines aggressive price subsidies (optimistic scenario) with tripling the development of charging station (ambitious expansion scenario). The policy addresses infrastructure constrains by reinforcing infrastructure loops (Plug and Play - R3 and Charging Station Capacity Balancing – B3). Simultaneously, the policy also increases EV affordability by strengthen the pricing driver loop (Value for Volt – R4).

As shown in Figure 14 (dashed line), this scenario simulation results in a notable improvement in EV adoption. However, despite a higher number of EVs adopted and charging stations, it remains insufficient to meet Indonesia's government goal in EV adoption. This suggests that even aggressive financial incentives and infrastructure investments may be insufficient without parallel efforts to shift consumer behavior and societal norms.

(b) Scenario 2: Optimistic Price Subsidy + Ambitious Infrastructure Expansion + Mass Advertisement

Building on Scenario 1, the second scenario introduces a mass advertising campaign to further accelerate adoption by driving awareness and influencing societal imitation. The additional policy, advertising campaign, activates Peer-Powered Growth Loop (R2) by increasing the average annual contact rate among potential adopter from 2.6 to 3.6 (assumption), thereby enhancing the role of social influence and imitation in driving EV adoption.

Mass advertisement could take the form of nationwide media efforts, collaboration with social media influencer, or public engagement led by government or key stakeholders. The simulation results (Figure 14 – blue line) indicate that under this scenario, charging station expansion meets government target by 2031, suggesting that this combined policy approach can accelerate infrastructure growth. Additionally, EV adoption improves significantly compared to the Integrated Policy Scenario 1 but only reaches the desired goal by 2038. This highlights the long-term nature of market transformation and continuous need for sustained policy support. As a result, more EV adopters lead to a decline in number of Non-EV, contributing to reduced emission and environmental benefit.

Key Insights

The findings suggest that a multi-pronged policy approach, combining pricing subsidies, infrastructure expansion, and behavioral interventions, is necessary to achieve Indonesia's ambitious EV adoption target. While price subsidies and infrastructure investments are crucial enabler, mass advertising plays a role in shifting consumers preference, increasing social influence and encouraging adoption through imitation.

However, it is important to acknowledge that incorporating mass advertising in the integrated policy brings financial and operational complexity. Large-scale campaigns, even if led by government, require substantial funding which could place additional fiscal burdens and currently less prioritized in Indonesia's EV roadmap. Additionally, infrastructure availability and pricing affordability remains critical concerns to solve first to ensure the effectiveness of mass advertisement, particularly in gaining public trust and EV attractiveness. Finally, successful implementation necessitates collaboration between multiple stakeholders, including government agencies, private sector investors, automakers, and influencers. A coordinated effort is required to ensure that advertising efforts translate into sustained adoption rather than short-term behavioral shifts.

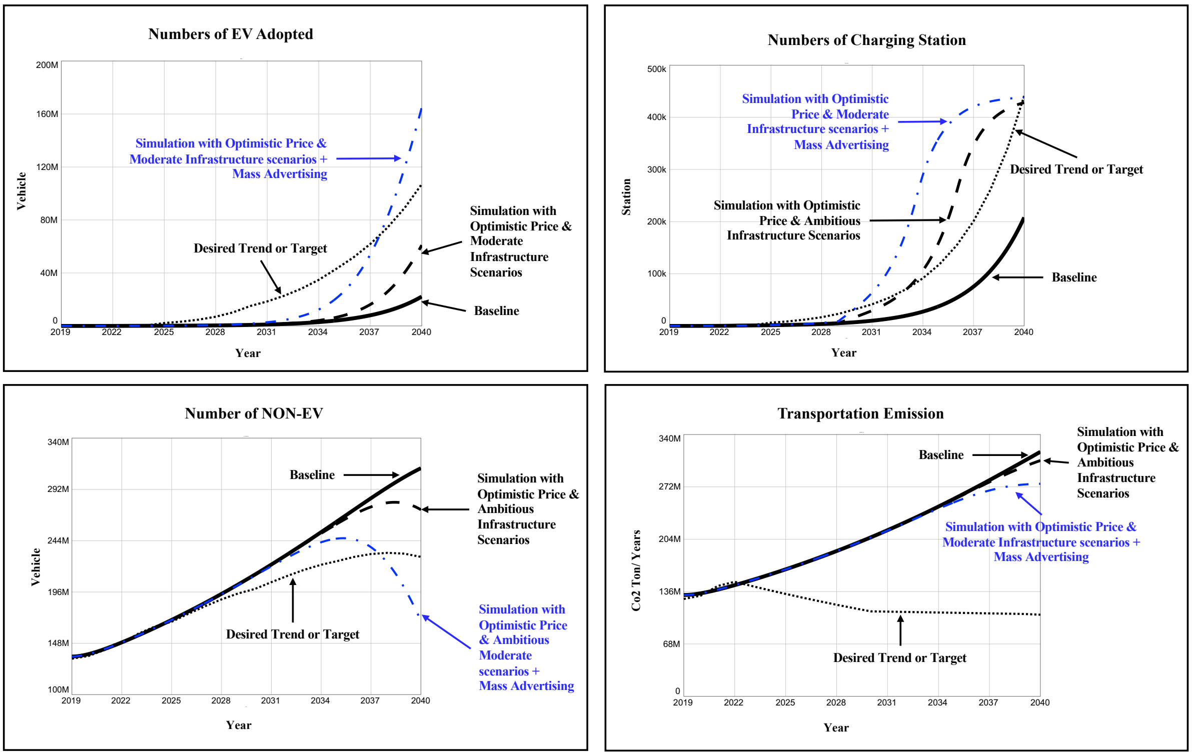

Figure 14: Policy Simulation Result – Integrated Policies

6. Conclusion and Future Research

To conclude, this study employs a System Dynamics approach to analyze the complex interaction of drivers influencing electric vehicle (EV) adoption in Indonesia, with a particular focus on imitation effects, infrastructure, pricing, and environmental concerns. The model captures Indonesia's early-stage EV adoption dynamics, revealing that while exponential growth in EV adoption and charging station is possible, it remains constrained mainly by infrastructure availability and price affordability. The Peer-Powered Growth Loop (R2) plays a critical role in driving early adoption while Infrastructure loop (R3) reinforces subsequent expansion. In contrast, environment-concern, while present, does not emerge as dominant driver, indicating that the adoption is more motivated by pricing and infrastructure driver, rather than sustainability values.

Policy simulations reveal that infrastructure development alone is insufficient to overcome affordability barriers, and price subsidies alone fails to address infrastructure challenges. However, combined policy approach, integrating price subsidies and infrastructure expansion, significantly improve EV Adoption and charging station (CS) expansion. This underscores the importance of government leadership and coordinated efforts among private sector stakeholders, including automotive manufacturers, energy providers, and state-owned electricity utilities, to implement infrastructure expansion and effective price subsidies. In addition, while mass advertisement could accelerate EV adoption, it must be implemented only after infrastructure and pricing barriers have been sufficiently. Otherwise, awareness efforts risk generating short-term visibility without sustained behavioral impact.

Despite the model's capability to capture the expected baseline behavior and policy impact, it has several limitations that warrant consideration. First, the model simplifies real-world complexities by assuming fixed parameters for social imitation in the Bass Diffusion structure rather than endogenous feedback structures. Second, the study does not distinguish the four-wheeled and two-wheeled EVs which may carry the different weight of drivers' attractiveness. Third, the study also assumes uniform affordability across Indonesia, overlooking the consumers' income disparities, which likely affect adoption rates. Lastly, the model does not incorporate lifecycle emission, particularly those related to battery production and disposal which could influence the long-term environmental credibility of EVs.

Hence, future research should explore and incorporate behavioral heterogeneity dynamics (e.g., consumer preferences, risk aversion, and response to campaigns), technological variables (e.g., battery technology, vehicle range), and production constraints, and deaveraged vehicle segmentation. Eventually, achieving Indonesia's EV ambition will require not only multi-lever policy design but also adaptive modeling tools which are capable of integrating evolving market behavior and technological advances.

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