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Impact of Net Zero Emission 2060 Initiatives to the Commercial Electric Vehicle Adoption in Indonesia: A System Dynamic Model Approach

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Abstract
Indonesia has committed to achieving Net Zero Emissions (NZE) by 2060, with transport electrification identified as one of the key mitigation strategies. This study investigates the impact of government policies on commercial electric vehicle adoption, particularly electric buses, in Indonesia using a System Dynamics approach. A simulation model was developed in Vensim® PLE 10.3.1 based on Causal Loop Diagrams (CLDs) and Stock-and-Flow Diagrams (SFDs) to evaluate 17 policy scenarios over the 2026–2060 period. The scenarios represent combinations of value-added tax (VAT) incentives, fuel price reforms, and electricity tariff policies under Indonesia's Enhanced Nationally Determined Contribution (ENDC). The findings indicate that, under business-as-usual conditions, commercial electric bus adoption remains limited, reaching only approximately 8,925 units by 2060. The Total Cost of Ownership (TCO) is identified as the primary determinant of adoption, with fuel prices exerting the strongest influence on market competitiveness. Among the evaluated scenarios, the combination of a 10% VAT incentive and fuel subsidy removal produces the best outcome, enabling the market to reach the projected saturation level of 132,000 electric buses while expanding domestic manufacturing capacity to more than 20,500 units annually. This scenario is also projected to reduce approximately 8,785 Gg CO_2 emissions in 2060, contributing 18–22% of the annual emissions reduction target under Indonesia's Second Nationally Determined Contribution (SNDC). The results highlight that fuel price reform is the most effective policy instrument, while VAT incentives and affordable electricity tariffs play complementary roles in accelerating commercial electric vehicle adoption.

INTRODUCTION

The Indonesian government has committed to reducing greenhouse gas emissions by 31.89% by 2030 as part of its Net Zero Emissions (NZE) 2060 initiative, as emphasized by the Coordinating Minister for Economic Affairs, Mr. Airlangga Hartarto, during the Special Event Road to G20 in October 2022 (Kementerian Perekonomian Republik Indonesia, 2022). Although the Coordinating Minister emphasized the importance of achieving this target, the Ministry of National Development Planning/National Development Planning Agency (Bappenas) has developed several scenarios that consider not only achieving NZE by 2060 but also accelerated and delayed pathways, targeting 2050 and 2070, respectively (Medrilzam, 2021).

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One of the key mitigation strategies outlined in Indonesia's Enhanced Nationally Determined Contribution (ENDC) is energy efficiency (Abi Suroso et al., 2022; Hamzah & Paliling, 2024; Haryanto et al., 2024; Hastuti, 2024; Kanugrahan & Hakam, 2023; Marbun & Lazuardi, 2026; Nurngaini & Rohma, 2025). Under Countermeasure 1 (the unconditional mitigation scenario), Indonesia targets the deployment of 15,197,000 electric vehicles on its roads by 2030 (Enhanced Nationally Determined Contribution Republic of Indonesia, 2022). From this perspective, the development of electric vehicles is inseparable from the NZE initiative and positions the electric vehicle industry as a promising sector for future economic growth and environmental sustainability (Fatkhurrahim & Fiandari, n.d.; Obando et al., 2024; Shelar, 2024; Xu, 2024).

Nevertheless, progress in decarbonizing the transport sector has been relatively slow, with greater policy emphasis placed on the adoption of biofuels (Mahalana, 2021). The Climate Transparency Report (2022) reported that the market share of electric vehicles in Indonesia accounted for only 0.02% of total vehicle sales in 2021 (Climate Transparency Report: Comparing G20 Climate Action, 2022). By November 2024, Indonesia had 195,084 electric vehicles in operation (Nurhuda, 2024), compared with 164,136,793 registered vehicles nationwide (Novelion, 2024), representing an electrification rate of approximately 0.12%. Of this electric vehicle population, as of July 2025, only 495 electric buses and 404 electric trucks were operating in Indonesia. Although these numbers continue to increase, the market penetration of electric vehicles remains extremely limited, accounting for well below 1% of the national vehicle fleet (Bin Ahmad et al., 2022; Dalkic-Melek et al., 2025; Goulias & Shi, 2023; Muratori et al., 2025; Razmjoo et al., 2022).

Therefore, the electric vehicle industry, particularly the commercial electric vehicle segment—including electric buses and electric trucks—plays a critical role in achieving the NZE 2060 target. Increasing the number of electric buses and trucks to replace internal combustion engine (ICE) buses and trucks has the potential to generate substantial emissions reductions because heavy-duty ICE vehicles are among the largest contributors to carbon emissions in the road transport sector.

Several critical research gaps motivate this study. First, most electric vehicle adoption research focuses on passenger vehicles, overlooking commercial electric vehicles, such as buses and trucks, which exhibit distinct adoption dynamics influenced by fleet operations and the Total Cost of Ownership (TCO). Second, existing studies typically evaluate individual policy instruments in isolation rather than examining the combined effects of VAT incentives, fuel price reforms, and electricity tariff policies within a unified analytical framework. Third, previous studies predominantly rely on static or econometric approaches that cannot adequately capture the dynamic feedback mechanisms inherent in the adoption process, including the reinforcing effects of manufacturing scale expansion and economies of scale. Finally, despite Indonesia's ambitious NZE commitments, quantitative modeling of commercial electric vehicle adoption trajectories within Indonesia's unique policy, economic, and infrastructural context remains limited.

Based on these conditions, this study aims to investigate the current state of NZE implementation in Indonesia's commercial electric vehicle industry, identify the key variables influencing commercial electric vehicle adoption, and analyze the relationships among these variables using a System Dynamics approach. By simulating various policy scenarios and

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changes in critical variables, the study evaluates their impacts on commercial electric vehicle adoption and provides strategic recommendations to support Indonesia's transition toward its Net Zero Emissions 2060 target. The study is limited to government policies related to energy efficiency and commercial electric vehicle adoption under the Enhanced Nationally Determined Contribution (ENDC) 2022 framework.

The expected contributions of this research are threefold. Theoretically, this study extends the application of System Dynamics modeling to commercial electric vehicle adoption in the Indonesian context by demonstrating how feedback loops and nonlinear system behavior influence policy effectiveness. Practically, the findings provide policymakers with a quantitative basis for designing effective combinations of policy instruments to accelerate commercial electric vehicle adoption. From a policy perspective, the study offers evidence-based recommendations for prioritizing policy interventions, highlighting the greater effectiveness of fuel price reform relative to other fiscal incentives in promoting the transition to commercial electric vehicles.

METHOD

This research examined the impact of Indonesia's Net Zero Emissions (NZE) 2060 initiatives on the adoption of commercial electric buses using a System Dynamics approach. A simulation model was developed in Vensim® PLE 10.3.1 based on Causal Loop Diagrams (CLDs) and Stock-and-Flow Diagrams (SFDs). The CLD identified five reinforcing loops: Initial Capital Expenditure (R1), Financing Options (R2), Charging Infrastructure (R3), Social Awareness (R4), and Technology (R5), as illustrated in Figure 1.

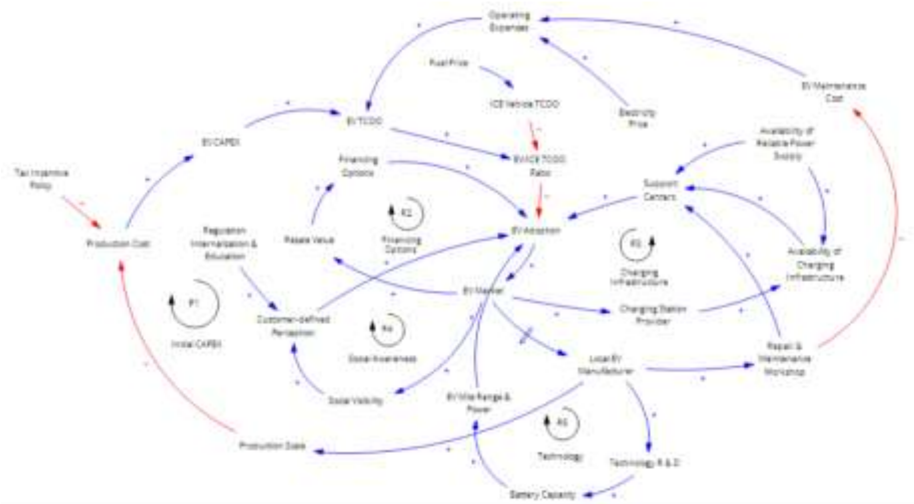

Figure 1: Causal Loop Diagram

Source: Author's Data

In quantitative behavious analysis, the Author analyzes correlation of components affecting the R1 (Initial CAPEX) to formulate the SFD, resulting 2 (two) stocks, i.e.:

1. EV Market

$$\text{EV Market}(t) = \int_{t_0}^{t} [\text{EV Adoption Rate}(t) - \text{EV Decaying Rate}(t)]dt + \text{EV Market}(t_0) \ldots (1)$$

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And referring to the same approach by Raoofi for charging station availability sector (Raoofi et al., 2025), Reinforcing Loop 1 – Initial CAPEX model the delay of two interconnected stocks, capturing the dynamics of Under Construction Local EV Manufacturer (UCM) and the Installed Local EV Manufacturer (IM) shown in below equations:

2. Finished Local EV Manufacturer

$$\mathrm{UCM}(t) = \int_{t_0}^{t} [\mathrm{BM}(t) - \mathrm{FM}(t)]dt \ldots (2)$$

$$\mathrm{IM}(t) = \int_{t_0}^{t} [\mathrm{FM}(t)]dt + \mathrm{IM}(t_0) \ldots (3)$$

Where, at time t, BM(t) represents the number of local EV manufacturers under development, FM(t) represents the number of completed local EV manufacturers, and $\mathrm{IM}(t_0)$ represents the initial number of existing local EV manufacturers. Figure 2 presents the Stock-and-Flow Diagram (SFD) developed in Vensim® to simulate commercial electric vehicle adoption in Indonesia. To improve model efficiency, several scenario-related variables were simplified or combined while preserving their ability to represent the corresponding policy scenarios accurately.

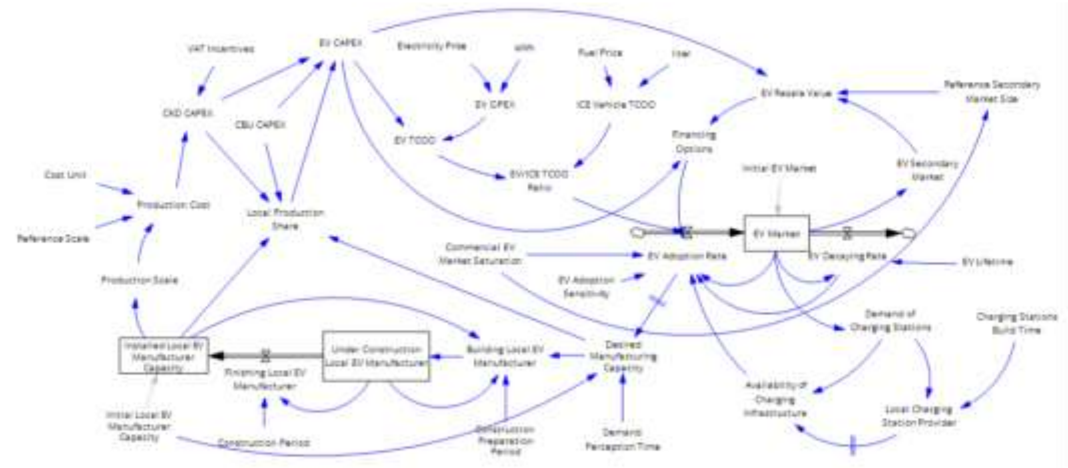

Figure 2: Stock and Flow Diagram

Source: Author's development using Vensim® PLE 10.3.1 (Sterman, 2000; Raoofi et al., 2025).

The model evaluated 17 policy scenarios for the 2026–2060 period based on three key policy instruments in Indonesia's 2022 Enhanced Nationally Determined Contribution (ENDC): VAT incentives, fuel price reform, and electricity tariff adjustments. Starting from 723 electric buses in operation in 2025, the baseline scenario projected that only approximately 8,925 electric buses would be operating by 2060, indicating that existing policies alone were insufficient to achieve the NZE target.

The findings showed that the Total Cost of Ownership (TCO) was the most influential factor affecting commercial electric vehicle adoption. Electric vehicle capital costs were influenced by VAT incentives, while operating costs depended primarily on electricity tariffs. In contrast, the operating costs of internal combustion engine (ICE) vehicles were largely driven by fuel prices. The model demonstrated that the relative cost competitiveness between

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electric and conventional vehicles was the primary driver of adoption, while charging infrastructure, domestic manufacturing capacity, and financing availability further supported market growth.

RESULT AND DISCUSSION

Model Verification and Model Validation

A model's goal is to help make better decisions, decisions informed by the best available model. Instead of viewing validation as a testing step after a model is completed, it recognizes that theory building and theory testing are intimately intertwined in an iterative loop. Instead of presenting evidence that the model is valid, good modelers focus the client on the limitations of the model so it can be improved and so clients will not misuse it (Sterman, 2000).

Model Verification

Verifying the model in Vensim is conducted in two ways, i.e. Units checking and Model checking. As mentioned earlier that each variable has their own unit, units checking are needed to be done to see the consistency of each variable since they are connected in the SFD. Further, model checking is required to examine if the formulas are workable in connecting related variables. The next Figures showing that the unit checking and model checking of the SFD by Vensim software are OK.

Figure 3: Units Checking

Figure 4: Model Checking

Source: Vensim® PLE 10.3.1 software output

Model Validation

Model Validation is conducted to see whether the model is able to reflect real-life or actual condition. Indonesian Ministry of Industry on February 2026 reported the registered electric bus and electric trucks between 2020 and 2025 are as follow:

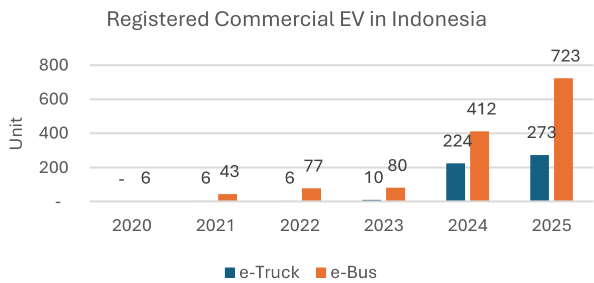

Figure 5: Registered Commercial EV in Indonesia 2020-2025

Source: Indonesian Ministry of Industry, 2026)

Although there were significant increase of adoption to electric bus since 2022, but lack data of the reasons of this hike other than that the Governor of Jakarta has issued the Decree of Jakarta Governor No. 1053 Year 2022 to initiate the replacement of TransJakarta ICE bus fleet

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to electric bus fleet, gradually until 100% EV adoption in 2030. It was more policy-driven instead of economic-driven and hardly used as validation to the model. Hence, validation testing to the model will be conducted into extreme condition testing and proxy data from other countries.

Extreme Condition Test

1. Extreme Test X1: Fuel Price : IDR 0/liter (free bio solar), which should create disincentive ICE Vehicle users to shift to EV, leads to zero EV Adoption Rate and decreasing EV Market from 723 Vehicles.

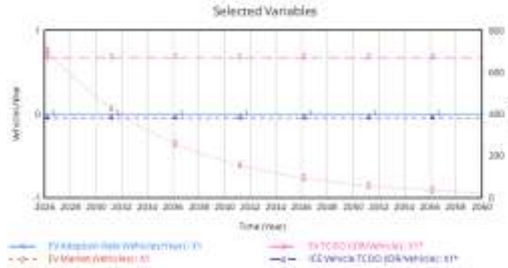

Figure 6: Extreme Test X1: Fuel Price = IDR 0/l

Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

2. Electricity Price : IDR 2,500/kWh (maximum tariff in public charging station), which should create disincentive ICE Vehicle users to shift to EV, leads to zero EV Adoption Rate and decreasing EV Market from recently 723 Vehicles.

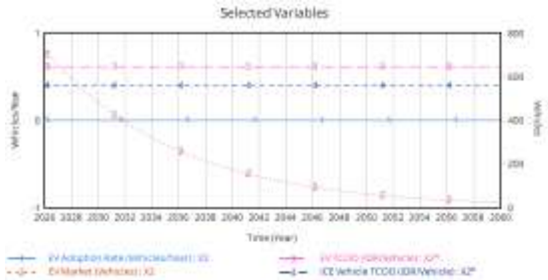

Figure 7: Extreme Test X2: Electricity Price = IDR 2,500/kWh (public charging station tariff)

Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

3. Fuel Price at Industrial Tariff (IDR 25,750/l) with limit of CKD Price is 50% of lowest CKD Price in Baseline to reflect economies of scale to the production cost and set the Commercial EV Market Saturation from presumably 132,000 Vehicles in 2060 to 1,000,000 Vehicles. It should make ICE Vehicle TCOO to be much higher than EV TCOO, leads to significant EV Adoption, give economic-driver for local manufacturer to build manufacturing facility locally, eventually increasing production scale and reducing production cost. Nevertheless, the S-Curve will reach its saturation at 1,000,000 Vehicles much longer than assumed maturation of 132,000 Vehicles in 2060 since the EV Market will keep growing and local manufacturing capacity will be built until nearly fulfill the market saturation.

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Figure 8: Extreme Test X3: Fuel Price = IDR 25,750 (Industrial Fuel) with 1,000,000 Market Saturation
Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

4. Extreme Text X4: VAT Incentives : 12% (full VAT exemption), which should reduce the CKD CAPEX of EV and lower its TCOO against ICE Vehicle TCOO. It will lead to EV Adoption and increase the EV Market. However, it may not automatically increase local manufacturer capacity.

Figure 9: Extreme Text X4: VAT Incentives = 12%
Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

Practice in Other Countries – China

Globally, China has the highest electric bus shares on total bus sales compare to other countries in the world, which 62% of operated bus in China are electric (The International Energy Agency, 2026). Further, China also the largest electric buses market in the world while at the same time is the leading electric bus manufacturer. There are around 780,000 electric buses were operated in the world in 2024, which 90% of it (around 700,000) are operated in China. Between 2014 and 2018, China had massive adoption of electric buses, from less than 10% electric bus share on total bus sales in 2014 to 65% in 2018, as shown in the following Figure 10 (Jaeger, 2025).

It was started few years back when China initiatied subsidy program for eletric buses in 10 pilot cities in 2009 which later implemented to 88 other cities in 2013. In doing so, China created regulations that constraint the operations of ICE bus, i.e. through purhase restrictions (license plate restriction policies or regular fuel vehicle restriction policies) and use restrictions, but also implement incentives for electric buses adoption mainly through subsidy, i.e. local purchase subsidies, charging subsidies, and national purchase subsidy (Yao et al., 2022). The following Figure 10 shows the electric bus shares on total bus sales in the time frame when the above combination policies of ICE bus restriction and electric bus incentive policies were implemented.

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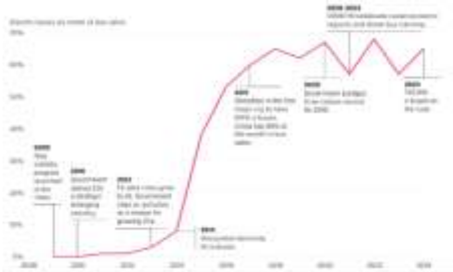

Figure 10: China Electric Bus Shares on Total Bus Sales 2008 – 2024

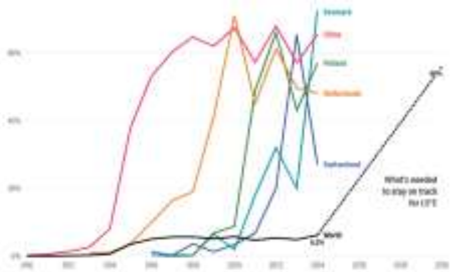

Figure 11: Electric Bus Shares on Total Bus Sales in Several Leading Countries on Electris Bus Adoptions

Source: Adapted from Jaeger, J. (2025). World Resources Institute

The above S-curve resulted from proper policy implementation between creating barriers for ICE bus while on the same time provide incentives to electric buses, also happen in European countries, i.e. Denmark, Finland, Netherlands and Switzerland as in the following Figure 11 (Jaeger, 2025). However, the time frame does matter, especially when in 2020 the world experienced global COVID-19 pandemic which also affected the sustaining growth of electric buses. While China's adoption was also policy-catalyzed, its S-curve shape and inflection dynamics are used here as a structure-oriented behavior test of the reinforcing-loop mechanism itself rather than as a test of the TCOO-driven baseline growth rate.

Proposed Implementation

Scenarios Development

Some exogenous variables will be made as proxies for scenarios development, following the Enhanced Nationally Determined Contribution mitigation in Energy Sector (Enhanced Nationally Determined Contribution Republic of Indonesia, 2022) are, as follows:

Table 1: Scenarios Development

Mitigation Actions	Relevant Variables	Unit	Scenarios
Energy Efficiency - Electric Vehicle	VAT Incentives	%	- 0% (Local Content: 0%) - 5% (Local Content: 20% - 40%) - 10% (Local Content: >40%)
Renewable Energy - Biofuel	Fuel Price	IDR/liter	- Bio Solar – Subsidy (IDR 6,800/liter) - Industrial Solar – B40 (IDR 25,750)
Renewable Energy - Direct Utilisation of Biomass and Biogas for off-grid power generation	Electricity Price	IDR/kWh	- Public Transport – Subsidy (IDR 731/kWh) - Biogas – REA (IDR 1,050/kWh) - Industrial Electricity (IDR 1600/kWh

Source: Developed by the author based on ENDC 2022

Initial data from Indonesian Ministry of Industry stated that until 2025, total population of electric bus and electric trucks are total 723 units and 273 units, respectively (Indonesian Ministry of Industry, 2026). As part of Enhanced NDC mitigation in the energy efficiency, i.e. increasing the population of electri vehicle, included but not limited to electri bus and electric trucks, the EV Adoption also related to not only CAPEX of the unit, but also the operational cost to operate the unit (OPEX). Altogether, EV CAPEX & EV OPEX will form a Total Cost of Ownership (TCOO) of an electric bus or electric truck which later comparable to the TCOO of Internal Combustion Engine (ICE) bus or truck.

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While the EV CAPEX is affected by VAT Incentives, the later EV OPEX is affected by the electricity price as well as ICE OPEX affected by fuel price, which are also part of the Enhanced NDC mitigation in Renewable Energy section. Further, some alternative values of related exogenous variables for simulation are defined as follow:

Table 2: Scenario Variables

Scenarios	VAT Incentives	Unit	Remarks
VAT_Base[1]	0%	%	Local Content <20%
VAT_1[2]	5%	%	Local Content 20% - 40%
VAT_2[3]	10%	%	Local Content >40%
Fuel_Base[4]	6,800	IDR/liter	Bio Solar - Subsidy
Fuel_1[5]	25,750	IDR/liter	Industrial Solar - HSD B-40
Electric_Base[6]	731	IDR/kWh	Public Transport Subsidy
Electric_1[7]	1,050	IDR/kWh	Biogas – REA
Electric_2[8]	1,600	IDR/kWh	Industrial Electricity

Source: Compiled from PMK No. 12/2025; Presidential Decree No. 112/2022; Pertamina Patra Niaga (2026).

[1] [2] [3] Decree of Finance Ministry of Indonesia No. 12 Year 2025

[4] 10 Jun 2026 (https://pertaminapatraniaga.com/page/harga-terbaru-bbm)

[5] 15-30 Jun 2026 (https://www.hargasolarindustri.com)

[6] [7] [8] Presidential Decree No. 112 Year 2022

Based on the above scenarios, configuration of each scenario will be run following the scenario configuration in the Table 3, which total 18 scenarios, included the Baseline.

Table 3: Scenarios Configuration

Scenarios	VAT Incentives	Fuel Price	Electricity Price	Remarks
Baseline	0%	Bio Solar - Subsidy	Public Tansport Subsidy	
S1	5%	Base	Base	**VAT Effect**
S2	10%	Base	Base	**VAT Effect**
S3	Base	Industrial Solar - HSD B-40	Base	**Fuel Price Effect**
S4	Base	Base	REA Biogas	**Electricity Price Effect**
S5	Base	Base	Industrial Electricity	**Electricity Price Effect**
S6	5%	Industrial Solar - HSD B-40	Base	**VAT & Fuel Effect**
S7	10%	Industrial Solar - HSD B-40	Base	**VAT & Fuel Effect**
S8	5%	Base	REA Biogas	**VAT & Electricity Effect**
S9	5%	Base	Industrial Electricity	**VAT & Electricity Effect**
S10	10%	Base	REA Biogas	**VAT & Electricity Effect**
S11	10%	Base	Industrial Electricity	**VAT & Electricity Effect**
S12	Base	Industrial Solar - HSD B-40	REA Biogas	**Fuel & Electricity Effect**
S13	Base	Industrial Solar - HSD B-40	Industrial Electricity	**Fuel & Electricity Effect**
S14	5%	Industrial Solar - HSD B-40	REA Biogas	**VAT, Fuel, Electricity Effect**
S15	5%	Industrial Solar - HSD B-40	Industrial Electricity	**VAT, Fuel, Electricity Effect**
S16	10%	Industrial Solar - HSD B-40	REA Biogas	**VAT, Fuel, Electricity Effect**
S17	10%	Industrial Solar - HSD B-40	Industrial Electricity	**VAT, Fuel, Electricity Effect**

Source: Developed by the author based on Table 2

1. Initial Condition (Baseline)

Baseline is initial condition of commercial EV industry in Indonesia where no incentives in fiscal policy, i.e. VAT exemption for commercial EV with local content, continued access

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to the IDR 731/kWh public transport electricity tariff (where in fact recent electric buses is mostly operated under municipal-owned enterprises providing public transportation so that they can receive the public transport subsidy electricity tariff). On the other hand, ICE vehicles can still use bio-solar subsidy.

2. VAT Incentives Effect

Government of Indonesia has provided regulations under the Decree of Finance Ministry of Indonesia No. 12 Year 2025 which providing Tax exemption of 5% and 10%, each for commercial EV with 20% to 40% local content and more than 40% local content. Specifically, criteria of the local content are bound under the Decree of Industrial Ministry of Indonesia No. 6 Year 2022. The implementation of these regulations will reduce the commercial EV price by lowering the VAT for products that meet the criteria required under the regulations. Hence, beside the Baselie scenario where there is 0% VAT Incentives, which means that the Company will have to bear 12% VAT, the scenarios built for this VAT Incentives Effect are as follow:

a. Scenario 1 : 5% VAT Incentives (effective VAT: 7%)
b. Scenario 2 : 10% VAT Incentives (effective VAT: 2%)

3. Fuel Price Effect

The use of Subsidy Bio Solar instead of Industrial Solar is increasing the State Budget burden to cover industrial activity instead of allocate the budget for public goods. Hence, instead of using Subsidy Bio Solar which only IDR 6,800/liter, the scenario build for this Fuel Price Effect will be only for the Company to use Industrial Solar for High Speed Diesel (HSD) B40, i.e.:

a. Scenario 3 : IDR 25,750/liter, Industrial Solar – HSD B-40

4. Electricity Price Effect

Recently, out of 723 electric buses operated in Indonesia until end of 2025, more than 50% (470 units) are being operated by TransJakarta, a municipal owned enterprises in Jakarta, to provide public transportation services. Hence, TransJakarta enjoys the electricity price of public transport subsidy, i.e. IDR 731/kWh. There are also other companies not for public transportation industry, i.e. in plantation or mining industry which will have no opportunity for public transport subsidy, instead have to rely on other electricity sources, either by building independent power station on their mining/site area or by taking industrial electricity rate provided by PLN.

Hence, there are two scenarios from this effect, i.e.:

a. Scenario 4 : IDR 1,050/kWh, using Renewable Energy Agreement rate estimated from the regulation under the Presidential Decree No. 112 Year 2022;
b. Scenario 5 : IDR 1,600/kWh, using Industrial Electricity price decided by the Ministry of Energy and Mineral Resources

5. VAT & Fuel Price Effect

A Company could also been affected, or a policy could also impact, on more than just one effect. A Companny could have bought an electric bus which has certain percentage of local content so could benefit them with lower price resulting from 5% or 10% VAT incentives and operate them with Public Transport Subsidy. On the other hand, this electric vehicle will replace their ICE vehicle which use Industrial Solar – HSD B-40. This efffect will be simulated under Scenario 6 and Scenario 7 as follows:

a. Scenario 6 : 5% VAT Incentive & Industrial Solar – HSD B-40

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b. Scenario 7 : 10% VAT Incentive & Industrial Solar – HSD B-40

6. VAT & Electricity Price Effect

The impact of VAT Incentives combined with alternative power station and industrial elctricity is simulated under the following scenarios, i.e.:

a. Scenario 8 : 5% VAT Incentives & electricity sources from REA tariff
b. Scenario 9 : 5% VAT Incentives & electricity with industrial rate from PLN
c. Scenario 10 : 10% VAT Incentives & electricity sources from REA tariff
d. Scenario 11 : 10% VAT Incentives & electricity with industrial rate from PLN

7. Fuel & Electricity Price Effect

There is also a possibility for a policy when the industry should take industrial solar with HSD B-40 for their ICE vehicle by buying commercial EV without receiving any VAT incentives due to unqualified local content in the product. On the other hand, if they are about to shift to commercial EV, they need to use renewable energy sources or industrial electriciy since they are not operating for public transportation services. Hence, this effect will be simulated under the following scenarios:

a. Scenario 12 : ICE with Industrial Solar – HSD B-40 price & electricity using renewable energy tariff
b. Scenario 13 : ICE with Industrial Solar – HSD B-40 price & electricity using industrial tariff

8. VAT, Fuel & Electricity Price Effect

Finally, once the local manufacturer could fulfill the requirement to earn VAT Incentives of their product and provide it to the buyer, while they also have to absorb the Industrial solar tariff if they still use ICE, but don't have the right to public transportation subsidy as their electricity price, the possibly scenarios are as follow:

a. Scenario 14 : 5% VAT Incentives & Industrial Solar – HSD B-40 & renewable energy electricity price
b. Scenario 15 : 5% VAT Incentives & Industrial Solar – HSD B-40 & industrial electricity price
c. Scenario 16 : 10% VAT Incentives & Industrial Solar – HSD B-40 & renewable energy electricity price
d. Scenario 17 : 10% VAT Incentives & Industrial Solar – HSD B-40 & industrial electricity price

Scenario Simulation Results

The following sections are the results of simulations for each scenario described in Table 3 using Vensim Software.

1. Initial Condition (Baseline)

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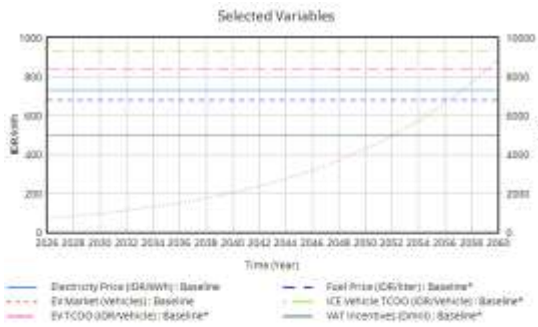

Figure 12: Baseline Scenario Assumptions

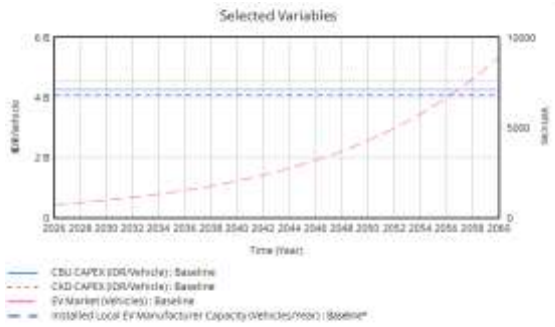

Figure 13: Baseline EV Market & Installed Local EV Manufacturer

Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

Figure 12 shows the Baseline scenario assumptions where nothing happens on the policy or the price, built on base assumptions in Table 2, where VAT Incentives = 0%; Fuel Price using Bio Solar – Subsidy = IDR 6,800/liter and Electricity Price from Public Transportation Subsidy = IDR 731/kWh. Within these assumptions, the EV TCOO is lower than ICE Vehicle TCOO which leads the EV Market increasing up to around 8,925 units in 2060. Nevertheless, the market growth is merely driven by EV CBU CAPEX which lower than EV CKD CAPEX resulting that no increasing Local EV Manufacturer which capacity remains 4,100 unit/year as in end of 2025, shown as flat line of Installed Local EV Manufacturer Capacity in Figure 13.

2. VAT Incentives Effect

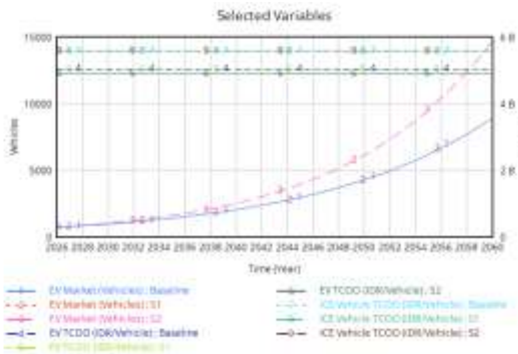

Figure 14: VAT Effect Scenario Results

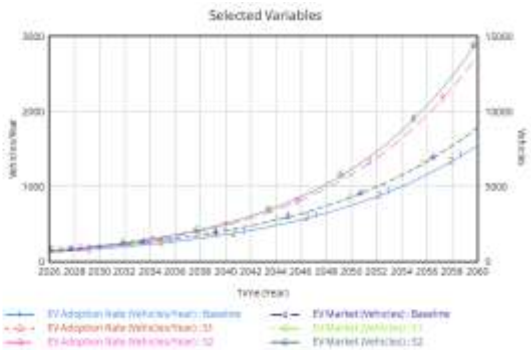

Figure 15: VAT Effect on EV Market & Adoption Rate

Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

Based on the VAT Effect scenarios of 5% VAT Incentives (Scenario 1) and 10% VAT Incentives (Scenario 2), the EV Market is higher in Scenario 2, while EV Market in Scenario 1 remains the same with Baseline. Figure 14 shows that 10% VAT Incentives slightly lowering the EV TCOO in Scenario 2 leads to increasing demand and thus increasing the EV Market up to 14,700 units in 2060. While in Scenario 1, with 5% VAT Incentives, the EV CKD CAPEX is still slightly higher than EV CBU CAPEX resulting in the market still choosing to buy from CBU instead of CKD, thus the EV Market in Scenario 1 is the same with Baseline.

Nevertheless, increasing EV Market in Scenario 2 until 14,700 units of electric bus only require EV Adoption Rate of 2,745 Vehicles/year in 2060 which can still be fulfilled with recently 4,100 unit/year local manufacturer capacity since no significant annual demand could tease local manufacturer to build more manufacturing plant. It is as shown in Figure 15 as the increasing EV Adoption Rate never exceeds 4,100 Vehicles/year, both in Scenario 1 and Scenario 2.

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3. Fuel Price Effect

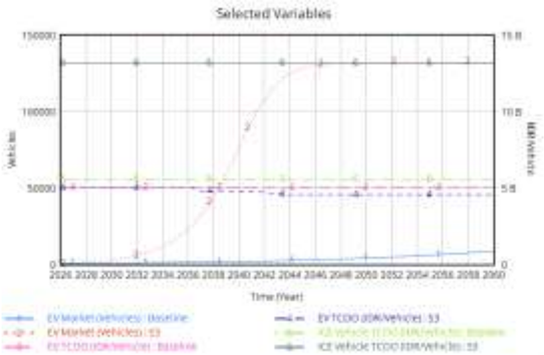

Figure 16: Fuel Price Effect Scenario Results

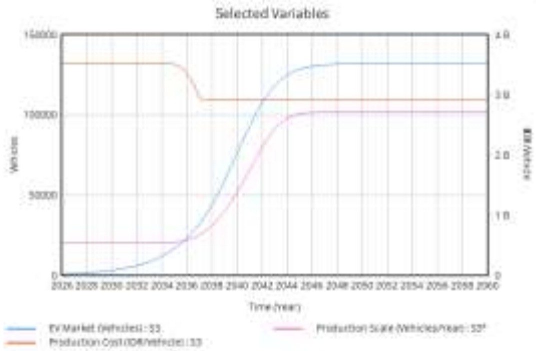

Figure 17: Fuel Price Effect on EV Market & Production Cost

Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

Customers without access or permit to use Bio Solar – Subsidy price of IDR 6,800/liter, may be constrained to use Industrial Solar of IDR 25,750/liter, the ICE Vehicle TCOO in Scenario 3 will increase significantly compared to EV TCOO. It leads the customer to huge shift from operating ICE Vehicle to operating Commercial EV so that the EV Market will started to reach its assumed market saturation of 132,000 units since 2048 onwards as shown in Figure 16. Notably, the saturation ceiling is a structural assumption, not a model output, and the primary uncertainty in the long-run equilibrium is the validity of the 132,000-unit projection, not the feedback dynamics that drive EV Market toward it.

Such significantly increasing demand for EV creates opportunities for local manufacturers to build manufacturing facilities to grab the market and thus increase the production scale and reduce the production cost of EV CKD CAPEX. The following Figure 17 shows how significantly increasing annual demand is more than recent manufacturing capacity of 4,100 unit/year which leads to increasing production scale from new manufacturing facility which further creates economies of scale so that production cost can be lowered to certain level. This lower production cost drives even lower EV TCOO that creates more EV demand by the market showing the reinforcing loop until the EV Market reaches its saturation, which shown as S-Curve. Although there is a certain limit of production cost that local manufacturer could reach despite how much demand is in the market. Hence, the increasing demand of EV mostly comes from effect of external factors, i.e. increasing ICE Vehicle TCOO due to the fuel price effect instead of lower EV CAPEX or EV TCOO.

4. Electricity Price Effect

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Figure 18: Electricity Price Effect Scenario Results
Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

Increasing electricity price will indeed increase the EV TCOO. At certain level, it will still create demand for EV although with low growth, as in Scenario 4 when the customer could not have access or not eligible for Public Transport Subsidy of IDR 731/kWh, but has the opportunity to use Renewable Energy Biogas with IDR 1,050 kWh.

However, for customers could only eligible for Industrial Electricity tariff with IDR 1,600 kWh, the EV TCOO will exceed ICE Vehicle TCOO so no addition EV Adoption is achieved. Existing EV Market will decrease along with 10-year of EV Lifetime.

5. VAT & Fuel Price Effect

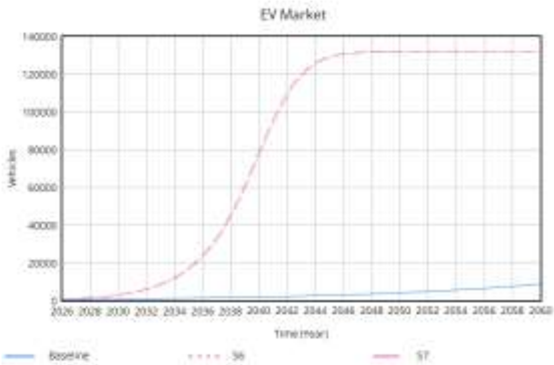

Figure 19: VAT Incentives and Fuel Price Effect Scenario Results
Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

Scenarios combination between VAT Incentives and Fuel Price Effect with Industrial Solar – HSD B-40 price of IDR 25,750/liter is most highly affected by the fuel price effect. It can be seen in the above Figure 19 where 5% VAT Incentives (S6) and 10% VAT Incentives (S7) is merely the same showing the significant EV Market growth reaching its saturation since nearly 2046. Hence, the analysis is merely the same with Figure 16 of Fuel Price Effect.

6. VAT & Electricity Price Effect

Figure 20: VAT Incentives and Electricity Price Effect Scenario Results
Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

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Scenarios combination between VAT Incentives and Electricity Price is highly affected to the electricity price changes. In the Scenario 10, even with 10% VAT Incentives, using IDR 1,050/kWh Biogas Renewable Energy electricity tariff will still decreasing the EV Market since the EV TCOO is dragged down by increasing electricity tariff. Let alone the rest Scenario 9 with only 5% VAT Incentives or Scenario 10 & Scenario 11 with higher IDR 1,600 kWh Industrial Electricity tariff which leads to lower EV Market growth or even zero growth as in Scenario 10 & Scenario 11.

7. Fuel & Electricity Price Effect

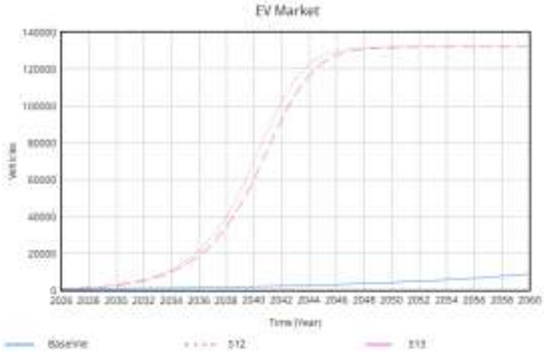

Figure 21: Fuel & Electricity Price Effect Scenario Results

Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

Scenario combination of Fuel and Electricity Price is surely most driven by the Fuel Price especially with expensive IDR 25,750/liter of Industrial Solar – HSD B-40, which leads to significantly increasing demand of EV creates opportunities for local manufacturers to build manufacturing facilities to grab the market and thus increase the production scale and reduce the production cost of EV CKD CAPEX. This lower production cost drives even lower EV TCOO that creates more EV demand by the market showing the reinforcing loop until the EV Market reaches its saturation, which shown as S-Curve in Figure 21 above. Higher Electricity Price using Industrial Electricity compare to Biogas Renewable Energy tariff will only slightly lowering the S-Curve

8. VAT, Fuel & Electricity Price Effect

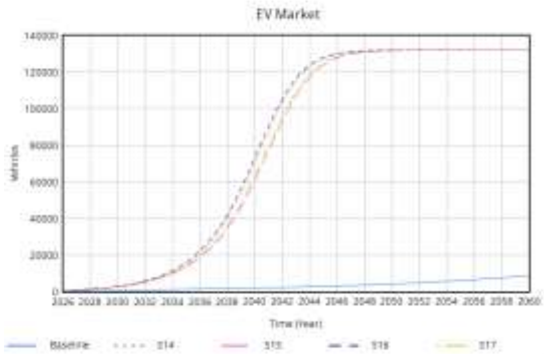

Figure 22: VAT, Fuel & Electricity Price Effect Scenario Results

Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

Running all three exogenous variables simultaneously, the effect of high fuel cost reflecting from expensive Industrial Solar – HSD B-40 leads the EV Market to significantly increase. Low 5% VAT Incentives and high Industrial Electricity price will only affect the S-curve slightly.

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Summary of Scenario Results

Out of all 17 scenarios, some scenarios could boost the adoption of EV Market significantly until it reaches its saturation. Nevertheless, it is also important to see which of those scenarios result in the highest local EV manufacturing capacity. The following Figure 36 shows the results of each scenarios to the EV Market (Vehicles) and Local Manufacturing Capacity (Vehicles/Year) in 2060.

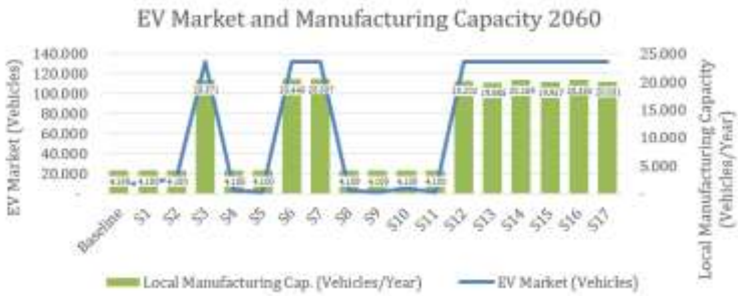

Figure 23: Scenarios Result Summary

Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

Some scenarios will reach the assumed EV market saturation in 2060, i.e. S3, S6, S7, S12, S13, S14, S15, S16, and S17. However, each of these scenarios result in different impact of local manufacturing capacity. Three amongst all scenarios with highest impact to the local manufacturing capacity are S3, S6 and S7.

Table 4: Scenarios Result Summary

Scenarios	EV Market 2060 (Vehicles)	Local Manufacturing Capacity (Vehicles/Year)	VAT Incentives	Fuel Price	Electricity Price
Baseline	8,925	4,100	0%	Bio Solar - Subsidy	Public Tansport Subsidy
S1	8,925	4,100	5%	Base	Base
S2	14,701	4,100	10%	Base	Base
S3	132,000	20,371	Base	Industrial Solar - HSD B-40	Base
S4	2,927	4,100	Base	Base	REA Biogas
S5	23	4,100	Base	Base	Industrial Electricity
S6	132,000	20,440	5%	Industrial Solar - HSD B-40	Base
S7	132,000	20,507	10%	Industrial Solar - HSD B-40	Base
S8	2,927	4,100	5%	Base	REA Biogas
S9	23	4,100	5%	Base	Industrial Electricity
S10	5,054	4,100	10%	Base	REA Biogas
S11	23	4,100	10%	Base	Industrial Electricity
S12	132,000	20,202	Base	Industrial Solar - HSD B-40	REA Biogas
S13	132,000	19,885	Base	Industrial Solar - HSD B-40	Industrial Electricity
S14	132,000	20,269	5%	Industrial Solar - HSD B-40	REA Biogas
S15	132,000	19,957	5%	Industrial Solar - HSD B-40	Industrial Electricity
S16	132,000	20,335	10%	Industrial Solar - HSD B-40	REA Biogas
S17	132,000	20,031	10%	Industrial Solar - HSD B-40	Industrial Electricity

Source: Simulation results using Vensim® PLE 10.3.1 (Author's data processing)

Best scenario in boosting the EV Market and increasing Local Manufacturing Capacity in 2060 is indeed the Scenario 7 with potentially reach the EV Market saturation and increase

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the Local Manufacturing Capacity up to 20,507 Vehicles/Year, which almost 5 (five) times of recent Local Manufacturing Capacity in end of 2025. Further, three best scenarios are the effect of the use of Industrial Solar instead of Subsidy Bio Solar for customers operating ICE Vehicles. Significant disparity between Industrial Solar price and Subsidy Bio Solar creates significantly higher ICE TCOO by higher Operational Cost of ICE Vehicles.

Commercial Electric Vehicles Emission Mitigation for Energy Sector in Indonesia Second Nationally Determined Contribution

Electric Vehicles was categorized as part of Subsector Energy Efficiency in the Sector Energy under the Enhanced Nationally Determined Contribution (ENDC) 2022, which target was 15,197,000 units under the Conditional Mitigation 1 (CM1). It is to achieve the emission reduction for unconditional target to 31.89% and conditional target to 43.20% against Business as Usual in 2030 (Enhanced Nationally Determined Contribution Republic of Indonesia, 2022). Further, under Second Nationally Determined Contribution (SNDC) 2025, the Government of Indonesia projected emission from each sector category and net emission for each scenario (Gg CO_2e) as in the following Table 5.

Table 5: Projected Net Emission in SNDC 2025

Scenario	Sector	2019	2025	2030	2035	2060
CPOS	Energy	655,568	1,032,127	1,310,969	1,419,126	1,561,764
	IPPU	63,729	74,658	79,465	93,580	109,397
	Waste	124,360	164,933	215,924	238,017	379,674
	Agriculture	79,996	79,572	79,457	79,634	83,504
	FOLU	221,384	133,675	94,635	-43,354	-247,434
Scenario	**Sector**	**2019**	**2025**	**2030**	**2035**	**2060**
LCCP_L	Energy	655,568	909,629	1,071,841	1,109,800	129,000
	IPPU	63,729	68,042	74,147	73,115	34,243
	Waste	124,360	164,905	215,750	168,477	9,069
	Agriculture	79,996	77,843	76,193	74,738	76,503
	FOLU	221,384	-12,886	-92,224	-168,412	-329,703
	Net Emission	**1,145,037**	**1,207,533**	**1,345,707**	**1,257,718**	**-80,888**
Scenario	**Sector**	**2019**	**2025**	**2030**	**2035**	**2060**
LCCP_H	Energy	655,568	964,610	1,239,463	1,336,312	129,000
	IPPU	63,729	70,656	78,960	78,304	34,375
	Waste	124,360	164,540	215,928	205,695	34,705
	Agriculture	79,996	77,570	75,708	75,452	78,307
	FOLU	221,384	-25,729	-118,585	-206,897	-347,540
	Net Emission	**1,145,037**	**1,251,647**	**1,491,474**	**1,488,866**	**-71,153**

Source: Indonesia Second NDC 2025 document

CPOS (Current Policy Scenario) or Conditional Mitigation 1 (CM1) of ENDC 2022, which scenario without additional measures. LCCP_L is Low Carbon Compatible with Paris Agreement target -1.5°C (LCCP) with projection of emission under LCCP is in line with 1.5°C as scenario with additional measures to achieve the NZE target in 2060 or sooner, with economic growth is assumed to reach 6.0% in 2030 and 6.7% in 2035. In this scenario, mitigation actions increase significantly with the assumption of funding, technology and capacity building support from international sources are available. LCCP_H is the same with

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LCCP_L, with additional measures to achieve the NZE target in 2060 or sooner with higher economic growth assumption of 7.0% in 2030 and 8.3% in 2035.

Since Electric Vehicle mitigation is under Sector Energy, emission projections growth/decline in Sector Energy can be seen in the following Table 6.

Table 6: Projected Net Emission in Sector Energy

Scenarios (Gg CO_2)	2019	2025	2030	2035	2060
CPOS	655,568	1,032,127	1,310,969	1,419,126	1,561,764
yoy increase/(decrease)		62,760	55,768	21,631	5,706
LCCP_L	655,568	909,629	1,071,841	1,109,800	129,000
yoy increase/(decrease)		42,344	32,442	7,592	(39,232)
LCCP_H	655,568	964,610	1,239,463	1,336,312	129,000
yoy increase/(decrease)		51,507	54,971	19,370	(48,292)

Source: Indonesia Second NDC 2025 document

In the context of CO_2 emission from ICE Vehicle bus, the calculation of emission refer to the Regulation of Industry Minister of Indonesia No. 48 Year 2020 regarding the Green Industry Standards for the Glass Packaging Industry as in the following :

Table 7: CO2 Emission Conversion per Bus

	Value
Conversion factor:	
- kg CO_2/TJ	74,100
- Net Calorific Value (NCV)	0.000036
- kg CO_2/liter	2.67
Mileage (liter/km)	0.33
Days operation per day (days)	360
Distance travelled per bus:	
- km per day	210
- km per year	75,600
Total emission per ICE Vehicle Bus:	
- kg-CO_2 per bus	66,551
- ton-CO_2 per bus	66.6

Source: Calculated based on Permenperin No. 48/2020

Hence, for every ICE Vehicle bus being replaced by electric bus, reduce 66.6 ton-CO_2 per year. Total emission reduced by applying policies to the best scenario (Scenario 7) can be seen as follow:

Table 8: Emission Reduction in S7 to SNDC 2025 Projection

Scenarios in SNDC 2025	2019	2025	2030	2035	2060
CPOS	655,568	1,032,127	1,310,969	1,419,126	1,561,764
yoy increase/(decrease)		62,760	55,768	21,631	5,706
LCCP_L	655,568	909,629	1,071,841	1,109,800	129,000
yoy increase/(decrease)		42,344	32,442	7,592	(39,232)
LCCP_H	655,568	964,610	1,239,463	1,336,312	129,000
yoy increase/(decrease)		51,507	54,971	19,370	(48,292)
Emission reduction per year from S7 (Gg CO_2)	**#N/A**	**#N/A**	**207**	**1,156**	**8,785**
- Compare to yoy increase/(decrease) in CPOS			0%	5%	154%

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Scenarios in SNDC 2025	2019	2025	2030	2035	2060
- Compare to yoy increase/(decrease) in LCPP_L			1%	15%	22%
- Compare to yoy increase/(decrease) in LCPP_H			0%	6%	18%

Source: Author's calculation based on simulation results and SNDC 2025

Table 8 shows that the annual emission reduction in 2060 from electric buses operated in Scenario 7 (8,785 Gg CO_2) could contribute 18% to 22% of year-on-year decrease in Scenario LCCP_H and LCCP_L in SNDC 2025.

Based on the CO_2 emission conversion factor specified in the Indonesian Ministry of Industry Regulation No. 48 of 2020, replacing one internal combustion engine (ICE) bus with an electric bus reduces approximately 66.6 tons of CO_2 emissions per year. Under the best-performing policy scenario (Scenario 7), the large-scale adoption of electric buses is projected to achieve an annual emission reduction of 8,785 Gg CO_2 by 2060, contributing approximately 18–22% of the annual emission reduction target projected under the LCCP_H and LCCP_L scenarios in Indonesia's Second Nationally Determined Contribution (SNDC) 2025.

CONCLUSION

This study evaluated the impact of Indonesia's Net Zero Emissions (NZE) 2060 policies on commercial electric bus adoption using a System Dynamics model. The findings showed that existing policies were insufficient to achieve substantial adoption under business-as-usual conditions, with only approximately 8,925 electric buses projected to be in operation by 2060. The Total Cost of Ownership (TCO) was identified as the primary factor influencing adoption, driven mainly by fuel prices, electricity tariffs, and vehicle costs. Among the simulated policy interventions, fuel subsidy removal proved to be the most effective, whereas VAT incentives provided only limited benefits unless combined with fuel price reform. The best-performing scenario, which combined a 10% VAT incentive with fuel subsidy removal, achieved the projected market saturation level, substantially expanded domestic manufacturing capacity, and was estimated to reduce CO_2 emissions by 18–22% relative to the projected 2060 baseline, highlighting fuel price reform as the most critical policy instrument for accelerating commercial electric bus adoption.

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