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Simulating EV Growth Scenarios in Jawa Madura Bali from 2024 to 2029: Balancing Power Grid Supply and Demand while Allocating Subsidies to Maintain Equilibrium

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Simulating EV Growth Scenarios in Jawa Madura Bali from 2024 to 2029: Balancing Power Grid Supply and Demand while Allocating Subsidies to Maintain Equilibrium

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Abstract: To regulate the growth of battery-based electric vehicles (BEVs) in Indonesia and mitigate their impact on the power grid's supply-demand balance, the government can adjust BEV regulations and offer subsidies. The Jawa-Madura-Bali (Jamali) electrical system, being the largest in Indonesia [1], faces the challenge of accommodating the increasing number of vehicles [2]. Subsequent to analyzing Jamali's electricity supply using data from the National Electricity Company (RUPTL) [3], simulations are constructed to model the grid's demand side. Input variables such as Jamali's population, internal combustion engine (ICE) and electric vehicle populations, initial charging time (ICT), slow- and fast-charging ratios, and BEV charge load curves are simulated. Scenario variables like supply capacity growth speed, vehicle population growth speed, subsidy impact on EV attractiveness, ICT, and fast-charging ratio are subsequently simulated for 2024-2029. Four key simulation outcomes are identified: the best-case scenario (Scenario 1776), achieves the highest EV growth with minimal grid disruption, resulting in a 45.38% EV percentage in 2029 and requiring an annual allocation of 492 billion rupiah to match supply with demand. The worst outcome scenario leads to a 23.12% EV percentage, necessitating 47.566 billion rupiah for EV subsidies in 2029. Additionally, the most and least probable scenarios based on literature research are evaluated. This simulation and its results provide insights into EV growth's impact on the grid's balance in one presidential term from 2024 to 2029 [4], aiding the government in planning regulations and subsidies effectively. Improving the simulation's accuracy depends on refining input variables over time.

Keywords: electric vehicle; power grid; supply demand balance; electrical grid; electricity demand simulation; electric vehicle subsidy; electric vehicle charge management;
electric vehicle growth simulation

1. Introduction

As Indonesia shifts from internal combustion engine (ICE) vehicles to battery-powered electric vehicles (BEVs), maintaining the growth of BEVs is essential to avoid disturbing the country's power grid balance. Given that the Jawa-Madura-Bali (Jamali) system is Indonesia's largest electrical system [1], and these islands host the highest total number of vehicles [2], it is imperative to simulate the accelerated growth of electric vehicles to evaluate its impact.

The analysis of the Jamali electricity supply involves utilizing data from the National Electricity Company's RUPTL [3]. Simulation of the grid's demand side incorporates various input variables, including the Jamali population, populations of internal combustion engine (ICE) vehicles and electric vehicles (EVs), initial charging time (ICT), the ratio between slow and fast charging, and the charge load curve for each vehicle type. Moreover, scenario variables such as the rate of growth in supply capacity, vehicle population growth, the impact of subsidies on EV attractiveness, ICT, and the fast-charging ratio are also simulated.

After analyzing the data and simulations for one presidential period of 2024-2029 [4], four key results stand out for analysis: The best-case scenario, which demonstrates the highest EV growth

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while maintaining the grid's supply-demand balance; the most likely scenario based on existing literature; the least likely scenario; and the worst-case scenario.

The inputs of this simulation are flexible to accommodate various requirements, and its outputs offer a framework for comprehending the influence of EV growth on the grid's supply-demand equilibrium from 2024 to 2029. Through an analysis of both the best and worst-case scenario outcomes, the government can formulate regulations and subsidies appropriately.

1.1. Jawa-Madura-Bali Power System (Grid Capacity and Peak Load Demand)

Figure 1. Jamali Power System [5].

The Jawa Bali grid system plays a vital role in providing power to the islands of Java and Bali in Indonesia, supporting their sizable populations and industrial sectors. With an installed capacity of 47,647 megawatts (MW) in 2023, it ranks among the most substantial electricity grids in Southeast Asia [1]. During that year, the system faced a peak load of approximately 40,223 MW during peak hours, indicating a relatively narrow margin between capacity and demand [1].

As of 2022, the population of the combined regions of Java and Bali in Indonesia is estimated to be around 157 million [6]. The expected population growth for Jawa and Bali regions to 2029 is projected to be significant, driven by factors such as natural population increase (births exceeding deaths) and migration from other parts of Indonesia to these regions. While specific population projections can vary depending on various factors and assumptions, it is estimated that the population of Jawa and Bali regions could surpass 164 million by 2029 (around 0,8% growth [6]).

However, the region's rapid economic expansion and urbanization are anticipated to drive an annual peak load increase of about 8% [1,7–14]. To accommodate this growth and ensure a dependable power supply, significant investments are being made in infrastructure and renewable energy sources to bolster the Jawa Bali grid system. The average capacity growth from 2014 to 2023 is 5.37% [1,7–14].

Table 1. Jamali System Supply and Demand Historical Data. [1,7–14].

Year	Total Installed Capacity in MW	Annual Change in %	Peak Demand Load in MW	Annual Change in %
2014	31,062		23,908	
2015	27,867	-10.29	24,269	1.51
2016	36,712	31.74	33,208	36.83
2017	36,517	-0.53	25,680	-22.67
2018	37,721	3.30	27,097	5.52
2019	40,174	6.50	26,657	-1.62
2020	40,685	1.27	24,420	-8.39

2021	41,743	2.60	25,852	5.86
2022	45,835	9.80	24,228	-6.28
2023	47,647	3.95	40,223	66.02
	Annual Change in average:	5.37	Annual Change in average:	8.53

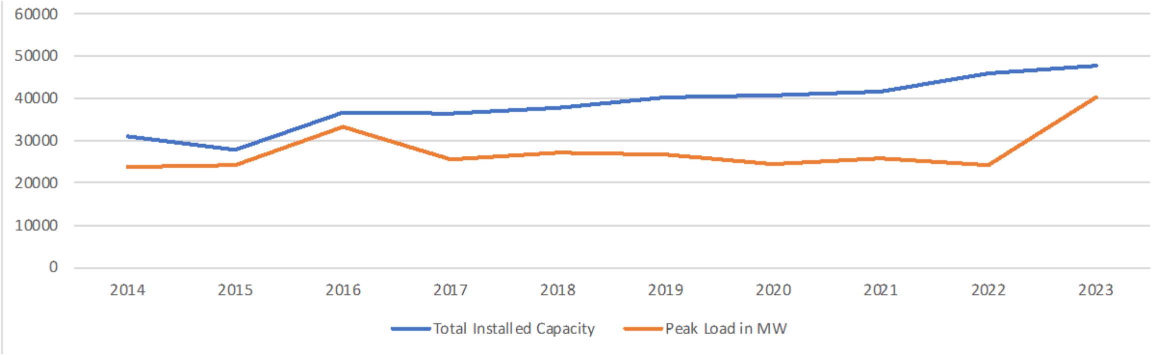

Figure 2. Jamali System Capacity and Peak Load Demand 2014-2023. [1,7–14].

Two key variables of Jamali system important for this simulation are Peak Load and Installed capacity. Peak Load represents the highest load reached by each system within a calendar year. Installed Capacity refers to the capacity of a single generating unit as indicated on the generator nameplate or prime mover, whichever is smaller [16]. Upon analyzing historical Supply-Demand data from the Jamali system, a notable increase in peak load is observed in 2023. This surge could suggest a rise in demand attributable to the growth of electric vehicles (EVs).

The peak load for the Jawa Bali grid system is usually during the day when demand is highest [17]. The peak load is driven by various factors, including the time of day, season, and economic activity. It is typically higher during the daytime as commercial and industrial activities are at their peak.

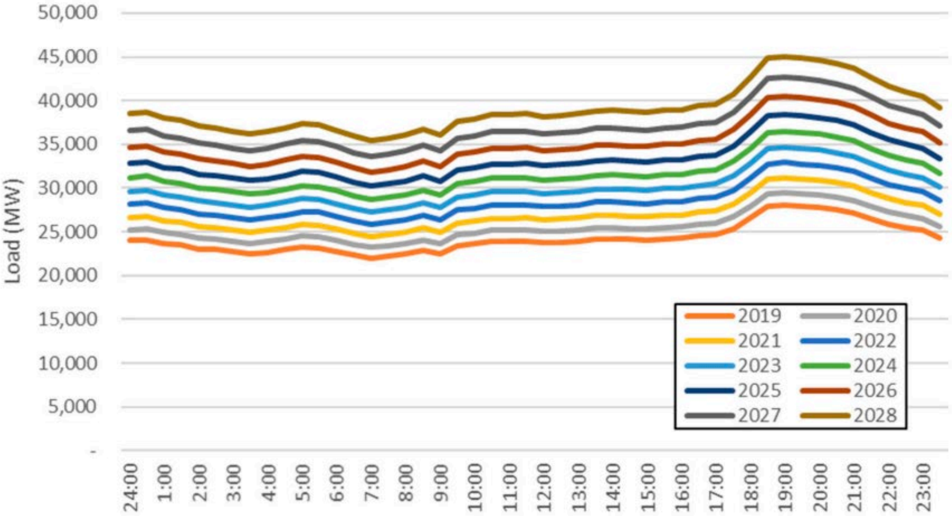

Figure 3. Jamali Hourly Peak Load. [17].

A crucial aspect of this simulation is the determination of the base peak load, which represents the electricity demand excluding the demand from electric vehicles (EVs). While obtaining this metric can be challenging, it can be estimated through extrapolation of historical data. Since the number of EVs before the introduction of subsidies and regulations in 2023 was minimal, their load demand was insignificant. Therefore, the peak load before that year can be closely regarded as the base peak load.

1.2. Java and Bali's EV Growth

The electric vehicle (EV) market in Indonesia is poised for significant growth over the next five years, with a range of factors driving this expansion. The government's supportive policies, including tax incentives and subsidies, are expected to encourage more consumers to switch to EVs [18]. Additionally, the country's commitment to reducing carbon emissions and addressing air pollution is likely to drive demand for cleaner transportation options.

In terms of EV preferences, the market in Indonesia is expected to be diverse. While there is a growing interest in luxury EVs, especially among affluent consumers in urban areas, there is also a significant demand for more affordable EVs that cater to daily commuting needs. In 2023, Hyundai sold 7,176 units of the Ioniq 5 and Wuling sold 5,575 units of the Air EV [19]. They have the highest sales number that year. This dual focus of market preferences is expected to shape the EV market in Indonesia, with manufacturers offering a range of EV models to meet different consumer needs.

Charging infrastructure is a crucial factor in the growth of the EV market and Indonesia is making efforts to expand its charging network. While slow-/home charging is more widely available and convenient for daily use, fast-/public charging stations are also being installed, particularly along major highways and in urban centers, to cater to longer trips and provide more flexibility to EV owners. As the charging infrastructure continues to improve, it is expected to further boost consumer confidence in EVs and drive their adoption in Indonesia. As the beginning of 2024, there are 1.124 public charger made available by PLN [20]. This does not count public charger made available by landowners or private companies.

1.3. Indonesia's EV Regulations and Subsidies

Indonesia has been implementing several regulations and incentives to encourage the adoption of electric vehicles (EVs) and address environmental and energy challenges. Some of these regulations include:

- Odd-even license plate policy: In major cities like Jakarta, the odd-even license plate policy restricts vehicles based on their license plate numbers on certain days. This measure aims to reduce traffic congestion and air pollution, indirectly encouraging the use of EVs. [21]
- Tax reduction: The government offers tax incentives for EVs, including lower import duties and luxury goods tax exemptions. These incentives make EVs more affordable for consumers and help stimulate the EV market. [22]
- Parking benefits: Some cities provide free or discounted parking for EVs to incentivize their use. This can reduce the overall cost of owning an EV and make them more attractive to consumers. [23]
- Charging infrastructure: The government has been investing in EV charging infrastructure to support the growth of the EV market. This includes installing charging stations in public areas and along highways. [20]

In terms of subsidies, the Indonesian government has implemented additional programs to expedite this transition. These include a 10% VAT tax deduction for four-wheeler electric vehicles (4wEV), as outlined in Ministry of Finance Regulation number 38 of 2023 [24], and an IDR 7,000,000 deduction for two-wheeler electric vehicles (2wEV), as specified in Ministry of Industry Regulation number 6 of 2023 [25].

The political landscape in Indonesia plays a crucial role in influencing the growth of electric vehicles (EVs) in the country. The regulations and subsidies pertaining to EVs until 2029 will be determined by the President elected in 2024, who will serve a single term of five years [4].

1.4. Current State of the Research Field

Previous research papers have explored various impacts of electric vehicle (EV) growth and proposed solutions. These include the use of Vehicle-to-Grid (V2G) technology [26], coordinated charging to manage load demand surges [27], and AI-based demand load prediction utilizing historical data [28], as well as factors like temperature, traffic [29], and user behavior data [30]. Additionally, some simulations have used a normal distribution for initial charging times [31].

The novelty of this simulation lies in its incorporation of additional growth factors and scenarios as inputs. Focused specifically on the Jawa Bali region, the simulation aims to forecast EV load based on growth projections, considering the region's distinct EV growth characteristics. The results of this simulation will provide valuable insights for policymakers regarding regulations and subsidies.

2. Materials and Methods

2.1. Data Gathering and Data Analysis

The analysis initiates with the acquisition of data pertaining to the present and anticipated growth of variables impacting both the supply and demand aspects of the grid. This data is imperative for the execution of the simulation.

2.1.1. Power Grid Capacity

Utilizing the National Electricity Company's data (RUPTL) [3], an analysis of the Jamali electricity supply can be conducted. The supply side of the grid is simulated by projecting the current capacity and a growth factor based on the RUPTL. The variables concerning the supply side include:

- Power Plant Capacity
- Power Plant Growth Factor

2.1.2. Demand Peak Load

The demand side of the grid contains two main components, which are the base peak load which is excluding electric vehicles load and the EV load itself. A demand simulation model for the EV load was created to calculate the total increase in demand load with a combination of ICE and Electric Vehicle population, initial charging time (ICT), the ratio between slow and fast charging, and the charge load curve of each type of vehicle using the data gathered. The variables related to the demand side and their values are as follows:

- Power Plant Capacity [1,7–14]
- Base Peak Load (excluding EV Load Demand) [1,7–14]
- Jamali Population [6]
- Personal Vehicle Population [32]
- Electric Vehicle Population Probability [33]
- 2- and 4Wheelers ratio [32]

Table 2. Demand side input variables values.

Variable	Label in Simulation	Value in 2024
Supply Side		
Power Plant Capacity	PowPlaCap_0	50,206,000 kW
Base Peak Load	BasPeaLoa_0	28,361,000 kW
Demand Side		
Java and Bali Population	JamPop_0	157,820,000
Personal Vehicle Population	TotVeh_0	89,757,134
EV Population Probability	PerEV_0	0.091%
2- and 4Wheelers Ratio	2w4wRat	120.04:16.41

2.1.3. Initial Charging Time

In the simulation of demand load, it is imperative to account for the Initial Charging Time (ICT), denoting the moment when EVs are connected to the grid for daily charging. For most EV users, ICT

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can be approximated as coinciding with the conclusion of their daily travel. As per the National Household Travel Survey (NHTS) findings, the distribution of end-of-travel times depicted in the graph conforms to a normal distribution [34]. Subsequently, the data for hourly Initial Charging Times is segmented into intervals of 12 minutes each (5 ICTs per hour, with a resolution of 12 minutes). The probability density function of the graph is presented as follows:

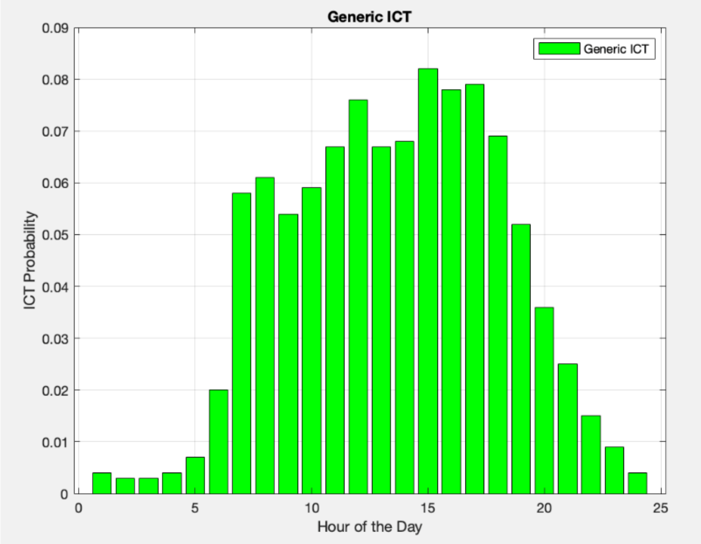


Figure 4. Generic Initial Charging Time.

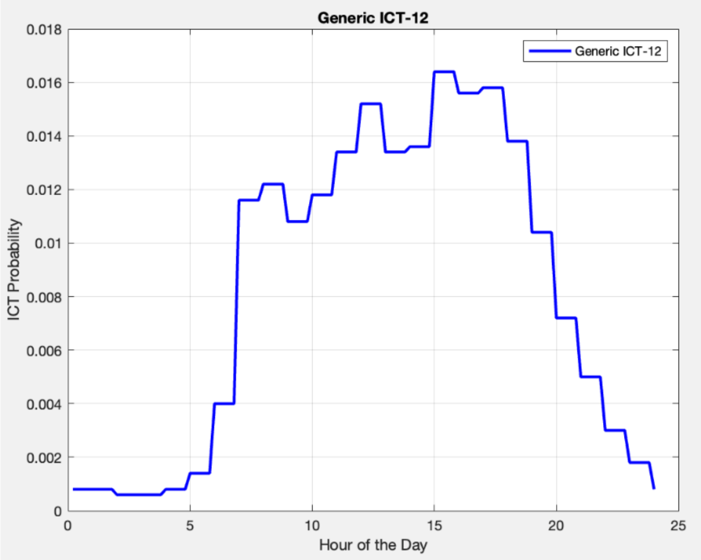


Figure 5. ICT with 12 minutes resultion.

2.1.4. Electric Vehicle’s Specification Details and Charge Curve

The total load demand will be divided into two categories: two types of four-wheelers EVs (4wEV) and two types of two-wheelers EVs (2wEV). Each category represents both a luxury and a daily-use type of vehicle for both four-wheeled and two-wheeled EVs. The samples are as follows:

- 2021 Hyundai Ioniq 5 Long Range
- 2023 Wuling Air EV Long Range
- 2022 United TX1800
- 2023 Viar new Q1L, with following specifications:

Table 3. EV Type Specifications.

Vehicle Type	Hyundai Ioniq 5 Long Range	Hyundai Ioniq 5 Long Range	Wuling Air EV Long Range	United TX1800	VIAR new Q1L
Label in Simulation	EVTyp1F	EVTyp1S	EVTyp2	EVTyp3	EVTyp4
Driving Range	450 km	450 km	300 km	65 km	60 km
Battery Size	72.6 kWh	72.6 kWh	26.7 kWh	1.68 kWh	1.38 kWh
DC Fast Charging Capability	Yes	Yes	No	No	No
Charging Duration	20 mins	720 mins	240 mins	90 mins	300 mins
Max Charging Load	224 kW DC	11 kW AC	6.6 kW AC	1.3 kW AC	0.24 kW AC
Daily Commute	30 km	30 km	30 km	30 km	30 km
Charge Frequency	15 days	15 days	10 days	2.17 days	2 days
Nationwide Yearly Sales in 2023	7,176 units	7,176 units	5,575 units	9,00 units	2,700 units
Production Start	2022	2022	2022	2022	2017

The charging load data for four-wheeled electric vehicles (4wEV) is based on the charge load curve of the 2021 Hyundai Ioniq5, which features a 72.6 kWh battery capacity [35]. The Hyundai Ioniq is Indonesia's top-selling 4wEV, with 7,176 units sold in 2023 [19]. During slow charging mode, the peak load of the Ioniq5 is 7.2 kW, while the peak demand during fast charging mode reaches 225 kW [35].

The frequency of charging for an electric vehicle (EV) is determined by the total travel distance covered per charge. For example, the IONIQ 5, with a range of 450 kilometers [35], divided by a norm of 30 kilometers traveled each day [36], would require charging approximately every 15 days. The graph below illustrates the charge curve of the IONIQ, measured during charging [37].

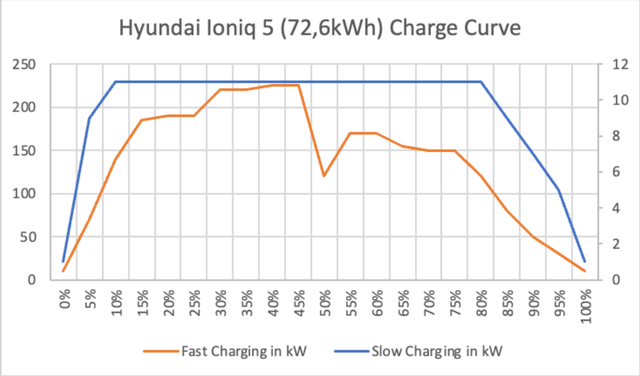


Figure 6. Hyundai Ioniq 5 Long Range Charge Curve.

Another source for charging load data for budget four-wheeled electric vehicles (4wEV) was obtained from the Wuling Air EV Long Range model [38]. The Air EV is the second best-selling 4wEV unit in 2023 [19]. Unlike the Ioniq5, it does not feature fast charging capability. Based on the average daily commute, the Wuling Air EV Long Range model requires charging approximately every 10 days.

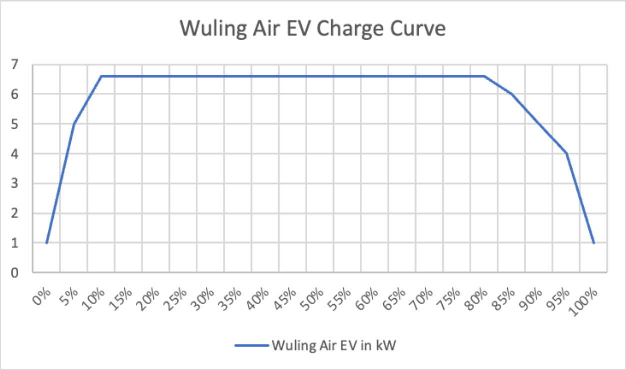


Figure 7. Wuling Air EV Long Range Charge Curve.

The total load from two-wheeled electric vehicles (2wEV) is calculated using charge load data obtained from the United TX1800 [39] and the budget-oriented VIAR new Q1L electric motorcycle, which was a pioneer of 2wEV in Indonesia in 2017 [40]. The United TX1800 has a 1300W charge peak [39], while the VIAR new Q1L has a 0.24 kW peak [40]. Daily distance traveled and initial charging time (ICT) are similar to the 4wEV load simulation. Generally, 2wEVs in Indonesia do not feature fast charging capabilities.

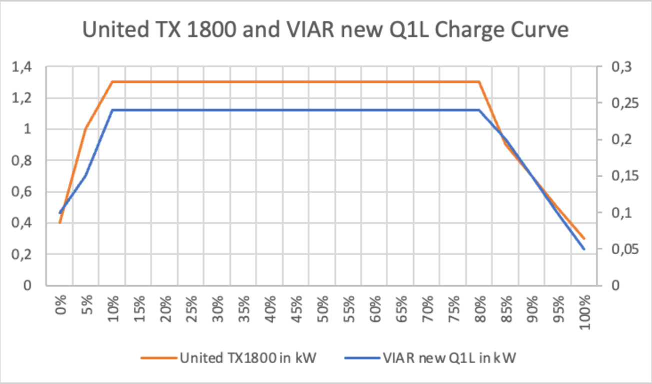


Figure 8. United TX 1800 and VIAR new Q1L Charge Curve.

These charge curves are utilized as inputs in the demand simulation. The total additional electricity demand from EVs is determined by the combination of the number and type of vehicles, ICT, and the fast/slow charging curve of each vehicle. The charge curves from each EV type used in the simulation are shown below:

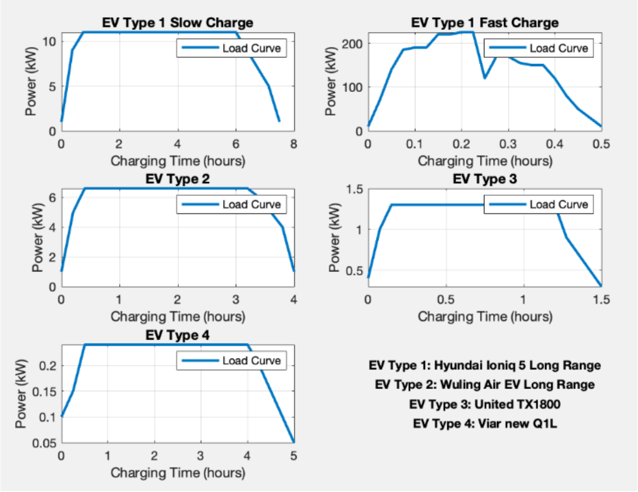


Figure 9. EV Charge Curves.

2.2. Supply-Demand Simulation

The collected data will be used as inputs in MATLAB and simulated in Simulink. The power plant capacity is used as the supply capacity in the simulation. The current capacity and its projected growth factor were obtained from the RUPTL PLN.

Actual Power Plant Capacity = Capacity in 2024 + (Number of Year x Capacity Growth Factor x Capacity in 2024) (1)

The base peak load, which excludes EV load, is also simulated using its current value and growth factor.

Actual Base Peak Load = Base Load in 2024 + (Number of Year x Base Load Growth Factor x Base Load in 2024) (2)

The demand load was calculated based on the Jamali population and its ratio to vehicle ownership. A certain percentage of these vehicles are EVs. The growth factor of EVs is influenced by their attractiveness and the impact of EV subsidies.

Actual Jawa Bali Population = Population in 2024 + (Number of Year x Population Growth Factor x Population in 2024) (3)

Actual Total Vehicle Population = (Actual Jawa Bali Population x Vehicle to Population Ratio) + (Number of Year x Vehicle Growth Factor x Total Vehicle Population in 2024) (4)

EV Growth Factor = EV Attractiveness Growth Factor + Subsidy Impact Growth Factor (5)

Actual EV Population = Total Vehicle Population x Total Vehicle to EV Ratio + (Number of Year x EV Population Growth Factor + EV Population in 2024 (6)

The demand simulation then progresses in Simulink. The simulations are conducted individually for each type of EV: including EVTyp_1F, EVTyp_1S, EVTyp2, EVTyp3, and EVTyp4.

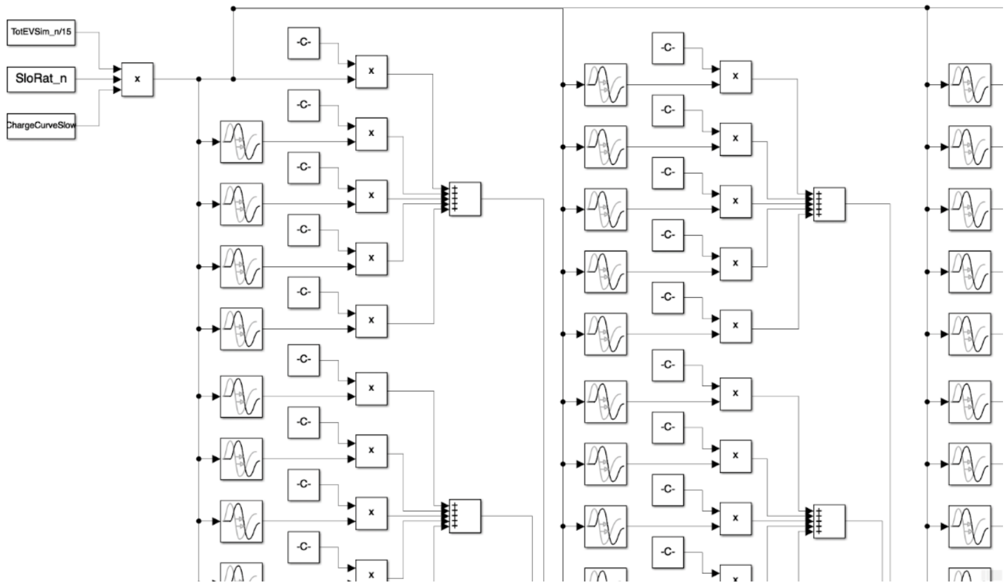


Figure 10. Simulink Model for EV Load Demand Simulation.

2.3. Scenario Permutations

In addition to the supply-demand simulations for the period 2024-2029, various scenarios are to be simulated. Each scenario involves variations in the growth speed of each supply-demand simulation's input variable. These variations in growth factors include:

- Power Plant Capacity Growth [1,7–14]

- Base Peak Load Growth Factor: using historical data projection [1,7–14]
- Personal Vehicle Growth Factor [2,41–44]
- Electric Vehicle Attractiveness Growth Factor [45]
- Subsidy Impact on EV Attractiveness
- Vehicle Type Preferences
- Home-/Public Charging Preferences, with following values:

Table 4. Input variation's value.

Variable	Label in Simulation	Scenario A	Value	Scenario B	Value	Scenario C	Value
Supply-Side							
Power Plant Capacity Growth	PowPlaGF	Slow	2.5%	Predicted	5%	Fast	7.5%
Base Peak Load Demand Growth	BasPeaLoaGF	Slow	6%	Predicted	8%	Fast	10%
Demand-Side							
Personal Vehicle Population Growth	TotVehGF	Slow	3.5%	Predicted	4.5%	Fast	5.5%
EV Attractiveness Growth	PerEVGF	Slow	15%	Predicted	17.5%	Fast	20%
Subsidy Impact on EV Attractiveness	SubImpGF	Less Impact	25%	Balanced	50%	High Impact	75%
Vehicle Type Preferences	PerEVTypGF	Luxury Oriented	Luxury 75% Daily 25%	Balanced	Luxury 50% Daily 50%	Daily Oriented	Luxury 25% Daily 75%
Home-/Public Charging Preferences	FasSloRatGF	Public Charging Oriented	Public 75% Home 25%	Balanced	Public 50% Home 50%	Home Charging Oriented	Public 25% Home 75%

In combinatorial mathematics, a permutation refers to the different ways of selecting and arranging objects. It represents an arrangement of objects in a specific order. When repetition is allowed and the order matters, the number of possible permutations of r elements taken from a set of n elements is given by (n^r) [46].

$$n^r = 3^7 = 2187 \tag{7}$$

Since combination's repetition is allowed, each of the 7 variable inputs can be filled with any of the 3 growth factor speed variation, giving us 2187 possible scenarios.

2.4. Global Simulations

The global simulation begins with the permutation of input scenarios. Each permutation provides values for the variables. With 3 possibilities for each of the 7 different variables, this results in 2187 scenarios. Based on the values of each scenario, the supply and demand simulations commence. Each supply-demand simulation runs for five years, covering the period from 2024 to 2029.

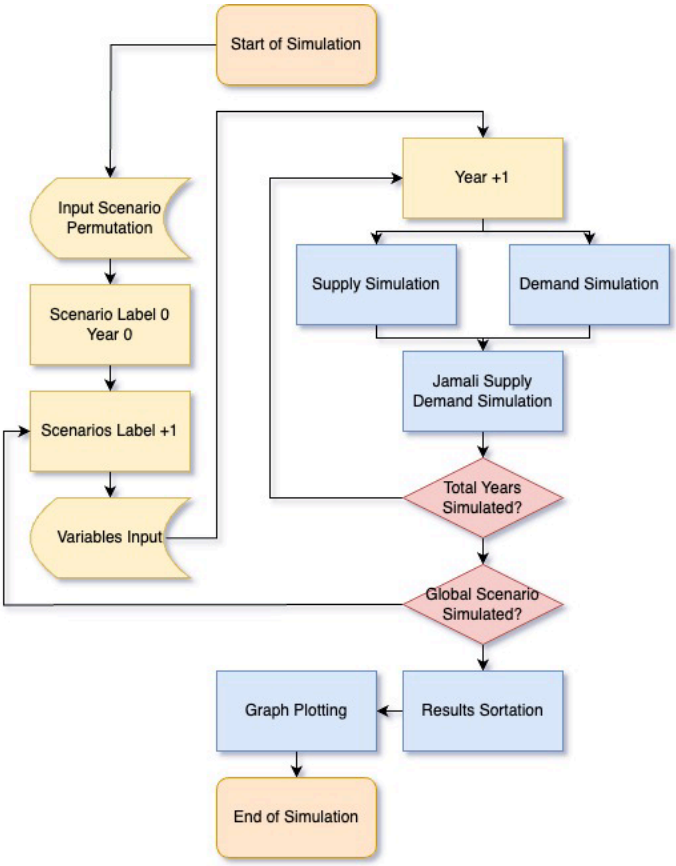


Figure 11. Simulation's Flowchart.

The three main outputs for each scenario are the end EV percentage by 2029, cost allocation for the additional yearly electricity supply, and cost allocation for the yearly EV subsidies. The total cost allocation for the additional yearly electricity supply was simulated by considering the deficit in power plant capacity by the end of 2029. The supply cost per kilowatt-hour (kWh) of Rp1,108/kWh was derived from BPP PLN. [47]

$$\text{Cost Allocation for Additional Electricity Supply} = (\text{Total Simulated Load 2029} - \text{Power Plant Capacity 2029}) \times \text{Supply Cost} \tag{8}$$

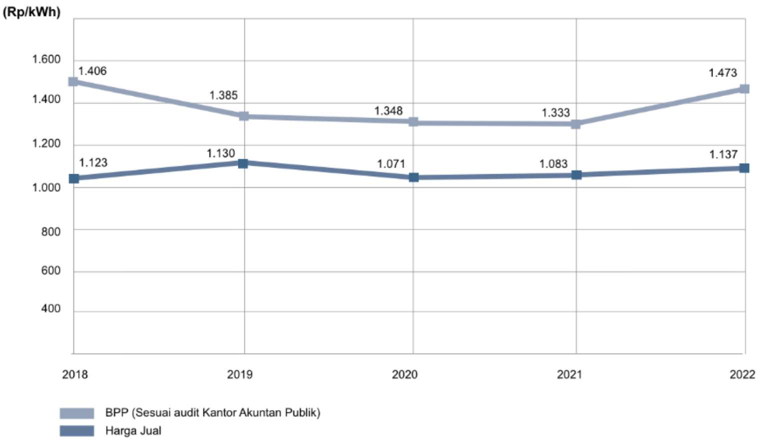


Figure 12. Supply Cost per kWh (BPP PLN) 2018-2022 [47].

On the contrary, the cost allocation for the yearly EV subsidies was determined by considering the surplus of the power plant capacity. To achieve a balance in the grid's supply and demand, a specific number of EVs must be added to offset the supply. These include a 10% VAT tax deduction each 4wEV [24] and an IDR 7,000,000 deduction for each 2wEV [25].

$$\text{Cost Allocation for the EV Subsidies} = -(\text{Total Simulated Load 2029} - \text{Power Plant Capacity 2029}) \times \text{Subsidy Cost} \tag{8}$$

The outputs from each of the 2187 scenarios are sorted based on three criteria. Given that EV growth is the primary goal of the government, the initial sorting criterion for the best scenarios is the highest EV percentage result in 2029. Subsequently, the scenarios are sorted by the minimum yearly cost allocation. Conversely, to identify the worst possible scenario, the simulation sorts by the least EV percentage with the highest yearly cost allocation.

Table 5. Output's Priority Order.

Output's Objective	Priority Order
High EV Growth	1st
and	
Low-Cost Allocation for Supply Low-Cost Allocation for Subsidy	2nd

The second sortation criterion (cost allocation for the additional yearly electricity supply and cost allocation for the yearly EV subsidies) will offset each other depending on the power plant capacity deficit by the year 2029. Apart from presenting the best and worst possible outputs given the scenarios available, the simulation should be able to execute the inputted scenarios.

3. Results

After simulating the scenarios, four results are worth considering: the scenario with the best outputs, the scenario with the worst outputs, and the most and least probable scenarios based on the information and predictions formed during the literature review.

Table 6. Scenario Outputs.

Simulation Result	Scenario Label	Scenario Permutation	EV Percentage in 2029	Cost Allocation on Supply	Cost Allocation on Subsidy
Best Scenario	1776	3213313	45.38%	Rp492,218,007,498	Rp0
Worst Scenario	163	1131111	23.12%	Rp0	Rp47,556,001,136,600
Most Probable	378	1222333	42.98%	Rp970,330,692,972	Rp0
Least Probable	1459	3111111	24.32%	Rp0	Rp45,475,187,899,827

The output graph of the global simulation is displayed below, featuring three graphs with the scenario number on the x-axis. These graphs illustrate the three outputs: EV Percentage in 2029, Mandatory Cost Allocation on Supply in 2029, and Cost Allocation on Subsidy in 2029.

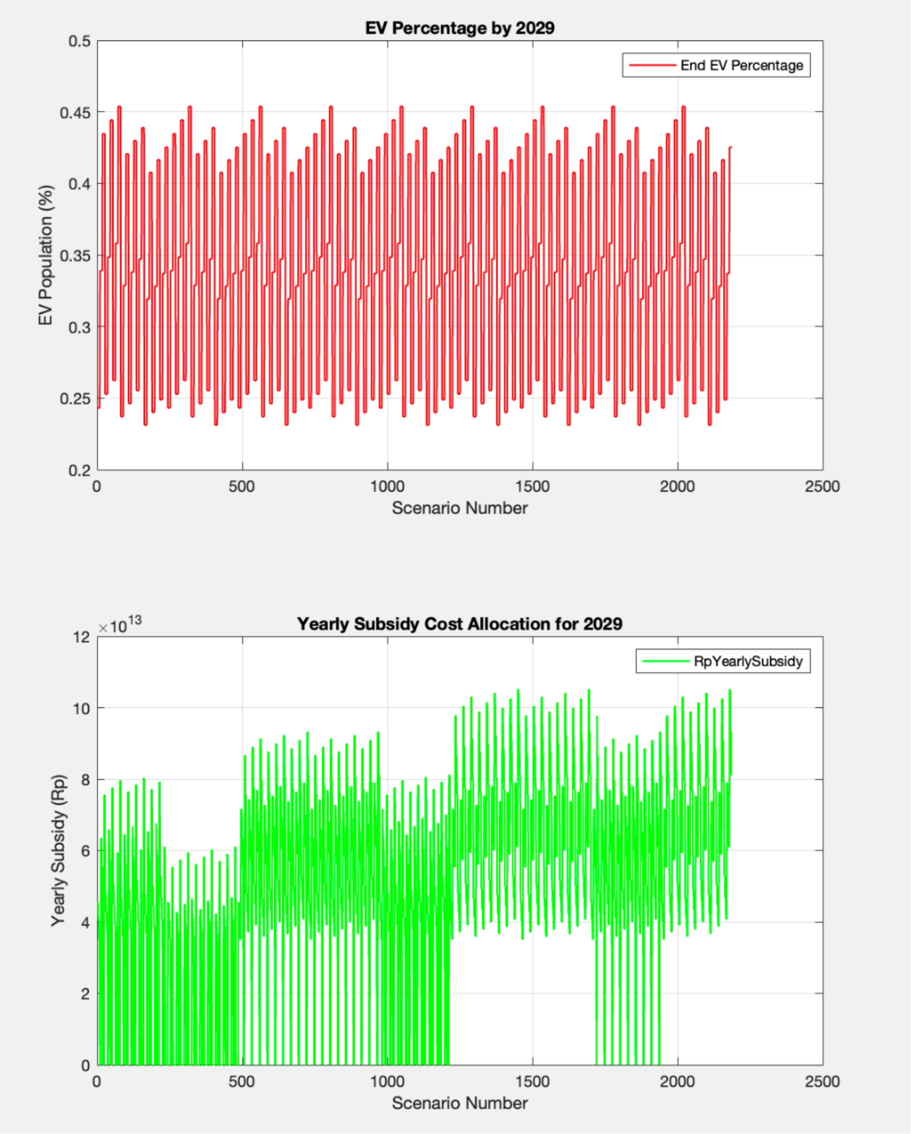
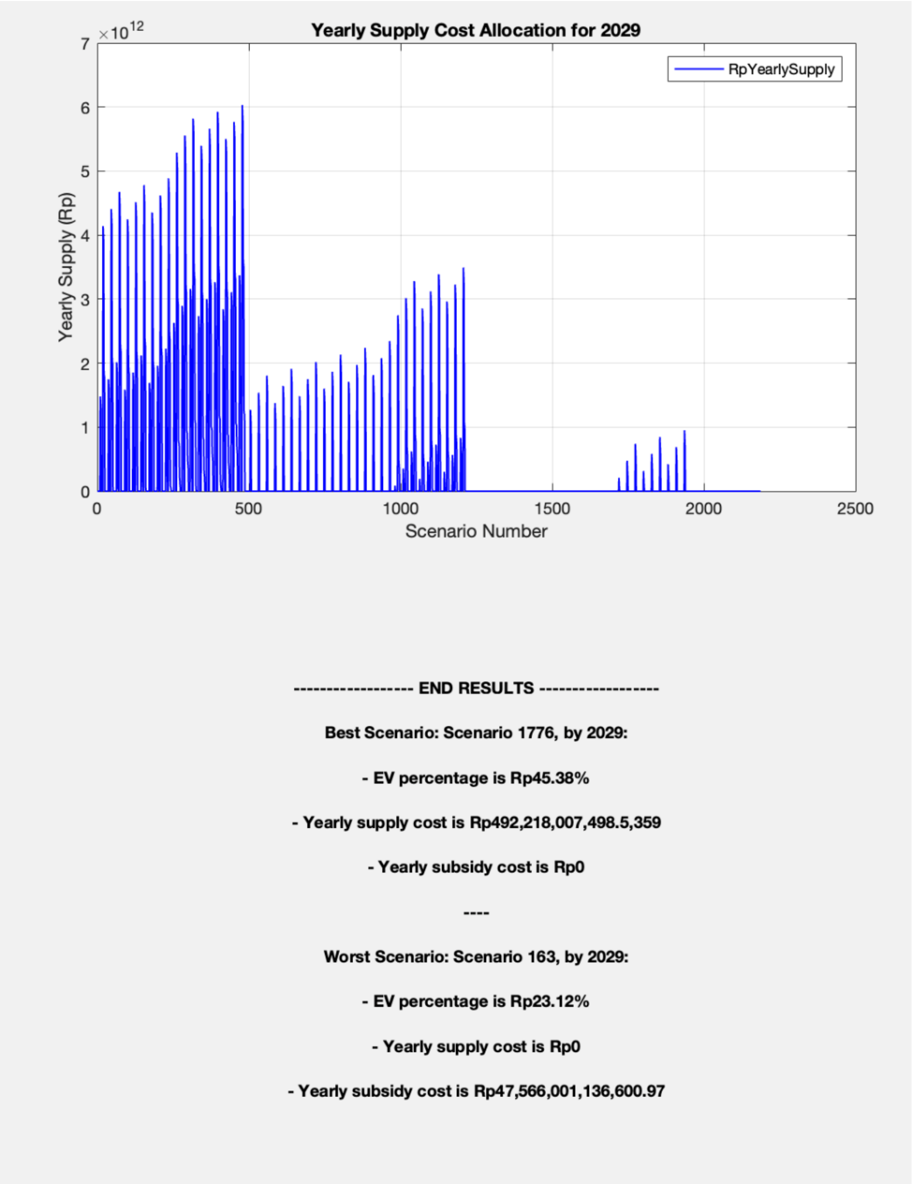


Figure 13. Global Simulations Output 1.



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------------------ END RESULTS ------------------

Best Scenario: Scenario 1776, by 2029:

- EV percentage is Rp45.38%

- Yearly supply cost is Rp492,218,007,498.5,359

- Yearly subsidy cost is Rp0

----

Worst Scenario: Scenario 163, by 2029:

- EV percentage is Rp23.12%

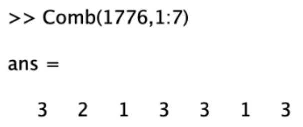
- Yearly supply cost is Rp0

- Yearly subsidy cost is Rp47,566,001,136,600.97
```

Figure 13. Global Simulations Output 2.

3.1. Best Case Scenario

Based on the output simulation of 2187 scenarios for 2024-2029, the best-case scenario achieves the highest EV growth without disturbing the grid's supply and demand balance. In the global scenario, all results were sorted, and the scenario with the highest EV percentage by 2029 was selected. Subsequently, all scenarios with the best EV percentage were sorted based on the lowest cost allocation for supply adjustment or subsidy allocation. This resulted in scenario label 1776. The output for this scenario permutation was 3213313, which translates to the following variable inputs (highlighted in blue):



```
>> Comb(1776,1:7)

ans =

     3     2     1     3     3     1     3
```

Figure 14. Best Scenario Input Permutation.

Table 7. Best Scenario Inputs.

Power Plant Capacity Growth	Base Peak Load Demand Growth	Personal Vehicle Population Growth	EV Attractiveness Growth	Subsidy Impact on EV Attractiveness	Vehicle Type Preferences	Home-/Public Charging Preferences
Slow Growth	Slow Growth	Slow Growth	Slow Growth	Less Impact	Luxury Oriented	Public Charging Oriented
Predicted Growth	Predicted Growth	Predicted Growth	Predicted Growth	Balanced	Balanced	Balanced
Fast Growth	Fast Growth	Fast Growth	Fast Growth	High Impact	Daily Oriented	Home Charging Oriented

This scenario resulted in supply and demand details below:

Table 8. Best Scenario Outputs.

Output	Label in Simulation	Value	Units
Power Plan Capacity	PowPlaCap	69,033,250	kW
Base Peak Load Demand	BasPeaLoa	39,705,400	kW
Personal Vehicle Population	TotVeh_n	105,460,000	units
Total EV Percentage	EndEVPer	45.38	%
EV Type 1 Percentage	EndEVPerTyp1	4	%
EV Type 2 Percentage	EndEVPerTyp2	1.3	%
EV Type 3 Percentage	EndEVPerTyp3	30	%
EV Type 4 Percentage	EndEVPerTyp4	10	%
EV Peak Load Demand	TotEVLoa	30,544,000	kW
Total Peak Load Demand	TotalLoad	70,249,000	kW
Plant Capacity Surplus/Deficit	PowPlaDef	121,620	kW
Cost Allocation for Supply	RpYearlySup	492,218,007,498	Rupiah
Cost Allocation for Subsidy	RpYearlySub	0	Rupiah

The hourly Demand for each EV type and the total power plant surplus/deficit are shown below:

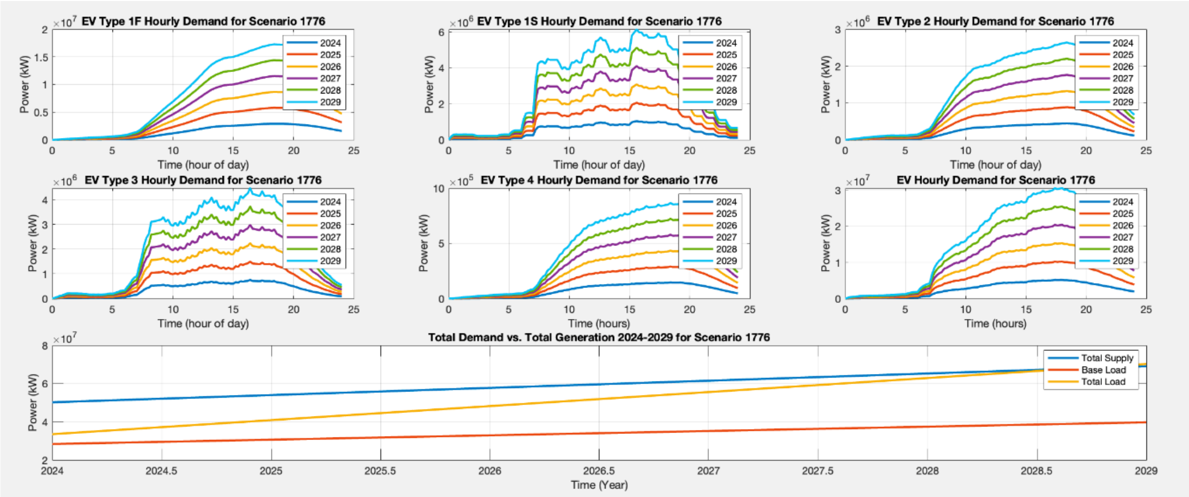
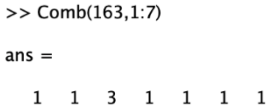


Figure 15. Best Scenario Output Graphs.

3.2. Worst Case Scenario

Based on the output simulation of 2187 scenarios for 2024-2029, the worst-case scenario was selected by sorting the scenarios with the least EV percentage in 2029. These scenarios were then re-sorted based on the highest cost allocation for supply adjustment or subsidy allocation. The worst-performing scenario was labeled 163. Its scenario permutation was 1131111 with the following input details (highlighted in blue):



```
>> Comb(163,1:7)

ans =

     1     1     3     1     1     1     1
```

Figure 16. Worst Scenario Input Permutation.

Table 9. Worst Scenario Inputs.

Power Plant Capacity Growth	Base Peak Load Demand Growth	Personal Vehicle Population Growth	EV Attractiveness Growth	Subsidy Impact on EV Attractiveness	Vehicle Type Preferences	Home-/Public Charging Preferences
Slow Growth	Slow Growth	Slow Growth	Slow Growth	Less Impact	Luxury Oriented	Public Charging Oriented
Predicted Growth	Predicted Growth	Predicted Growth	Predicted Growth	Balanced	Balanced	Balanced
Fast Growth	Fast Growth	Fast Growth	Fast Growth	High Impact	Daily Oriented	Home Charging Oriented

This scenario resulted in supply and demand details below:

Table 10. Worst Scenario Outputs.

Output	Label in Simulation	Value	Units
Power Plan Capacity	PowPlaCap	56,481,750	kW
Base Peak Load Demand	BasPeaLoa	36,869,300	kW
Personal Vehicle Population	TotVeh_n	114,440,000	units
Total EV Percentage	EndEVPer	23.12	%
EV Type 1 Percentage	EndEVPerTyp1	2	%
EV Type 2 Percentage	EndEVPerTyp2	0.6	%
EV Type 3 Percentage	EndEVPerTyp3	15	%
EV Type 4 Percentage	EndEVPerTyp4	5	%
EV Peak Load Demand	TotEVLoa	17,222,000	kW
Total Peak Load Demand	TotalLoad	54,092,000	kW
Plant Capacity Surplus/Deficit	PowPlaDef	-2,390,100	kW
Cost Allocation for Supply	RpYearlySup	0	Rupiah
Cost Allocation for Subsidy	RpYearlySub	47,556,001,136,600	Rupiah

The hourly Demand for each EV type and the total power plant surplus/deficit are shown below:

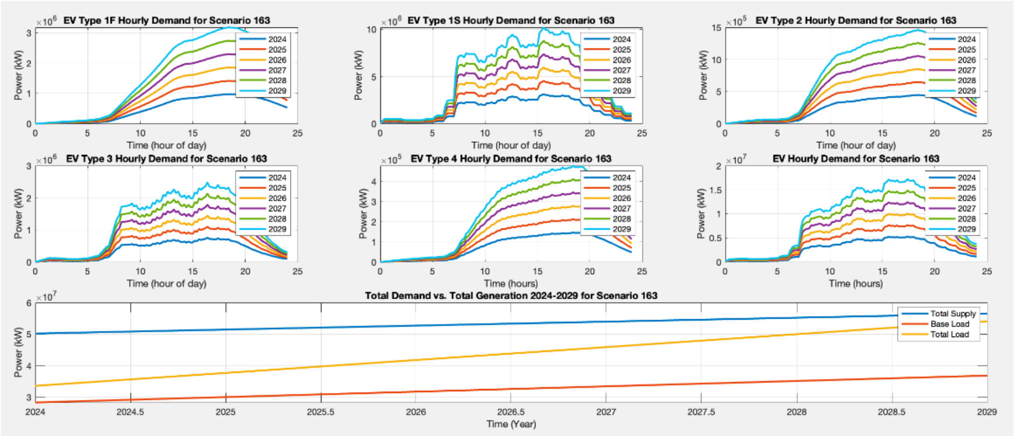


Figure 17. Worst Scenario Output Graphs.

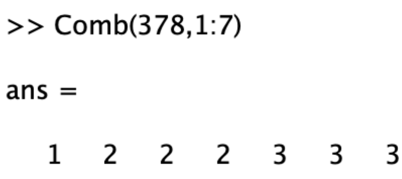
3.3. Most Probable Scenario

Another simulation result worth analyzing is the most probable scenario. This scenario was determined based on information collected during literature research. The growth of power plant capacity is expected to be slow due to PLN's current oversupply issue [48]. Normal predictions are made for base peak load demand, personal vehicle population, and EV attractiveness growth [49]. According to a survey conducted by Indonesia Cerah in January 2024, subsidies are expected to have a high impact on EV attractiveness in Indonesia [50]. In the last year, there has been a strong preference for budget daily cars, reflecting the direction of the Indonesian market [51]. Home charging is strongly preferred over public charging [52].

Table 11. Most Probable Scenario Inputs.

Power Plant Capacity Growth	Base Peak Load Demand Growth	Personal Vehicle Population Growth	EV Attractiveness Growth	Subsidy Impact on EV Attractiveness	Vehicle Type Preferences	Home-/Public Charging Preferences
Slow Growth	Slow Growth	Slow Growth	Slow Growth	Less Impact	Luxury Oriented	Public Charging Oriented
Predicted Growth	Predicted Growth	Predicted Growth	Predicted Growth	Balanced	Balanced	Balanced
Fast Growth	Fast Growth	Fast Growth	Fast Growth	High Impact	Daily Oriented	Home Charging Oriented

The scenario permutation of 1222333 (highlighted in blue) translates to Scenario label 378. This scenario resulted in a 42.98% EV percentage in 2029. In that year, there is a power plant capacity deficit of 2,397 MW. To achieve supply-demand balance, a cost allocation of Rp970,330,692,972 needs to be prepared.



```
>> Comb(378,1:7)

ans =

   1   2   2   2   3   3   3
```

Figure 18. Most Probable Scenario Input Permutation.

Table 12. Most Probable Scenario Outputs.

Output	Label in Simulation	Value	Units
Power Plan Capacity	PowPlaCap	56,481,750	kW
Base Peak Load Demand	BasPeaLoa	39,705,400	kW
Personal Vehicle Population	TotVeh_n	109,950,000	units
Total EV Percentage	EndEVPer	42.98	%
EV Type 1 Percentage	EndEVPerTyp1	1.3	%
EV Type 2 Percentage	EndEVPerTyp2	3.8	%
EV Type 3 Percentage	EndEVPerTyp3	9.5	%
EV Type 4 Percentage	EndEVPerTyp4	28.4	%
EV Peak Load Demand	TotEVLoa	19,174,000	kW
Total Peak Load Demand	TotalLoad	58,879,000	kW
Plant Capacity Surplus/Deficit	PowPlaDef	2,397,600	kW
Cost Allocation for Supply	RpYearlySup	970,330,692,972	Rupiah
Cost Allocation for Subsidy	RpYearlySub	0	Rupiah

The hourly Demand for each EV type and the total power plant surplus/deficit are shown below:

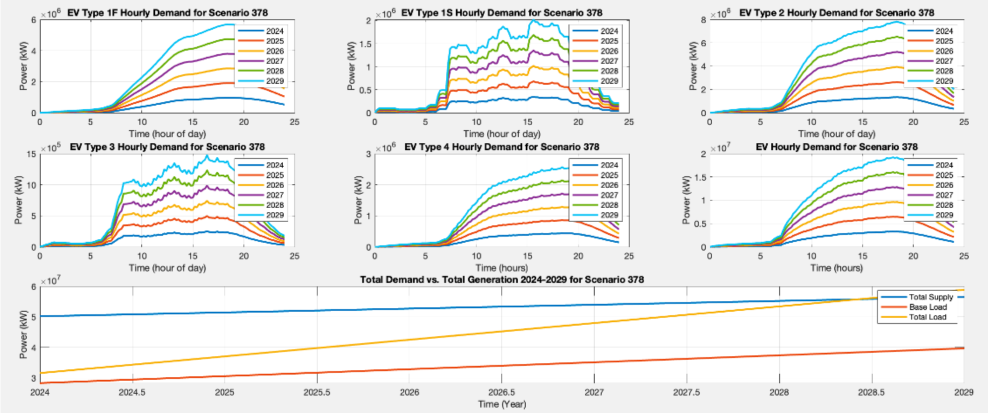


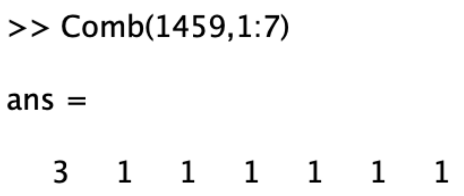
Figure 19. Most Probable Scenario Output Graphs.

3.4. Least Probable Scenario

On the other hand, the least probable scenario, based on the literature review, features inputs that are the opposite of the most probable scenario. The inputs for scenario 1621 of 3111111 (highlighted in blue) are shown in the table below:

Table 13. Least Scenario Inputs.

Power Plant Capacity Growth	Base Peak Load Demand Growth	Personal Vehicle Population Growth	EV Attractiveness Growth	Subsidy Impact on EV Attractiveness	Vehicle Type Preferences	Home-/Public Charging Preferences
Slow Growth	Slow Growth	Slow Growth	Slow Growth	Less Impact	Luxury Oriented	Public Charging Oriented
Predicted Growth	Predicted Growth	Predicted Growth	Predicted Growth	Balanced	Balanced	Balanced
Fast Growth	Fast Growth	Fast Growth	Fast Growth	High Impact	Daily Oriented	Home Charging Oriented



```
>> Comb(1459,1:7)

ans =

     3     1     1     1     1     1     1
```

Figure 20. Least Probable Scenario Input Permutation.

This scenario resulted in supply and demand details below:

Table 14. Least Probable Scenario Outputs.

Output	Label in Simulation	Value	Units
Power Plan Capacity	PowPlaCap	69,033,250	kW
Base Peak Load Demand	BasPeaLoa	36,869,300	kW
Personal Vehicle Population	TotVeh_n	105,460,000	units
Total EV Percentage	EndEVPer	24.32	%
EV Type 1 Percentage	EndEVPerTyp1	2.1	%
EV Type 2 Percentage	EndEVPerTyp2	0.7	%
EV Type 3 Percentage	EndEVPerTyp3	16	%
EV Type 4 Percentage	EndEVPerTyp4	5.3	%
EV Peak Load Demand	TotEVLoa	16,696,000	kW
Total Peak Load Demand	TotalLoad	53,566,000	kW
Plant Capacity Surplus/Deficit	PowPlaDef	-15,467,600	kW
Cost Allocation for Supply	RpYearlySup	0	Rupiah
Cost Allocation for Subsidy	RpYearlySub	45,475,187,899,827	Rupiah

The hourly Demand for each EV type and the total power plant surplus/deficit are shown below:

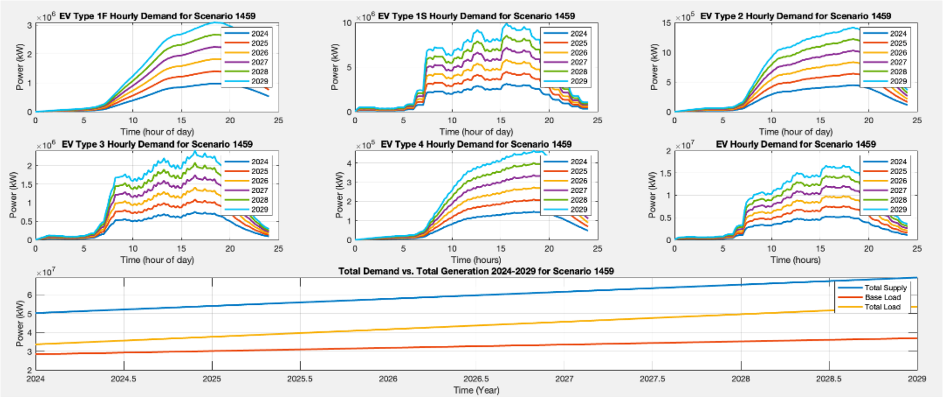


Figure 21. Least Scenario Output Graphs.

4. Discussion and Conclusions

These simulation outputs should serve as predictive guidelines to forecast and take action to maintain the balance of supply and demand in Jamali's power grid, considering the growth of electric vehicles and the impact of subsidies.

Based on the best scenario, the key to achieving a high EV percentage by 2029 with the lowest possible cost allocation is to have slow and controlled EV population growth while maximizing the subsidy impact on EV attractiveness and promoting home charging. Interestingly, the most probable scenario based on literature research closely approaches the best possible outcome. Having sufficient supply capacity and controlling the pace of slow and steady EV growth would lead to a higher EV percentage by 2029 with approximately half the yearly cost allocation between these two scenarios.

The worst scenario illustrates the adverse effects of rapid and unmanaged electric vehicle (EV) growth, coupled with low subsidy impact and a strong preference for public charging. This scenario results in a notably low EV percentage by 2029 and a high-cost allocation for subsidies. It serves as a cautionary example, highlighting the importance of strategic planning and policy implementation to steer EV adoption toward sustainable and balanced growth.

Due to constraints in data availability and simulation capability, variables such as dynamic population growth factors, dynamic peak load curves on weekends, and dynamic initial charging times (ICT) were not included in this simulation. These variables could be incorporated in future improvements to enhance the accuracy of the model. Improving the simulation's inputs and considering additional variables should greatly increase its accuracy.

Author Contributions: Conceptualization, J.T. and R.D.; methodology, J.T. and R.D.; software, J.T.; validation, J.T. and R.D.; formal analysis, J.T. and R.D.; investigation, J.T. and R.D.; resources, J.T. and R.D.; data curation, J.T.; writing—original draft preparation, J.T.; writing—review and editing, J.T.; visualization, J.T.; supervision, R.D.; project administration, R.D.; funding acquisition, R.D. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: We encourage all authors of articles published in MDPI journals to share their research data. In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Where no new data were created, or where data is unavailable due to privacy or ethical restrictions, a statement is still required. Suggested Data Availability Statements are available in section "MDPI Research Data Policies" at https://www.mdpi.com/ethics.

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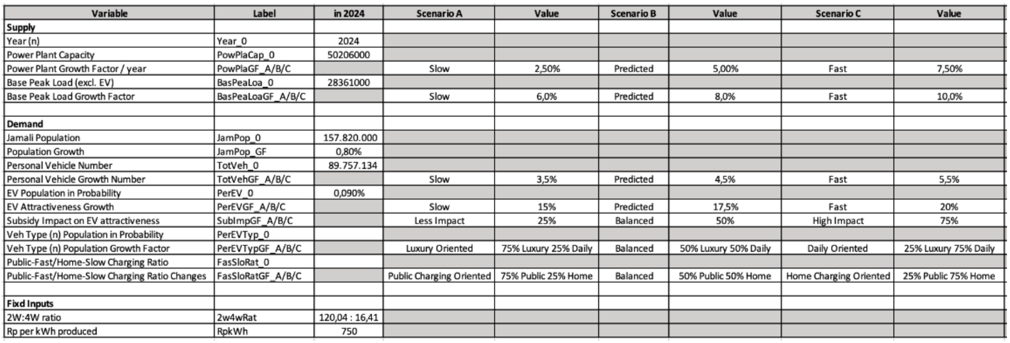
Conflicts of Interest: The authors declare no conflicts of interest.

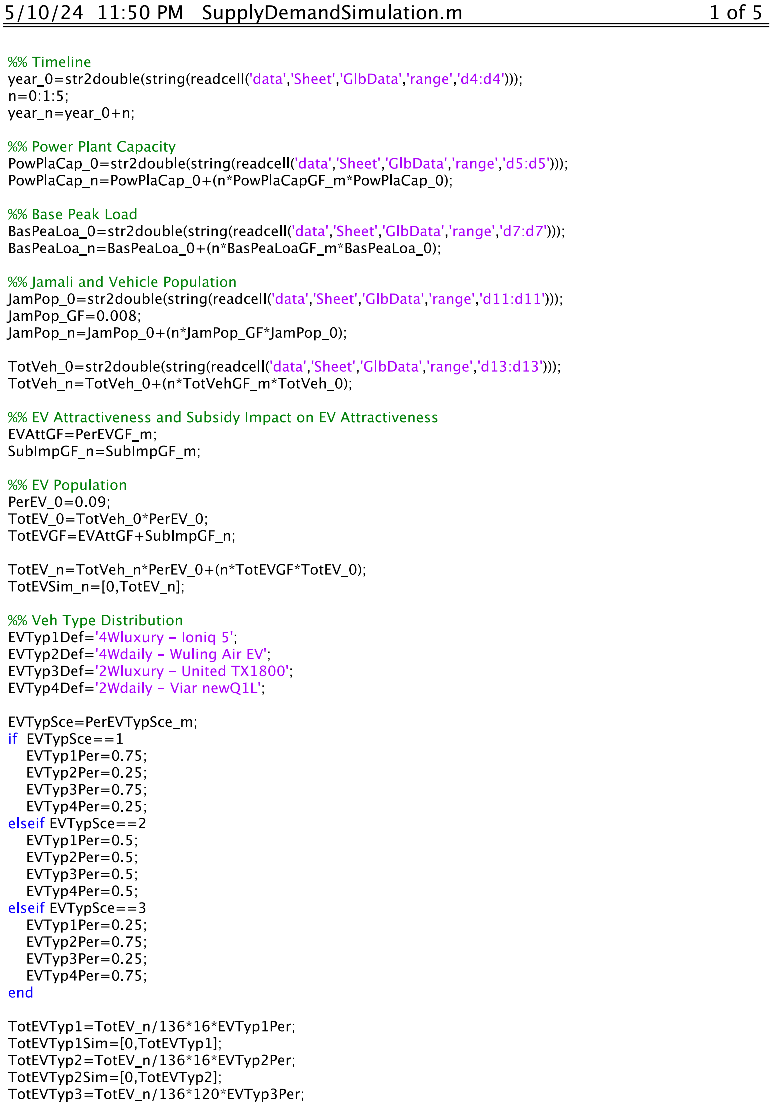
Appendix A – Simulation Input Excel Data



Variable	Label	in 2024	Scenario A	Value	Scenario B	Value	Scenario C	Value
Supply								
Year (n)	Year_0	2024						
Power Plant Capacity	PowPlaCap_0	50206000						
Power Plant Growth Factor / year	PowPlaGF_A/B/C		Slow	2,50%	Predicted	5,00%	Fast	7,50%
Base Peak Load (excl. EV)	BasPeaLoa_0	28361000						
Base Peak Load Growth Factor	BasPeaLoaGF_A/B/C		Slow	6,0%	Predicted	8,0%	Fast	10,0%
Demand								
Jamali Population	JamPop_0	157.820.000						
Population Growth	JamPop_GF	0,80%						
Personal Vehicle Number	TotVeh_0	89.757.134						
Personal Vehicle Growth Number	TotVehGF_A/B/C		Slow	3,5%	Predicted	4,5%	Fast	5,5%
EV Population in Probability	PerEV_0	0,090%						
EV Attractiveness Growth	PerEVGF_A/B/C		Slow	15%	Predicted	17,5%	Fast	20%
Subsidy Impact on EV attractiveness	SubImpGF_A/B/C		Less Impact	25%	Balanced	50%	High Impact	75%
Veh Type (n) Population in Probability	PerEVTyp_0							
Veh Type (n) Population Growth Factor	PerEVTypGF_A/B/C		Luxury Oriented	75% Luxury 25% Daily	Balanced	50% Luxury 50% Daily	Daily Oriented	25% Luxury 75% Daily
Public-Fast/Home-Slow Charging Ratio	FasSloRat_0							
Public-Fast/Home-Slow Charging Ratio Changes	FasSloRatGF_A/B/C		Public Charging Oriented	75% Public 25% Home	Balanced	50% Public 50% Home	Home Charging Oriented	25% Public 75% Home
Fixd Inputs								
2W:4W ratio	2w4wRat	120,04 : 16,41						
Rp per kWh produced	RpkWh	750						

Figure A1. Screen capture of the initial input excel data.

Appendix B – MATLAB Scripts (Supply Demand Simulation)



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```
%% Timeline
year_0=str2double(string(readcell('data','Sheet','GlbData','range','d4:d4')));
n=0:1:5;
year_n=year_0+n;

%% Power Plant Capacity
PowPlaCap_0=str2double(string(readcell('data','Sheet','GlbData','range','d5:d5')));
PowPlaCap_n=PowPlaCap_0+(n*PowPlaCapGF_m*PowPlaCap_0);

%% Base Peak Load
BasPeaLoa_0=str2double(string(readcell('data','Sheet','GlbData','range','d7:d7')));
BasPeaLoa_n=BasPeaLoa_0+(n*BasPeaLoaGF_m*BasPeaLoa_0);

%% Jamali and Vehicle Population
JamPop_0=str2double(string(readcell('data','Sheet','GlbData','range','d11:d11')));
JamPop_GF=0.008;
JamPop_n=JamPop_0+(n*JamPop_GF*JamPop_0);

TotVeh_0=str2double(string(readcell('data','Sheet','GlbData','range','d13:d13')));
TotVeh_n=TotVeh_0+(n*TotVehGF_m*TotVeh_0);

%% EV Attractiveness and Subsidy Impact on EV Attractiveness
EVAttGF=PerEVGF_m;
SubImpGF_n=SubImpGF_m;

%% EV Population
PerEV_0=0.09;
TotEV_0=TotVeh_0*PerEV_0;
TotEVGF=EVAttGF+SubImpGF_n;

TotEV_n=TotVeh_n*PerEV_0+(n*TotEVGF*TotEV_0);
TotEVSim_n=[0,TotEV_n];

%% Veh Type Distribution
EVTyp1Def='4Wluxury - Ioniq 5';
EVTyp2Def='4Wdaily - Wuling Air EV';
EVTyp3Def='2Wluxury - United TX1800';
EVTyp4Def='2Wdaily - Viar newQ1L';

EVTypSce=PerEVTypSce_m;
if EVTypSce==1
    EVTyp1Per=0.75;
    EVTyp2Per=0.25;
    EVTyp3Per=0.75;
    EVTyp4Per=0.25;
elseif EVTypSce==2
    EVTyp1Per=0.5;
    EVTyp2Per=0.5;
    EVTyp3Per=0.5;
    EVTyp4Per=0.5;
elseif EVTypSce==3
    EVTyp1Per=0.25;
    EVTyp2Per=0.75;
    EVTyp3Per=0.25;
    EVTyp4Per=0.75;
end

TotEVTyp1=TotEV_n/136*16*EVTyp1Per;
TotEVTyp1Sim=[0,TotEVTyp1];
TotEVTyp2=TotEV_n/136*16*EVTyp2Per;
TotEVTyp2Sim=[0,TotEVTyp2];
TotEVTyp3=TotEV_n/136*120*EVTyp3Per;
```

Figure B1. Supply-demand simulation script page 1 of 5.

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```
TotEVTyp3Sim=[0,TotEVTyp3];
TotEVTyp4=TotEV_n/136*120*EVTyp4Per;
TotEVTyp4Sim=[0,TotEVTyp4];

%% Charging Time Distribution
GenICTRead=str2double(string(readcell("data.xlsx","sheet","ChargeTimeDistribution","Range","a2:b25")));
GenICT=GenICTRead(1:24,1:2);

GenICTRead12=str2double(string(readcell("data.xlsx","sheet","ICT12","Range","d2:e121")));
GenICT12=GenICTRead12(1:120,1:2);

%% Charge Curve (VehType1)
% slow charging
Typ1ChargeCurveSlowPIT=str2double(string(readcell("data.xlsx","sheet","ChargeCurve","Range","c3:c23")));
Typ1ChargeCurveSlowLoad=str2double(string(readcell("data.xlsx","sheet","ChargeCurve","Range","d3:↙
d23")));
Typ1ChargeCurveSlow=[Typ1ChargeCurveSlowPIT,Typ1ChargeCurveSlowLoad];

% fast charging
Typ1ChargeCurveFastPIT=str2double(string(readcell("data.xlsx","sheet","ChargeCurve","Range","f3:f23")));
Typ1ChargeCurveFastLoad=str2double(string(readcell("data.xlsx","sheet","ChargeCurve","Range","g3:↙
g23")));
Typ1ChargeCurveFast=[Typ1ChargeCurveFastPIT,Typ1ChargeCurveFastLoad];

%% Charge Curve (VehType2)
Typ2ChargeCurvePIT=str2double(string(readcell("data.xlsx","sheet","ChargeCurve","Range","i3:i23")));
Typ2ChargeCurveLoad=str2double(string(readcell("data.xlsx","sheet","ChargeCurve","Range","j3:j23")));
Typ2ChargeCurve=[Typ2ChargeCurvePIT,Typ2ChargeCurveLoad];

%% Charge Curve (VehType3)
Typ3ChargeCurvePIT=str2double(string(readcell("data.xlsx","sheet","ChargeCurve","Range","l3:l23")));
Typ3ChargeCurveLoad=str2double(string(readcell("data.xlsx","sheet","ChargeCurve","Range","m3:m23")));
Typ3ChargeCurve=[Typ3ChargeCurvePIT,Typ3ChargeCurveLoad];

%% Charge Curve (VehType4)
Typ4ChargeCurvePIT=str2double(string(readcell("data.xlsx","sheet","ChargeCurve","Range","o3:o23")));
Typ4ChargeCurveLoad=str2double(string(readcell("data.xlsx","sheet","ChargeCurve","Range","p3:p23")));
Typ4ChargeCurve=[Typ4ChargeCurvePIT,Typ4ChargeCurveLoad];

%% Slow/Fast Charging Ratio
FasSloSce=FasSloRatSce_m;
if FasSloSce==1
    FasRat=0.75;
    SloRat=0.25;

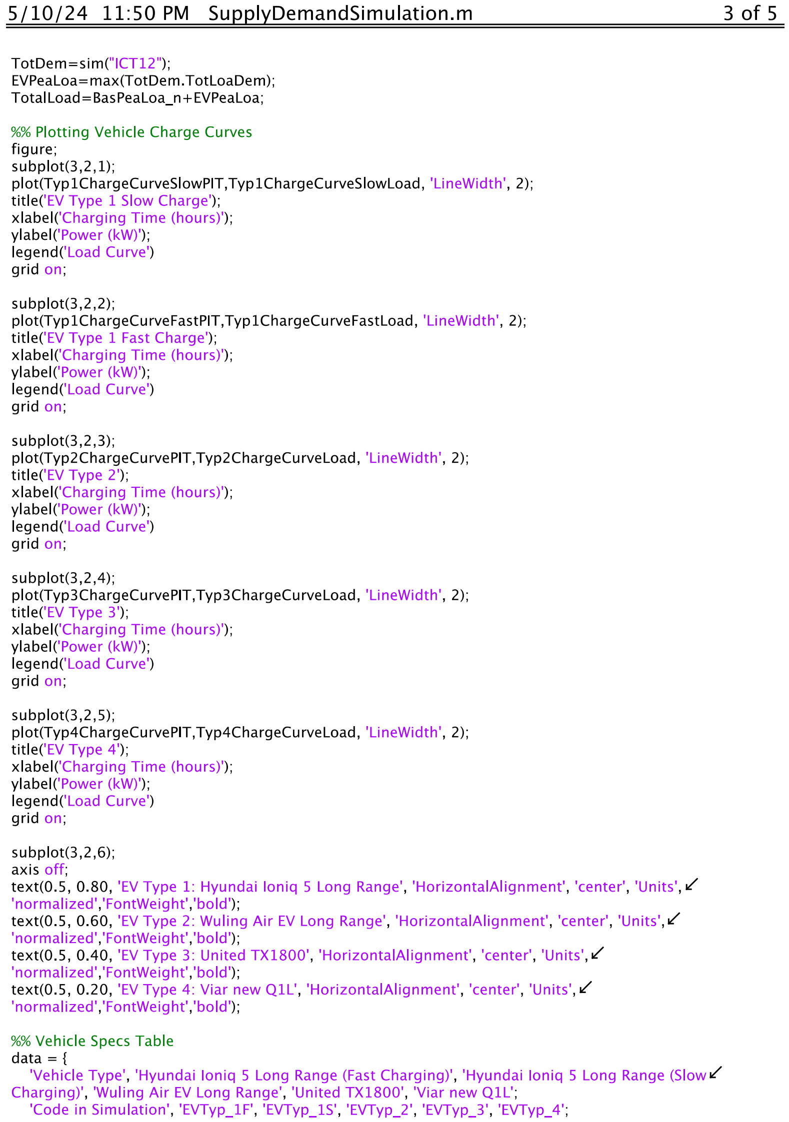
    FasRat_n=[FasRat,FasRat,FasRat,FasRat,FasRat,FasRat,FasRat];
    SloRat_n=[SloRat,SloRat,SloRat,SloRat,SloRat,SloRat,SloRat];
elseif FasSloSce==2
    FasRat=0.5;
    SloRat=0.5;

    FasRat_n=[FasRat,FasRat,FasRat,FasRat,FasRat,FasRat,FasRat];
    SloRat_n=[SloRat,SloRat,SloRat,SloRat,SloRat,SloRat,SloRat];
elseif FasSloSce==3
    FasRat=0.25;
    SloRat=0.75;

    FasRat_n=[FasRat,FasRat,FasRat,FasRat,FasRat,FasRat,FasRat];
    SloRat_n=[SloRat,SloRat,SloRat,SloRat,SloRat,SloRat,SloRat];
end

%% Run Demand Simulation and Peak Load
```

Figure B2. Supply-demand simulation script page 2 of 5.



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```
TotDem=sim("ICT12");
EVPeaLoa=max(TotDem.TotLoaDem);
TotalLoad=BasPeaLoa_n+EVPeaLoa;

%% Plotting Vehicle Charge Curves
figure;
subplot(3,2,1);
plot(Typ1ChargeCurveSlowPIT,Typ1ChargeCurveSlowLoad, 'LineWidth', 2);
title('EV Type 1 Slow Charge');
xlabel('Charging Time (hours)');
ylabel('Power (kW)');
legend('Load Curve')
grid on;

subplot(3,2,2);
plot(Typ1ChargeCurveFastPIT,Typ1ChargeCurveFastLoad, 'LineWidth', 2);
title('EV Type 1 Fast Charge');
xlabel('Charging Time (hours)');
ylabel('Power (kW)');
legend('Load Curve')
grid on;

subplot(3,2,3);
plot(Typ2ChargeCurvePIT,Typ2ChargeCurveLoad, 'LineWidth', 2);
title('EV Type 2');
xlabel('Charging Time (hours)');
ylabel('Power (kW)');
legend('Load Curve')
grid on;

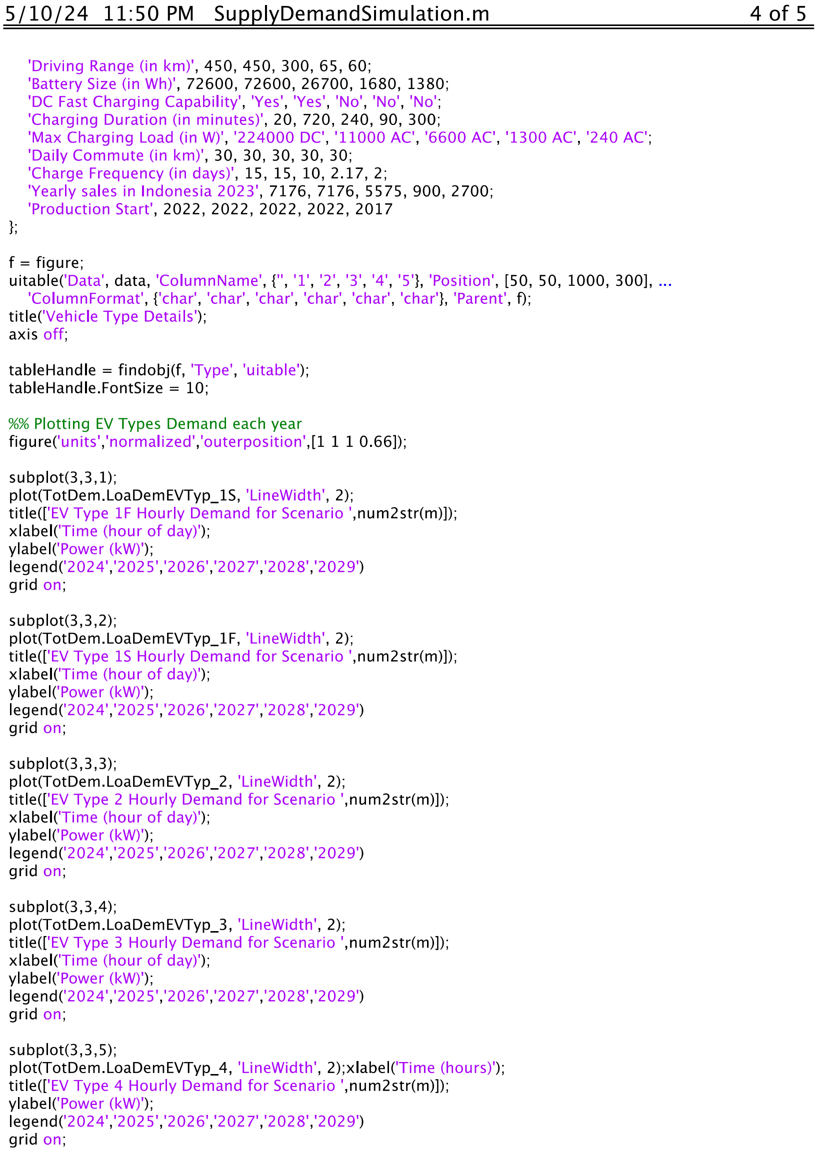
subplot(3,2,4);
plot(Typ3ChargeCurvePIT,Typ3ChargeCurveLoad, 'LineWidth', 2);
title('EV Type 3');
xlabel('Charging Time (hours)');
ylabel('Power (kW)');
legend('Load Curve')
grid on;

subplot(3,2,5);
plot(Typ4ChargeCurvePIT,Typ4ChargeCurveLoad, 'LineWidth', 2);
title('EV Type 4');
xlabel('Charging Time (hours)');
ylabel('Power (kW)');
legend('Load Curve')
grid on;

subplot(3,2,6);
axis off;
text(0.5, 0.80, 'EV Type 1: Hyundai Ioniq 5 Long Range', 'HorizontalAlignment', 'center', 'Units',↙
'normalized','FontWeight','bold');
text(0.5, 0.60, 'EV Type 2: Wuling Air EV Long Range', 'HorizontalAlignment', 'center', 'Units',↙
'normalized','FontWeight','bold');
text(0.5, 0.40, 'EV Type 3: United TX1800', 'HorizontalAlignment', 'center', 'Units',↙
'normalized','FontWeight','bold');
text(0.5, 0.20, 'EV Type 4: Viar new Q1L', 'HorizontalAlignment', 'center', 'Units',↙
'normalized','FontWeight','bold');

%% Vehicle Specs Table
data = {
    'Vehicle Type', 'Hyundai Ioniq 5 Long Range (Fast Charging)', 'Hyundai Ioniq 5 Long Range (Slow↙
Charging)', 'Wuling Air EV Long Range', 'United TX1800', 'Viar new Q1L';
    'Code in Simulation', 'EVTyp_1F', 'EVTyp_1S', 'EVTyp_2', 'EVTyp_3', 'EVTyp_4';
```

Figure B3. Supply-demand simulation script page 3 of 5.



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```
    'Driving Range (in km)', 450, 450, 300, 65, 60;
    'Battery Size (in Wh)', 72600, 72600, 26700, 1680, 1380;
    'DC Fast Charging Capability', 'Yes', 'Yes', 'No', 'No', 'No';
    'Charging Duration (in minutes)', 20, 720, 240, 90, 300;
    'Max Charging Load (in W)', '224000 DC', '11000 AC', '6600 AC', '1300 AC', '240 AC';
    'Daily Commute (in km)', 30, 30, 30, 30, 30;
    'Charge Frequency (in days)', 15, 15, 10, 2.17, 2;
    'Yearly sales in Indonesia 2023', 7176, 7176, 5575, 900, 2700;
    'Production Start', 2022, 2022, 2022, 2022, 2017
};

f = figure;
uitable('Data', data, 'ColumnName', {'', '1', '2', '3', '4', '5'}, 'Position', [50, 50, 1000, 300], ...
    'ColumnFormat', {'char', 'char', 'char', 'char', 'char', 'char'}, 'Parent', f);
title('Vehicle Type Details');
axis off;

tableHandle = findobj(f, 'Type', 'uitable');
tableHandle.FontSize = 10;

%% Plotting EV Types Demand each year
figure('units','normalized','outerposition',[1 1 1 0.66]);

subplot(3,3,1);
plot(TotDem.LoaDemEVTyp_1S, 'LineWidth', 2);
title(['EV Type 1F Hourly Demand for Scenario ',num2str(m)]);
xlabel('Time (hour of day)');
ylabel('Power (kW)');
legend('2024','2025','2026','2027','2028','2029')
grid on;

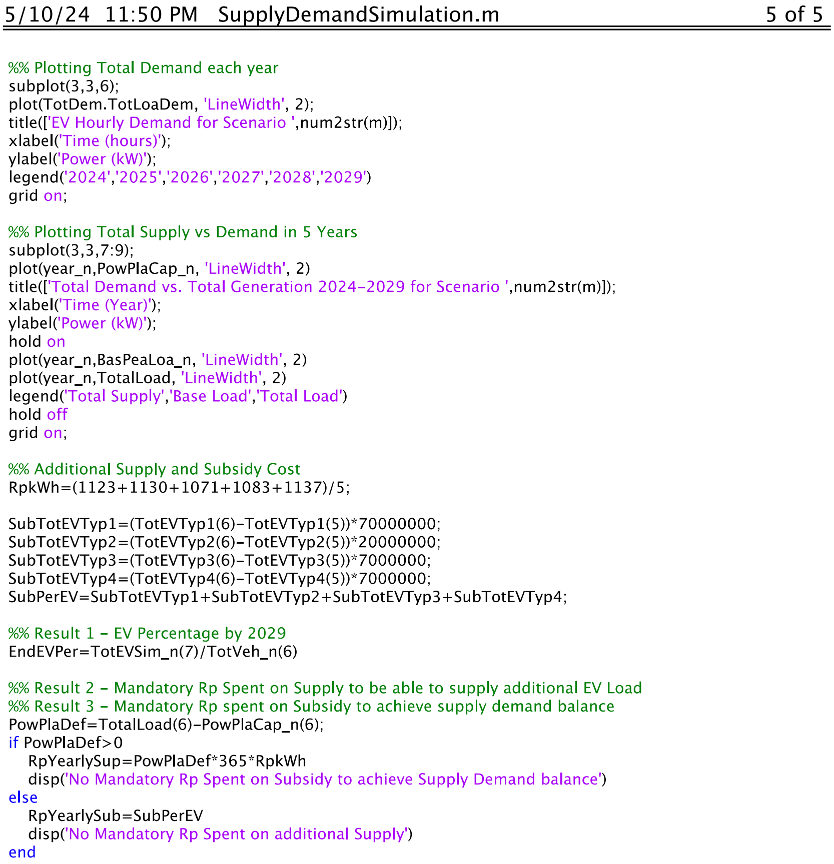
subplot(3,3,2);
plot(TotDem.LoaDemEVTyp_1F, 'LineWidth', 2);
title(['EV Type 1S Hourly Demand for Scenario ',num2str(m)]);
xlabel('Time (hour of day)');
ylabel('Power (kW)');
legend('2024','2025','2026','2027','2028','2029')
grid on;

subplot(3,3,3);
plot(TotDem.LoaDemEVTyp_2, 'LineWidth', 2);
title(['EV Type 2 Hourly Demand for Scenario ',num2str(m)]);
xlabel('Time (hour of day)');
ylabel('Power (kW)');
legend('2024','2025','2026','2027','2028','2029')
grid on;

subplot(3,3,4);
plot(TotDem.LoaDemEVTyp_3, 'LineWidth', 2);
title(['EV Type 3 Hourly Demand for Scenario ',num2str(m)]);
xlabel('Time (hour of day)');
ylabel('Power (kW)');
legend('2024','2025','2026','2027','2028','2029')
grid on;

subplot(3,3,5);
plot(TotDem.LoaDemEVTyp_4, 'LineWidth', 2);xlabel('Time (hours)');
title(['EV Type 4 Hourly Demand for Scenario ',num2str(m)]);
ylabel('Power (kW)');
legend('2024','2025','2026','2027','2028','2029')
grid on;
```

Figure B4. Supply-demand simulation script page 4 of 5.



5/10/24 11:50 PM SupplyDemandSimulation.m 5 of 5

```
%% Plotting Total Demand each year
subplot(3,3,6);
plot(TotDem.TotLoaDem, 'LineWidth', 2);
title(['EV Hourly Demand for Scenario ',num2str(m)]);
xlabel('Time (hours)');
ylabel('Power (kW)');
legend('2024','2025','2026','2027','2028','2029')
grid on;

%% Plotting Total Supply vs Demand in 5 Years
subplot(3,3,7:9);
plot(year_n,PowPlaCap_n, 'LineWidth', 2)
title(['Total Demand vs. Total Generation 2024-2029 for Scenario ',num2str(m)]);
xlabel('Time (Year)');
ylabel('Power (kW)');
hold on
plot(year_n,BasPeaLoa_n, 'LineWidth', 2)
plot(year_n,TotalLoad, 'LineWidth', 2)
legend('Total Supply','Base Load','Total Load')
hold off
grid on;

%% Additional Supply and Subsidy Cost
RpkWh=(1123+1130+1071+1083+1137)/5;

SubTotEVTyp1=(TotEVTyp1(6)-TotEVTyp1(5))*70000000;
SubTotEVTyp2=(TotEVTyp2(6)-TotEVTyp2(5))*20000000;
SubTotEVTyp3=(TotEVTyp3(6)-TotEVTyp3(5))*7000000;
SubTotEVTyp4=(TotEVTyp4(6)-TotEVTyp4(5))*7000000;
SubPerEV=SubTotEVTyp1+SubTotEVTyp2+SubTotEVTyp3+SubTotEVTyp4;

%% Result 1 - EV Percentage by 2029
EndEVPer=TotEVSim_n(7)/TotVeh_n(6)

%% Result 2 - Mandatory Rp Spent on Supply to be able to supply additional EV Load
%% Result 3 - Mandatory Rp spent on Subsidy to achieve supply demand balance
PowPlaDef=TotalLoad(6)-PowPlaCap_n(6);
if PowPlaDef>0
    RpYearlySup=PowPlaDef*365*RpkWh
    disp('No Mandatory Rp Spent on Subsidy to achieve Supply Demand balance')
else
    RpYearlySub=SubPerEV
    disp('No Mandatory Rp Spent on additional Supply')
end
```

Figure B5. Supply-demand simulation script page 4 of 5.

Appendix C – MATLAB Scripts (Global Simulation)

5/10/24 11:44 PM GlobalSimulationStart.m 1 of 3

```
%% Start
clear
clc
close all

%% Input Permutation
Comb=combinator(3,7,'p','r');

i=(2:2188)';
PermPowPlaGF=[i,Comb(1:2187,1)]-1;
PermBasPeaLoaGF=[i,Comb(1:2187,2)]-1;
PermTotVehGF=[i,Comb(1:2187,3)]-1;
PermPerEVGF=[i,Comb(1:2187,4)]-1;
PermSubImpGF=[i,Comb(1:2187,5)]-1;
PermPerEVTypGF=[i,Comb(1:2187,6)]-1;
PermFasSloRatGF=[i,Comb(1:2187,7)]-1;

InpPerm=sim("InputPermutation.slx");

PowPlaGF=InpPerm.PowPlaGF;
BasPeaLoaGF=InpPerm.BasPeaLoaGF;
TotVehGF=InpPerm.TotVehGF;
PerEVGF=InpPerm.PerEVGF;
SubImpGF=InpPerm.SubImpGF;
PerEVTypSce=InpPerm.PerEVTypSce;
FasSloRatSce=InpPerm.FasSloRatSce;

%% Simulation Loop
for m=1:1:2187
    disp ('------------')
    disp (['m is equal to ',num2str(m)])

    PowPlaCapGF_m=PowPlaGF(m,1);
    BasPeaLoaGF_m=BasPeaLoaGF(m,1);
    TotVehGF_m=TotVehGF(m,1);
    PerEVGF_m=PerEVGF(m,1);
    SubImpGF_m=SubImpGF(m,1);
    PerEVTypSce_m=PerEVTypSce(m,1);
    FasSloRatSce_m=FasSloRatSce(m,1);

    run("SupplyDemandSimulation.m")

    EndEVPercentage(m)=EndEVPer;
    if PowPlaDef>0
    RpYearlySupply(m)=RpYearlySup;
    RpYearlySubsidy(m)=0;
    else
    RpYearlySupply(m)=0;
    RpYearlySubsidy(m)=RpYearlySub;
    end
end

%% find best result
disp ('------------')
disp ('END RESULTS')

RpYearlySupplyNonzero=RpYearlySupply(RpYearlySupply~=0);
RpYearlySubsidyNonzero=RpYearlySubsidy(RpYearlySubsidy~=0);

[BestEVPer,idxbest]=max(EndEVPercentage);
AltBest=find(EndEVPercentage==BestEVPer);
```

Figure C1. Global simulation script page 1 of 3.

doi:10.20944/preprints202405.0955.v1

5/10/24 11:44 PM GlobalSimulationStart.m 2 of 3

```
RpBestYearly=[RpYearlySupply(1,AltBest),RpYearlySubsidy(1,AltBest)];
RpBestYearlyNonzero=RpBestYearly(RpBestYearly~=0);
RpBestMin=min(RpBestYearlyNonzero);

idxBestSupply=find(RpYearlySupply==RpBestMin);
idxBestSubsidy=find(RpYearlySubsidy==RpBestMin);

if isempty(idxBestSupply)
    idxBest=idxBestSubsidy(1);
else
    idxBest=idxBestSupply(1);
end

disp (['Best case scenario is Scenario ',num2str(idxBest), ', by 2029:'])
disp (['Yearly supply cost is Rp',num2str(RpYearlySupply(idxBest))])
disp (['Yearly subsidy cost is Rp',num2str(RpYearlySubsidy(idxBest))])

%% find worst result
[WorstEVPer,idxworst]=min(EndEVPercentage);
AltWorst=find(EndEVPercentage==WorstEVPer);

RpWorstYearly=[RpYearlySupply(1,AltWorst),RpYearlySubsidy(1,AltWorst)];
RpWorstYearlyNonZero=RpWorstYearly(RpWorstYearly~=0);
RpWorstMax=max(RpWorstYearlyNonZero);

idxWorstSupply=find(RpYearlySupply==RpWorstMax);
idxWorstSubsidy=find(RpYearlySubsidy==RpWorstMax);

if isempty(idxWorstSupply)
    idxWorst=idxWorstSubsidy(1);
else
    idxWorst=idxWorstSupply(1);
end

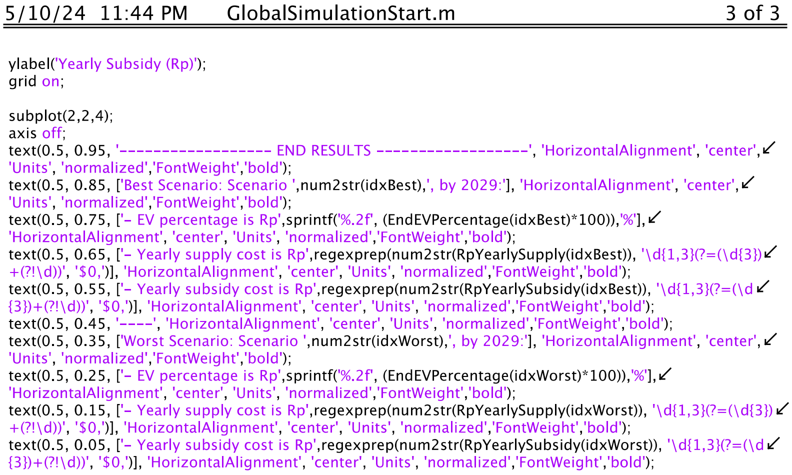
disp ('--')
disp (['Worst case scenario is Scenario ',num2str(idxWorst), ', by 2029:'])
disp (['Yearly supply cost is Rp',num2str(RpYearlySupply(idxWorst))])
disp (['Yearly subsidy cost is Rp',num2str(RpYearlySubsidy(idxWorst))])

%% Plotting End Results
figure('units','normalized','outerposition',[0 0 1 1]);
subplot(2,2,1);
plot(EndEVPercentage,'r', 'LineWidth', 1)
legend('End EV Percentage')
title('EV Percentage by 2029');
xlabel('Scenario Number');
ylabel('EV Population (%)');
grid on;

subplot(2,2,2);
plot(RpYearlySupply,'b', 'LineWidth', 1)
legend('RpYearlySupply')
title('Yearly Supply Cost Allocation for 2029');
xlabel('Scenario Number');
ylabel('Yearly Supply (Rp)');
grid on;

subplot(2,2,3);
plot(RpYearlySubsidy,'g', 'LineWidth', 1)
legend('RpYearlySubsidy')
title('Yearly Subsidy Cost Allocation for 2029');
xlabel('Scenario Number');
```

Figure C2. Global simulation script page 2 of 3.



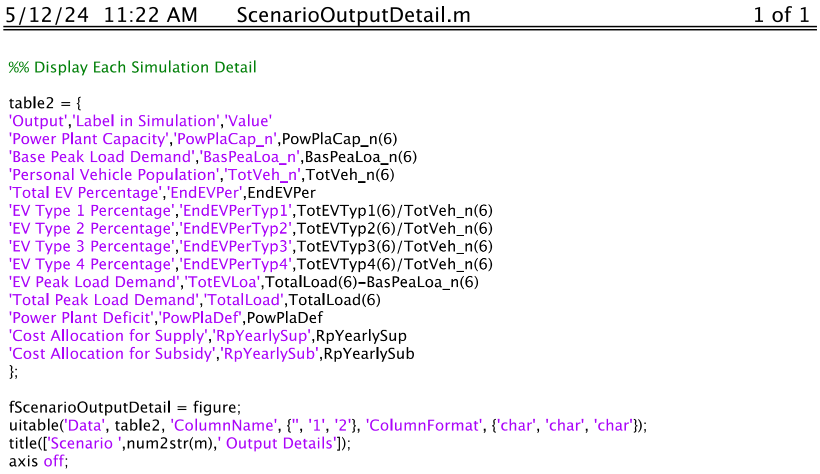
5/10/24 11:44 PM GlobalSimulationStart.m 3 of 3

```
ylabel('Yearly Subsidy (Rp)');
grid on;

subplot(2,2,4);
axis off;
text(0.5, 0.95, '------------------ END RESULTS ------------------', 'HorizontalAlignment', 'center',↙
'Units', 'normalized','FontWeight','bold');
text(0.5, 0.85, ['Best Scenario: Scenario ',num2str(idxBest),', by 2029:'], 'HorizontalAlignment', 'center',↙
'Units', 'normalized','FontWeight','bold');
text(0.5, 0.75, ['- EV percentage is Rp',sprintf('%.2f', (EndEVPercentage(idxBest)*100)),'%'],↙
'HorizontalAlignment', 'center', 'Units', 'normalized','FontWeight','bold');
text(0.5, 0.65, ['- Yearly supply cost is Rp',regexprep(num2str(RpYearlySupply(idxBest)), '\d{1,3}(?=(\d{3})↙
+(?!\d))', '$0,')], 'HorizontalAlignment', 'center', 'Units', 'normalized','FontWeight','bold');
text(0.5, 0.55, ['- Yearly subsidy cost is Rp',regexprep(num2str(RpYearlySubsidy(idxBest)), '\d{1,3}(?=(\d↙
{3})+(?!\d))', '$0,')], 'HorizontalAlignment', 'center', 'Units', 'normalized','FontWeight','bold');
text(0.5, 0.45, '----', 'HorizontalAlignment', 'center', 'Units', 'normalized','FontWeight','bold');
text(0.5, 0.35, ['Worst Scenario: Scenario ',num2str(idxWorst),', by 2029:'], 'HorizontalAlignment', 'center',↙
'Units', 'normalized','FontWeight','bold');
text(0.5, 0.25, ['- EV percentage is Rp',sprintf('%.2f', (EndEVPercentage(idxWorst)*100)),'%'],↙
'HorizontalAlignment', 'center', 'Units', 'normalized','FontWeight','bold');
text(0.5, 0.15, ['- Yearly supply cost is Rp',regexprep(num2str(RpYearlySupply(idxWorst)), '\d{1,3}(?=(\d{3})↙
+(?!\d))', '$0,')], 'HorizontalAlignment', 'center', 'Units', 'normalized','FontWeight','bold');
text(0.5, 0.05, ['- Yearly subsidy cost is Rp',regexprep(num2str(RpYearlySubsidy(idxWorst)), '\d{1,3}(?=(\d↙
{3})+(?!\d))', '$0,')], 'HorizontalAlignment', 'center', 'Units', 'normalized','FontWeight','bold');
```

Figure C3. Global simulation script page 3 of 3.

Appendix D – MATLAB Script (Scenario Output Details)



5/12/24 11:22 AM ScenarioOutputDetail.m 1 of 1

```
%% Display Each Simulation Detail

table2 = {
'Output','Label in Simulation','Value'
'Power Plant Capacity','PowPlaCap_n',PowPlaCap_n(6)
'Base Peak Load Demand','BasPeaLoa_n',BasPeaLoa_n(6)
'Personal Vehicle Population','TotVeh_n',TotVeh_n(6)
'Total EV Percentage','EndEVPer',EndEVPer
'EV Type 1 Percentage','EndEVPerTyp1',TotEVTyp1(6)/TotVeh_n(6)
'EV Type 2 Percentage','EndEVPerTyp2',TotEVTyp2(6)/TotVeh_n(6)
'EV Type 3 Percentage','EndEVPerTyp3',TotEVTyp3(6)/TotVeh_n(6)
'EV Type 4 Percentage','EndEVPerTyp4',TotEVTyp4(6)/TotVeh_n(6)
'EV Peak Load Demand','TotEVLoa',TotalLoad(6)-BasPeaLoa_n(6)
'Total Peak Load Demand','TotalLoad',TotalLoad(6)
'Power Plant Deficit','PowPlaDef',PowPlaDef
'Cost Allocation for Supply','RpYearlySup',RpYearlySup
'Cost Allocation for Subsidy','RpYearlySub',RpYearlySub
};

fScenarioOutputDetail = figure;
uitable('Data', table2, 'ColumnName', {'', '1', '2'}, 'ColumnFormat', {'char', 'char', 'char'});
title(['Scenario ',num2str(m),' Output Details']);
axis off;
```

Figure D1. Scenario Output Details Script.

Appendix E – Simulink Model (Supply Demand Simulation)

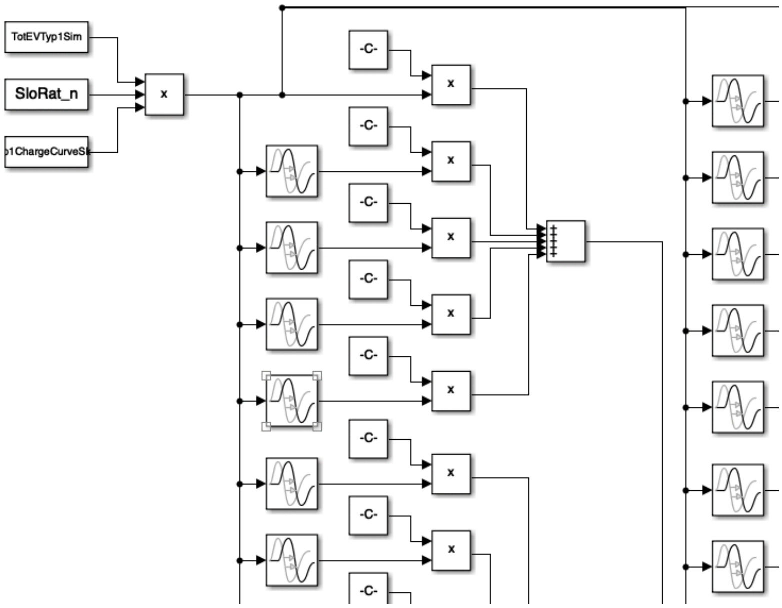


Figure E1. Simulink Model for Demand Simulation 1.

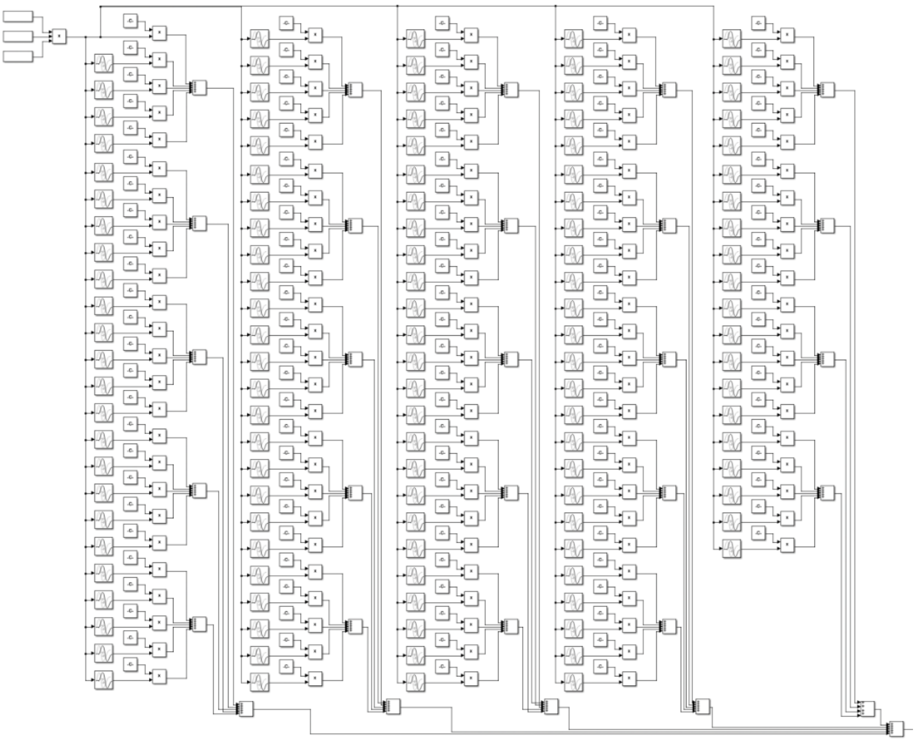


Figure E2. Simulink Model for Demand Simulation 2.

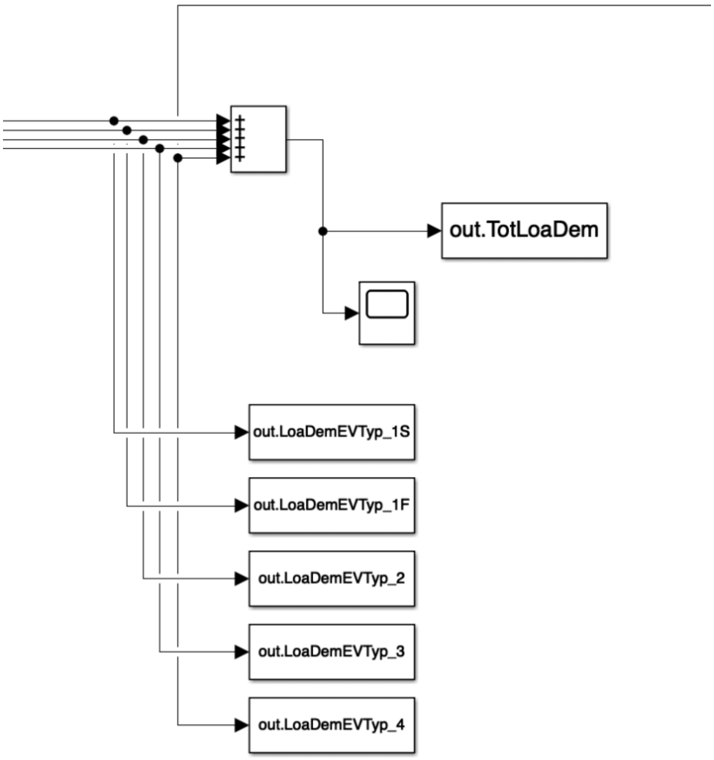


Figure E3. Simulink Model for Demand Simulation 3.

Figure E4. Simulink Model for Demand Simulation 4.

Appendix F – Simulink Model (Input Permutation)

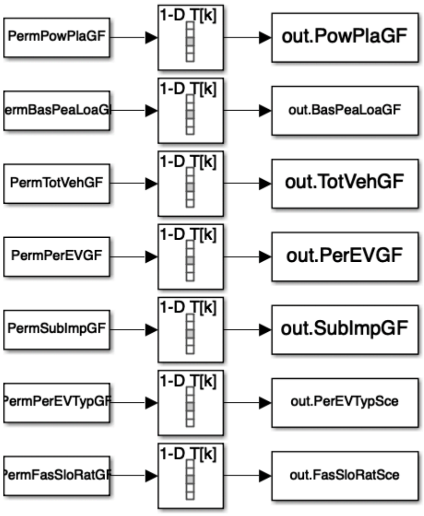


Figure F1. Simulink Model Input Permutation.

Appendix G – Results Data and Graphs

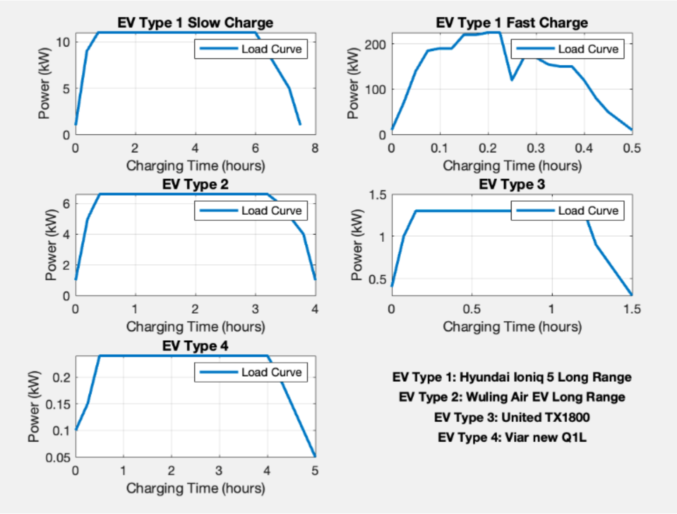
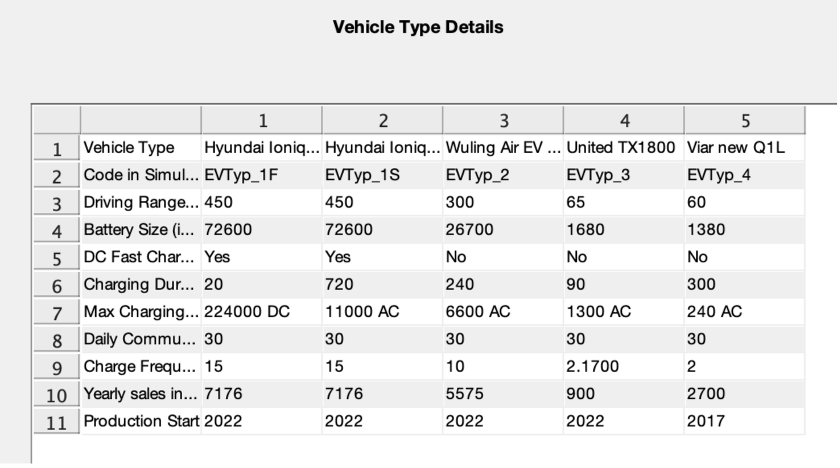


Figure G1. EV Charge Curves.



Vehicle Type Details

		1	2	3	4	5
1	Vehicle Type	Hyundai Ioniq...	Hyundai Ioniq...	Wuling Air EV ...	United TX1800	Viar new Q1L
2	Code in Simul...	EVTyp_1F	EVTyp_1S	EVTyp_2	EVTyp_3	EVTyp_4
3	Driving Range...	450	450	300	65	60
4	Battery Size (i...	72600	72600	26700	1680	1380
5	DC Fast Char...	Yes	Yes	No	No	No
6	Charging Dur...	20	720	240	90	300
7	Max Charging...	224000 DC	11000 AC	6600 AC	1300 AC	240 AC
8	Daily Commu...	30	30	30	30	30
9	Charge Frequ...	15	15	10	2.1700	2
10	Yearly sales in...	7176	7176	5575	900	2700
11	Production Start	2022	2022	2022	2022	2017

Figure G2. EV Type Specifications.

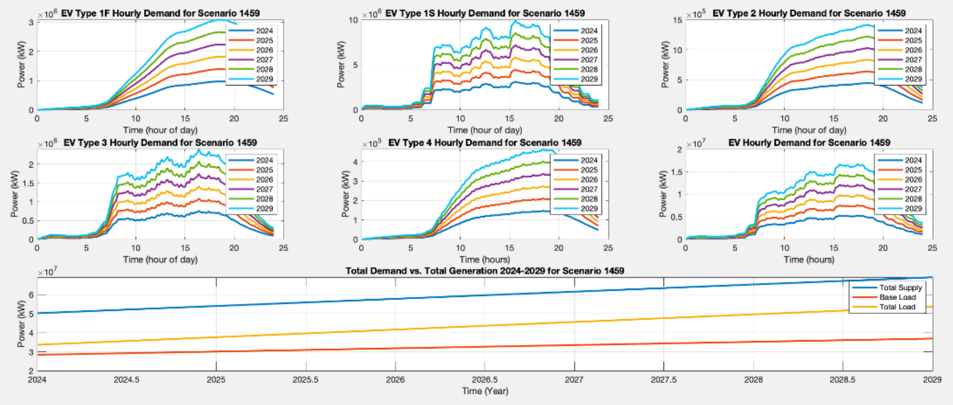
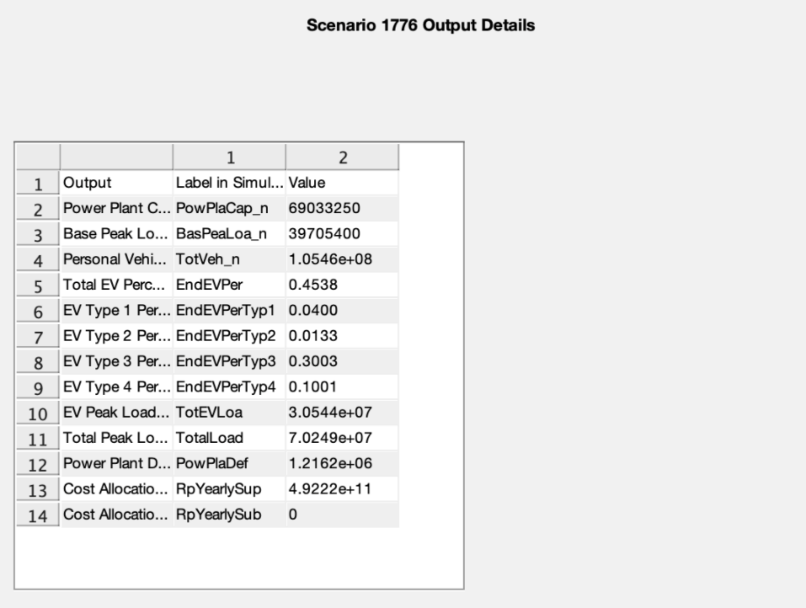


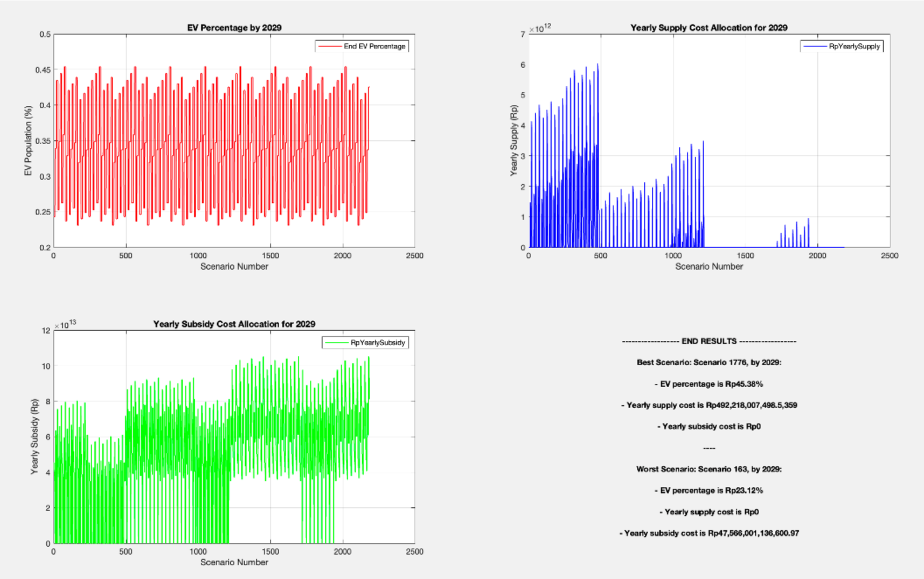
Figure G3. Scenario Output Graphs.



Scenario 1776 Output Details

		1	2
1	Output	Label in Simul...	Value
2	Power Plant C...	PowPlaCap_n	69033250
3	Base Peak Lo...	BasPeaLoa_n	39705400
4	Personal Vehi...	TotVeh_n	1.0546e+08
5	Total EV Perc...	EndEVPer	0.4538
6	EV Type 1 Per...	EndEVPerTyp1	0.0400
7	EV Type 2 Per...	EndEVPerTyp2	0.0133
8	EV Type 3 Per...	EndEVPerTyp3	0.3003
9	EV Type 4 Per...	EndEVPerTyp4	0.1001
10	EV Peak Load...	TotEVLoa	3.0544e+07
11	Total Peak Lo...	TotalLoad	7.0249e+07
12	Power Plant D...	PowPlaDef	1.2162e+06
13	Cost Allocatio...	RpYearlySup	4.9222e+11
14	Cost Allocatio...	RpYearlySub	0

Figure G4. Scenario Output Details.



```
----------------- END RESULTS -----------------

Best Scenario: Scenario 1776, by 2029:

- EV percentage is Rp45.38%

- Yearly supply cost is Rp492,218,007,496.5,359

- Yearly subsidy cost is Rp0

----

Worst Scenario: Scenario 163, by 2029:

- EV percentage is Rp23.12%

- Yearly supply cost is Rp0

- Yearly subsidy cost is Rp47,566,001,136,600.97
```

Figure G5. Global Simulation Output Graphs.

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