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Regional Case Study

Analysis of Greenhouse Gas Emission Load and Emission Reduction from Switching to Electric Vehicles: A Case Study of Java Island

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Abstract

In order to mitigate the impact of climate change arising from Greenhouse Gas (GHG) emissions generated from the transportation sector, many countries including Indonesia, have initiated to develop policies to encourage environmentally friendly transportation technologies. Electric vehicles represent a highly sustainable alternative when compared to conventional vehicles. This study aims to assess the potential reduction of GHG emissions from the shifting to electric vehicle utilization on Java Island. The research method was conducted by modeling conventional vehicles until 2033 where there was a transition to electric vehicles throughout the model year and then calculating the GHG emission. This study employs three scenarios : Business As Usual (BAU), Electric Vehicle Plan (EVP) with existing scenario power plant and Electric Vehicle Plan (EVP) with National Energy Plan (NEP) scenario power plant. Model results revealed potential GHG emission reductions within 12.11% from the Existing EVP scenario and 12.54% from the NEP scenario against the BAU scenario due to the shifting usege of electric vehicles on Java island. Based on the model results, it is possible to determine that shifting from conventional vehicles to electric vehicles can reduce GHG emissions from conventional vehicle use.

Keywords: GHG; Electric Vehicle; Java Island

1. Introduction

The increase in greenhouse gas (GHG) emissions were influenced by various human activities including fossil fuel combustion, deforestation, agriculture, transportation and industrial waste (Cahyono et al, 2022). The resulting emissions are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halocarbons (a group of gases containing fluorine, chlorine and bromine). These gases accumulate in the atmosphere, causing the concentration to increase over time (Ya-Min et al, 2014). The resulting increase in GHG emissions could alter the global climate balance, leading to rising global temperatures, increased intensity of extreme weather phenomena and significant changes in the natural environment (Solomon et. al, 2007).

Greenhouse gas (GHG) emissions from the vehicle sector are one of the most significant environmental issues worldwide, especially in countries with high vehicle use. For example, the US Environmental Protection Agency (US EPA) reported in 2021 that GHG emissions in the United States reached 6,34 million cubic meters of CO_2 equivalent, with the transportation sector accounting for the largest share, at 28% of total emissions. In Indonesia, the transportation sector accounted for 44,2% of total national energy consumption in 2021, up about 6,7% compared to 2020 (Dewan Energi Nasional, 2022). This high energy consumption is proportional to the energy demand and emissions produced. One source of GHG emissions is the combustion of fossil fuels such as petroleum, natural gas, and coal that release CO_2 and other greenhouse gases into the atmosphere (Perera, 2019). The Java-Bali region has the highest energy consumption in the transportation sector (Dewan Energi Nasional, 2022). According to central statistics agency of Indonesia data in 2022, Java Island has 11.335.573 motor vehicles, or about 66% of the total vehicles in Indonesia, indicating the highest vehicle mobilization in the country.

The demand for transportation in fulfilling the transportation requirements of both people and commodities as an economic activity has led to the high consumption of oil and fuel. This also has an environmental impact on the increase in greenhouse gas emissions produced as explained based on data from the Indonesian Ministry of Energy and Mineral Resources that in 2021 the transportation sector produces ± 143 million tons of CO_2 equivalent. Therefore, the challenge for Indonesia's transportation sector is to develop policies to reduce the use of fossil fuels and also take action to reduce greenhouse gas emissions, such as the use of electric cars.

The development of electric vehicles is actually not a new technology within the transportation sector. Electric vehicle technology has been discovered and widely used since the 18th century. Indonesia has now begun to carry out policies related to the transition from the use of fossil fuels to renewable energy sources, including the issuance of *Peraturan Presiden Republik Indonesia Nomor 55 tahun 2019 tentang "Percepatan Program Kendaraan Bermotor Listrik Berbasis Baterai* (Battery Electric Vehicle) *Untuk Transportasi Jalan"* and *Instruksi Presiden Republik Indonesia Nomor 7 tahun 2022 tentang "penggunaan kendaraan bermotor listrik berbasis baterai* (battery electric vehicle) *sebagai kendaraan dinas operasional dan/atau kendaraan perorangan dinas instansi Pemerintah Pusat dan Pemerintah Daerah"*. Government regulations on EV adoption are expected to encourage growth in electricity car use, which is expected to reduce CO2 emissions from the consumption of fossil fuels. Reducing CO_2 by reducing fossil fuels can reduce global warming potential which affects climate change (lelieveld. 2019).

The shifting of conventional vehicles to electric vehicles provides various benefits such as a significant reduction in fossil energy demand (Johansson et al, 2012), energy efficiency (Aziz and Oda, 2017), minimizing environmental impacts and improving driver performance (Aziz and Huda, 2019), and will not produce exhaust emissions (Simbolon, 2022). Research in New York City shows that the adoption of electric vehicles can reduce emissions by 1,100 tons/day (Lokhandwala & Cai, 2020). A similar thing is also explained by Guo's (2023) research in China, which explains that the adoption of electric vehicles has proven effective in promoting energy savings and emission reduction. If examined more deeply, high mobility in the transportation sector in Java Island which reaches around 66% of the total number vehicles in Indonesia will have a significant impact for reducing emissions from the transportation sector. Thus, further research is needed to assess what kind of impact will result from the transition to electric vehicles.

When compared based on exhaust gases, electric vehicles are definitely more environmentally friendly compared to conventional vehicles, but by using electric vehicles doesn't mean there are no CO_2 emissions produced, because electric vehicles require electrical energy from power plants. Power plants in Indonesia are mostly generated by utilizing fossil fuels (fuels formed from the natural processes of organisms that have died millions of years ago such as coal, petroleum, or natural gas). The composition of electricity generation in Indonesia based on energy use statistics is coal by 63,07%, natural gas by 11,01%, liquefied natural gas by 4,09% fuel oil by 2,56% while the remaining 19,17% is sourced from new renewable energy (ESDM-RI, 2022). Thus, electricity generation in Indonesia is still highly dependent on fossil energy (80,73%) with coal still dominating.

The high level of fossil fuel use in Indonesia's power plants has prompted the government to look at ways to provide policies for reducing CO_2 emissions. Besides the policy of using electric cars, the government also has a policy of implementing carbon pricing instruments or *Nilai Ekonomi Karbon* (NEK). This policy instrument will provide economic value for GHG emissions so that arbitrary emission behavior will be minimized, including in this case power plants. The current implementation of carbon pricing in Indonesia is carbon tax, carbon tax is a tax imposed on carbon emissions that have a negative impact on the environment which is regulated in "*Peraturan Pemerintah Republik Indonesia Nomor 50 tahun 2022 tentang Tata Cara Pelaksanaan Hak dan Pemenuhan Kewajiban Perpajakan*".

Besides the energy used and emissions produced, the challenges of using electric vehicles in Indonesia currently are the reliance on electric charging stations is still very high, the efficiency of electric vehicle charging time is very long, the price of electric batteries is still very expensive, which affects the selling price of electric vehicles (Simbolon, 2022). To overcome this, the government is currently encouraging the provision of subsidies for the general public who want to buy electric vehicles to switch from conventional vehicles. The relationship between the economic values of electric vehicles today is of course very influential in terms of the electric vehicle growth in Indonesia considering that the majority of Indonesian people are 29.5% of the lower middle class and 63.4% of the lower class (Central Bureau of Statistics, 2020).

There are several similar studies that support the author to research on this topic. In research from Simbolon (2022), it is explained about the electric vehicle policy literature adopted from the comparison of electric vehicle policies in South Korea and Indonesia, it is concluded that BEVs have advantages they do not produce exhaust emissions. This encourages the author to conduct research to quantitatively prove the comparison of emissions from electric vehicles with conventional vehicles whether it is really environmentally friendly or not. Meanwhile, Ulfa, et. al. (2017) explains the concept of calculating GHG emissions from mobile vehicle sources, this becomes the author's reference in calculating electric vehicle emissions because they are the same as mobile emission sources. The studies that explained by Susanto, et. al. (2012) is taken as a reference source because the researcher uses a dynamic model approach for explaining the residential energy use in the city of Suita, considering the installation of solar PV systems and government subsidies to promote installations related to socio-economic driving factors with variables used including population, number of families, GDP per capita, the effect of energy consumption on family income, residential energy consumption, CO_2 emissions generated, solar panel installation capacity, installation rate. While Azmi (2016) had research that are explains emissions from passenger vehicles in Malaysia and its projections in the coming year using a dynamic modeling system which is demographically and geographically similar to Indonesia.

Based on the existing literature reviews and Based on the research background that has been described, this research will examine the reduction in GHG emissions, as well as the subsidy costs required from the shift to the use of electric vehicles in units of rupiah per kg of CO_2 with a dynamic modeling approach. The software used is Analytica 6.1 with dynamic mathematical principles. The case study in this research includes motorcycle and car type vehicles with regional coverage in Java Island due to considering the large number of vehicles owned and the centralization of the Indonesian economy in Java Island.

The high mobility of transportation in Indonesia is directly proportional to the GHG emissions that are produced. Electric vehicles are expected to be more energy efficient and reduce GHG emissions. In accordance with the subsidy policy set by the Indonesian government to encourage the use of electric vehicles, the problem arises to convince the Indonesian people of the emission reduction potential of using electric vehicles. Thus, this research is expected to provide information to the public on how energy efficiency and emissions generated from electric vehicles that are projected for the next few years.

2. Methods

The study was conducted on the island of Java, which is the center of economic activity in Indonesia. The mainland of Java Island stretches from west to east with an area of approximately 128,297 km2. Administratively, Java Island consists of 6 provinces including Banten, DKI Jakarta, West Java, Central.

This research scenario model uses 2 scenarios, namely Business as Usual (BAU) and Electric Vehicle Plan (EVP). The BAU scenario assumes that the trend of conventional vehicle use will continue throughout the modeled years assuming there is no government subsidy policy or transition policy towards electric vehicles. while the EVP Scenario assumes that the trend of conventional vehicle use will continue throughout the modeled years but there will be a transition to electric vehicles due to the Indonesian Government subsidy policy.

Table 1. Model scenario

Komponen	BAU	EVP
Definition	Assumed vehicle growth without a policy to shift towards electric vehicles	Shift towards electric vehicles depending on government subsidies
Driving Force : Subsidies	Without a subsidy policy for electric vehicle switching	With government subsidies, electric vehicles are assumed to replace and reduce the number of conventional vehicles.
	Number of Vehicles	
Assumption :	There is no transition from conventional vehicles to electric vehicles	Subsidies are expected to influence people to shift towards electric vehicles
Indicator to be evaluated	CO_2 emissions Subsidy cost / policy cost	
Time : Time horizon of the model	2015 – 2033	
Modeled subsidy policy time	-	2023 – 2033 (10 years for modeling)

2.1. Vehicle growth

Number of vehicles is the main variable for calculating GHG emissions that are analyzed in these modeling systems. Vehicles in this research model are limited to two-wheeled vehicles (motorcycles) and four-wheeled vehicles (cars) with the justification that these vehicles are possible to be purchased privately and used by the general public. The growth of vehicle numbers will be calculated in both model scenarios used, the calculation number of vehicles is used to determine how many vehicles are in the modeling year.

1) Conventional Vehicle Growth (BAU Scenario)

   The BAU model scenario assumes that conventional vehicle use will continue throughout the modeled years, namely 2023 - 2033, with no government subsidy policies and electric vehicle switching policies assumed. The number of vehicles in 2015 to 2022 uses historical data sourced from BPS (Central Bureau of Statistics) Indonesia, while the number of vehicles 2023 to 2033 uses modeling projection data.

2) Electric Vehicle Growth (EVP Scenario)

   The EVP model assumes that conventional vehicle usage trend will continue during the modeled years but the number of vehicles will be affected by the shift to electric vehicles due to the Indonesian Government's subsidy policy. The number of electric vehicles is calculated based on the percentage obtained from secondary data and then accumulated based on the existing number of electric vehicles in 2022. Secondary data literature comes from research conducted by the Asian Development Bank (ADB, 2022), in that research the percentage of electric vehicle growth was obtained based on economic aspects such as population growth and government subsidies in one of the Java Island regions, thus in this research the percentage is used as an assumption for the calculation of the electric vehicle growth model.

Table 2. Electric vehicle growth percentage scenario

Years	Precentage[1]
2023	219%
2024	130%
2025	95%
2026	72%
2027	60%
2028	51%
2029	51%
2030	52%
2031	53%
2032	54%
2033	55%

Source: ADB, 2022

2.1.1. Energy Consumption

Number of vehicles from the model results that have been obtained are then processed with further data to obtain the total amount of energy consumption, energy consumption unit used is terajoule (TJ). The TJ unit was used following the GHG calculation guidelines from IPCC 2006. To be able to determine the energy demand of the vehicle, it is necessary to know the average daily vehicle travel distance of the vehicle owner, the amount of fuel usage based on the mileage, fuel type, fuel density, and fuel calorific value. For ease of explanation, these input variables in the energy projection modeling are described in Table 3.

Table 3. Input variables in energy consumption calculation

Variable	BAU	EVP
Average vehicle travel distance (km/day) [1]	Car = 28,64 km/day Motorcycle = 17,35 km/day	Car = 28,64 km/day Motorcycle = 17,35 km/day
Energy consumption of the vehicle (L/km) [2]	Car = 1 liter / 10 km Motorcycle = 1 liter / 59,5 km	Car = 0,0000004224075 Tj/km Motorcycle = 0,0000000954 Tj/km
Density or specific gravity of fuel (for conventional vehicles) is assumed to be gasoline (pertalite). [3]	729,63 kg/m³	-
***Calor Value* (for conventional vehicles)** [4]	Net Calori Value (NCV)= 44,3 TJ/Gg Lower Calori Value = 42,5 TJ/Gg Upper Calori Value = 44,8 TJ/Gg	-

Source:
[1] questionnaire

[2] *Automobile distributor web*

[3] *Yanuar, et. al., 2018*

[4] *IPCC 2006 Chapter 1*

The data in Table 3 are equalized to TJ units and were calculated for each year (365) days throughout the modeling year following the number of vehicles in each year. After the units are equalized, the next step is to calculate the GHG emissions generated based on energy use each year.

2.1.2. Estimated Greenhouse Gas (GHG) emission loading

Calculation of GHG emission load is divided into 2 scenarios, namely:

1) Conventional Vehicle Growth (BAU Scenario)

The GHG emission calculation of conventional vehicles used the guidelines of "IPCC 2006 chapter 3: mobile combustion" using the Tier 1 method.

$$\text{Emission}(CO_2, CH_4, NO_2) = \sum \text{Fuel (Tj)x emission factor} \left(\frac{\text{Kg}}{\text{Tj}}\right)$$

Table 4. CO2 emission factor of gasoline fuel

	Emission Factor		
	CO_2 (Kg/TJ)	CH_4 (Kg/TJ)	N_2O (Kg/TJ)
Lower	67.500	9,6	0,96
Default	69.300	33	3,2
Upper	73.000	110	11

2) Electric Vehicle Growth (EVP Scenario)

The calculation of GHG emissions of electric vehicles used the guidelines of "IPCC 2006 chapter 2: stationary combustion" with the Tier 2 method. Electric vehicle emissions originated from coal, oil and gas-fired power plants. In this study, Power vehicles' energy consumption is derived from power plants. In this study, energy consumption is calculated using 2 scenarios, namely the "**Existing (EKS)**" scenario based on the percentage of power plants obtained from Indonesia's energy use statistics in 2022 which is assumed to remain unchanged until 2033 and the "**National Energy Policy (NEP)**" scenario which is the target of the Government of Indonesia based on Government Regulation No. 79 of 2014 concerning the National Energy Policy.

$$\text{Emission}(CO_2, CH_4, NO_2) = \sum \text{Fuel (Tj)x emission factor} \left(\frac{\text{Kg}}{\text{Tj}}\right)$$

Table 5. Coal-fired power plant emission factor

	Emission Factor		
	CO_2 (Kg/TJ)	CH_4 (Kg/TJ)	N_2O (Kg/TJ)
Lower	87.300	0,3	0,5
Default	94.600	1	1,5
Upper	101.000	3	5

Table 6. Emission factor of fuel oil power plants

	Emission Factor		
	CO_2 (Kg/TJ)	CH_4 (Kg/TJ)	N_2O (Kg/TJ)
Lower	67.500	1	0,2
Default	69.300	3	0,6
Upper	73.000	10	2

Table 7. Natural gas power plant emission factor

	Emission Factor		
	CO_2 (Kg/TJ)	CH_4 (Kg/TJ)	N_2O (Kg/TJ)
Lower	54.300	0,3	0,03
Default	56.100	1	0,1
Upper	58.300	3	0,3

GWP is an index that measures how much heat (radiation force) will be trapped by one unit of GHG in the atmosphere over a certain period of time expressed by the amount of CO_2 that will be trapped.

Table 8. Greenhouse gases and the value of global warming potential

Greenhouse Gases	Global Warming Potential (CO_2-eq) in 100 year
CO_2	1
CH_4	27
N_2O	273

Source: IPCC, 2021

2.1.3. Greenhouse Gas Analysis with Dynamic Modeling

The greenhouse gas analysis method used is a dynamic model simulation using Analytica 6.1 software. The development of the dynamic model begins with the conceptualization of the GHG emission system generated using a causal-loop diagram or loop diagram. Loop diagrams will explain the relationship between variables in the system that will illustrate the cause and effect in the system. The structure of the model is created and simulated based on Monte Carlo simulation, Prediction using Monte Carlo requires that the same data be tested repeatedly using random numbers that are different but have uniformity so that information can be generated more efficiently.

The model structure is organized in the form of flow diagrams in Analytica 6.1 software. Modeling using Analytica 6.1 software is used to map the relationship between variables in the model diagram.

Table 9. Explanation of Input Diagram in Analityca 6.1

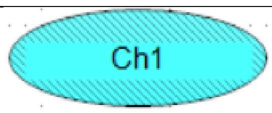
Diagram	Description
	Variable node or variable symbol is a diagram with dark blue color. The function of this diagram is to streamline the calculation mechanism and input equations/formulas in the analysis. Each calculation inputted based on the diagram will automatically provide a connecting arrow.
	Chance node or possibility symbol is a diagram with light blue color. The function of this diagram is to input probabilistic data that is used as the basis for calculations on variable nodes such as average travel distance and emission factors.

Diagram	Description
	Constant node or constant symbol is a diagram with brown color. The function of this diagram is to input constant / fixed data which is used as the basis for calculations on variable nodes such as the number of days and the number of existing vehicles based on secondary data.
	Index node or index symbol is a diagram with purple color. The function of this diagram is to input data that has a different type which is used as the basis for calculations on variable nodes, in this model the index node is for inputting different types of power plants.

2.2. Model Validation

Model validation was carried out to determine errors and deficiencies in a model created by comparing historical data and model output values. The model validation stage requires consistency of units and model formulations set. It is necessary to compare the output values generated from modeling in Analytica 6.1 with data pairing tests using actual data. Model validation at this stage focuses on the independent variables that have been collected from 2015 to 2022. The comparison of historical data with modeling output values was carried out using Microsoft Excel in entering the numbers of both data, and then data verification was carried out to determine the projections that had been generated from the comparison of modeling output values and historical values.

Historical data was analyzed using the Mean Absolute Percentage Error (MAPE) equation where MAPE is the calculation of an absolute error in each period divided by the real observed value for that period. MAPE can be an error measurement that calculates the size of the percentage of a deviation between actual data and presumed data. MAPE is an error measurement that calculates the size of the percentage deviation between actual data and forecast data. This method is calculated by going through the absolute error of each period, then dividing by the actual value in that period. Furthermore, it can calculate the average accuracy of the sum of the absolute percentages (Khair, 2017).

3. Result and Discussion

Data processing analysis was carried out using Microsoft excel to process data, such as primary data and secondary data. The calculation standard uses the 2006 International Panel on Climate Change (IPCC) guidelines for National Greenhouse Gas Inventories, especially for Mobile and Stationary Combustion. Data were calculated and searched for mean, standard deviation, normal distribution based on the Bussines as Usual (BAU) scenario, as well as the Electric Vehicle Plan (EVP) growth scenario. These can be used in scenario modeling in Analytica 6.1.

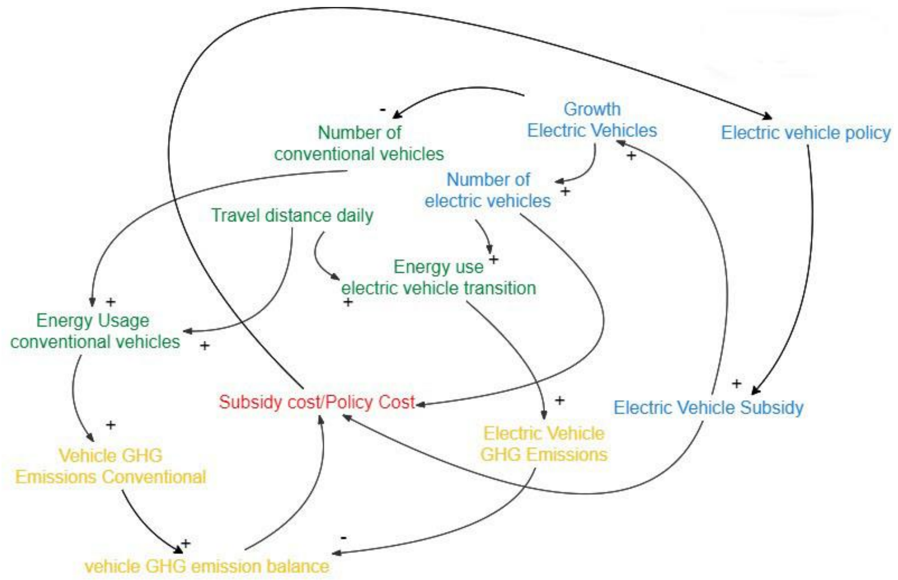


Figure 1. Loop diagram of the research

The loop diagram explains that There is an Indonesian Government policy in the transition from conventional vehicles to electric vehicles by incentivizing subsidies for both motorcycles and cars. With subsidies from the Government of Indonesia, the adoption of electric vehicles is assumed to replace the number of conventional vehicles. Emissions are generated from energy use based on the daily travel distance of motor vehicle owners. The shift from conventional vehicles to electric vehicles has the potential to reduce greenhouse gases produced from conventional vehicles. Calculation of GHG emissions was carried out by analyzing the energy use of conventional vehicles and electric vehicles. Analyzing the GHG emission reduction potential and subsidy costs that need to be spent by the Government of Indonesia for emission reduction that occurs based on the analysis results. The results of the analysis can be used to criticize and provide advice or input on current electric vehicle policies to be developed in the future.

3.1. Dynamic Model Structure

3.1.1 Model Structure of BAU Scenario

The BAU model assumes that conventional vehicle use will continue throughout the modeled years and assumes that there is no government subsidy policy or electric vehicle switch policy. GHG emission modeling is made by calculating the number and growth rate of conventional vehicles until 2033. Furthermore, the amount of energy consumed each year was calculated based on fuel consumption and daily travel distance. The amount of energy use that has been identified is then calculated by multiplying it by the emission factor.

Based on the emission modeling that was carried out for both motor vehicles and cars, the next step is to summarize each GHG emission produced and make it equivalent as GWP. GWP is an index that measures how much heat (radiation force) will be trapped by one unit of GHG in the atmosphere during a certain period of time when compared to the amount of CO_2 that will be trapped in the same amount (Ajadi et al., 2020). For GHG emissions that are not CO_2, when measured using GWP, they are referred to as CO_2 equivalent (CO_2-eq) or CO_2-equivalent emissions. The larger the GWP, the more the gas warms the earth over a certain period of time, the time period used is usually for the 100-year lifetime of the GHG in the atmosphere (US EPA, 2022b). The overall BAU model is shown in Figure 2.

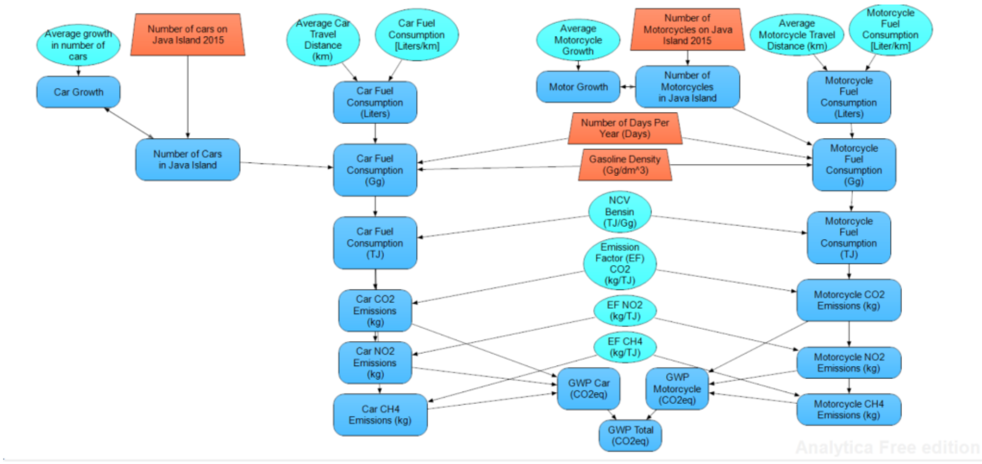


Figure 2. BAU scenario model

3.1.2 Model Structure of EVP Scenario

The EVP model assumes that the trend of conventional vehicle use continues throughout the modeled years but will be affected by the switching to electric vehicles due to the subsidy policy implemented by the Government of Indonesia. The growth of electric vehicles is analyzed based on secondary data and then accumulated based on the existing number of electric vehicles in 2022. The EVP model calculates GHG emissions based on the power plant which is the energy source for electric vehicles. The power plant itself is divided into 2 scenarios, namely with the existing scenario power plant (EKS) and with the National Energy Policy scenario power plant (NEP).

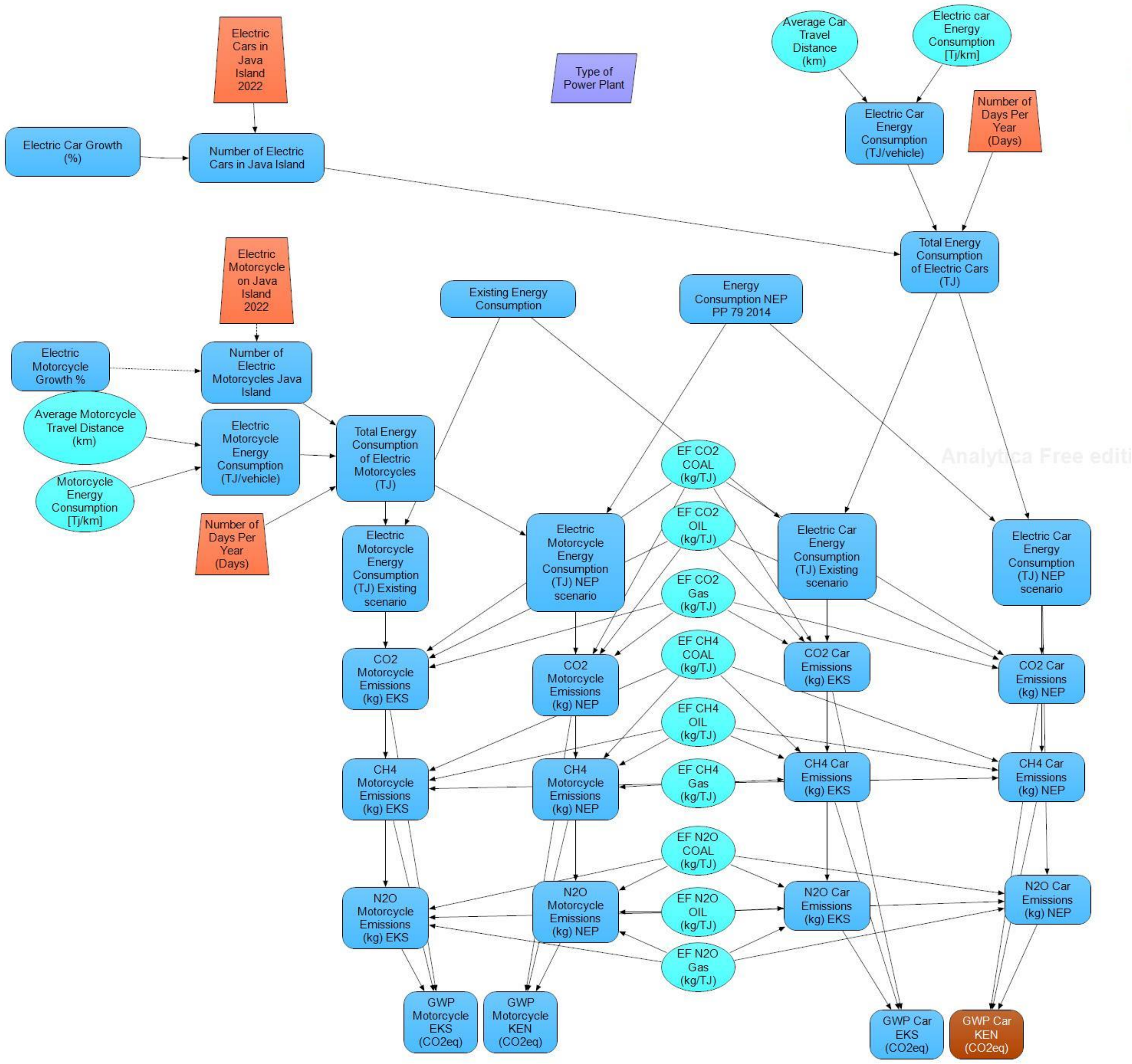


Figure 3. EVP Scenario Model

3.2. Model Validation

3.2.1 Consistency of units

Modeling requires measuring variables in the same units as other real variables. Unit consistency within the measurement for each variable is the most basic thing in validating the model. Errors in unit consistency will affect errors and result in poor or imperfect model results.

The consistency of units implemented in the measurement of each variable depends on the units used in the real system. There are 4 types of measurement units used in unit consistency, including vehicle units (related to the number of vehicles), Percent (related to the percentage of growth), Tera Joule (related to energy) and kg (related to the mass of emissions produced).

The variables used are in accordance with actual data derived from various literature sources, namely the Central Statistics Agency (BPS), IPCC, and similar literature presented in the citations of this study. Consistency in this modeling has been confirmed that the initial value used in the unit equation, which has been entered into the model, is dimensionally consistent. This aims to determine that the units derived from actual data and those used in modeling remain consistent.

3.2.2 Historical Data Matching Test Results

Matching the output values generated from modeling on Analytica 6.1 needs to be done with a data matching test using actual data. Model validation at this stage focuses on the independent variables that have been collected, where the independent variables have actual data over the past 7 years or from 2015 to 2022. Matching historical data with modeling output values, assisted by using Microsoft Excel in entering numbers from both data, which is then verified to determine the forecasts that have been generated from matching modeling output values and historical values.

Historical data testing is done using the Mean Absolute Percentage Error (MAPE) equation, MAPE is a calculation calculated using an absolute error in each period divided by the real observation value for that period. MAPE can measure the error by calculating the size of the percentage of deviation between actual data and presumed data. Conventional vehicles in this model are limited to motorcycles and cars. Historical data on the number of vehicles was obtained from the Central Statistic Agency for the time period 2015 - 2022. In this study, the projected number of vehicles in 2023 to 2033 is obtained through the model.

Table 10. MAPE Analysis of conventional car vehicle historical data

Year	Conventional Car Vehicle (unit)		MAPE [%]
	Historical Data	Model Output	
2015	8.509.551	8.509.551	0,00
2016	9.084.553	8.908.649	1,94
2017	9.649.155	9.326.465	3,34
2018	10.221.084	9.763.876	4,47
2019	10.730.116	10.221.802	4,74
2020	10.858.053	10.701.204	1,44
2021	11.240.618	11.203.091	0,33
2022	11.714.172	11.728.515	0,12
Mean Absolute Percent Error (MAPE)			2,0

Table 11. MAPE analysis of conventional motorcycle historical data

Year	Conventional Motorcycle (Unit)		MAPE [%]
	Historical Data	Model Output	
2015	52.074.157	52.074.157	0,00
2016	55.904.792	54.797.635	1,98
2017	59.436.758	57.663.552	2,98
2018	63.334.913	60.679.355	4,19
2019	67.033.394	63.852.886	4,74
2020	68.387.436	67.192.392	1,75
2021	71.177.978	70.706.554	0,66
2022	74.078.873	74.404.507	0,44
Mean Absolute Percent Error (MAPE)			2,1

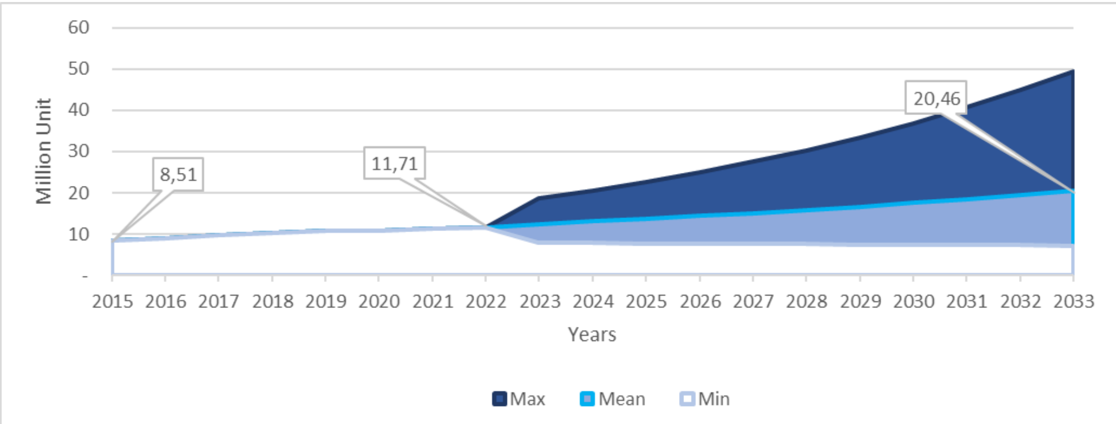
Model validation based on MAPE calculations in table 7 shows that the percentage error in modeling the number of car vehicles is 0,12% to 4,74% with an average percentage error of 2% while in table 8 the percentage error in modeling the number of motor vehicles is 0,44% to 4,74% with an average percentage error of 2,1%. It can be concluded that the predictive ability of the model is good because it has a MAPE value <10% (maricar, 2019).

3.3. GHG Emissions Modeling Results Business As Usual (BAU) Scenario

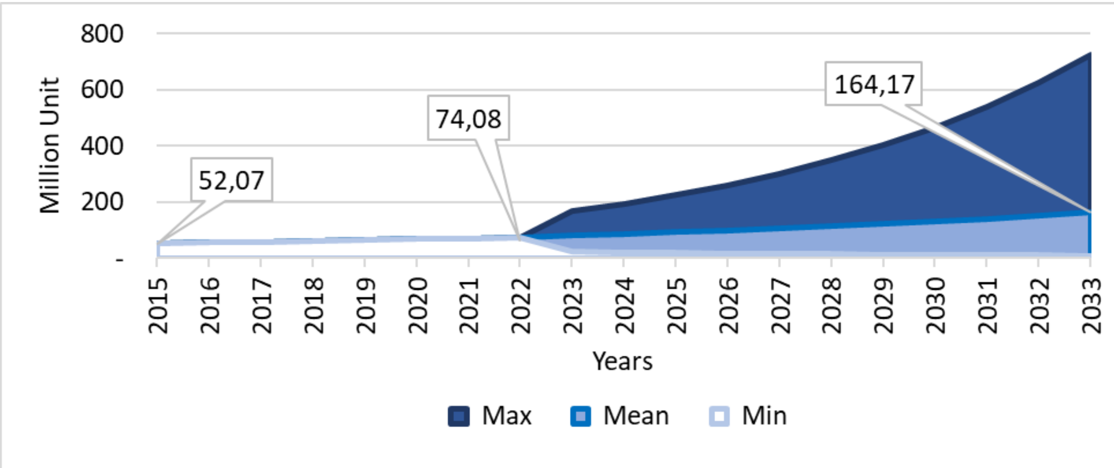
The BAU scenario assumed that the trend of conventional vehicles will increase throughout 2023 - 2033 assuming no government subsidy policy and electric vehicle switching policy.

3.3.1 Number of Conventional Vehicles

Conventional vehicles in this model are limited to motorcycles and cars. Historical data on the number of vehicles was obtained from the Central Statistic Agency (*BPS*) for the time period 2015 - 2022. In this study, the projected number of vehicles in 2023 to 2033 is obtained through the model. The number of vehicles in 2015 to 2022 uses historical data sourced from Central Statistic Agency (*BPS*), while the number of vehicles 2023 to 2033 uses modeling projection data.



(a)



(b)

Figure 4. Projected growth of conventional vehicles cars (a) and motorcycles (b)

There is an increasing trend in the number of vehicles throughout 2015 - 2022 which is historical data. The projection results for 2022-2033 show the growth of conventional car vehicles by 75% which in 2022 amounted to 11,7 million to 20,46 million in 2033 while motor vehicles increased by 121.7% which in 2022 amounted to 74,08 million to 164,17 million in 2033.

3.3.1. Projected Energy Demand of Conventional Vehicles

The number of vehicles from the model projection results that have been obtained is then processed to obtain the total amount of energy use with the unit of energy consumption used is terajoule (TJ). To be able to determine the energy needs of vehicles, it is necessary to know the average daily vehicle mileage of vehicle owners, the amount of fuel use based on mileage, fuel type, fuel density, and fuel calorific value.

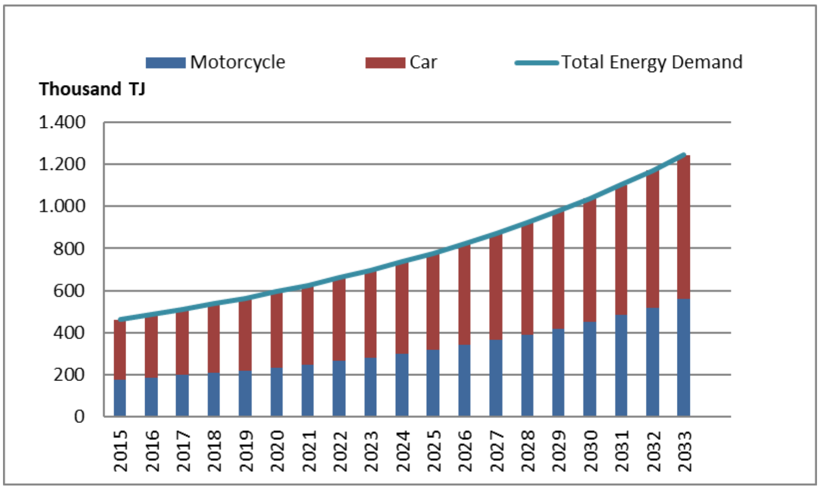


Figure 5. Conventional vehicle energy demand

The simulation results in the modeling indicate a trend in energy consumption by vehicle type, showing an increase from 2015 to 2033 in line with the projected number of vehicles. Energy use from motor vehicles was 177,312 TJ in 2015 and is expected to increase by 215% to 559,065 TJ by 2033. For cars, energy consumption was 284,849 TJ in 2015, rising by 140% to 685,023 TJ by 2033. Despite there being more motor vehicles, cars consume more energy due to higher fuel consumption and longer travel distances compared to motorcycles.

3.3.2. Projected GHG Emissions of Conventional Vehicles

The calculation of GHG emissions produced was referred to the IPCC 2006 Chapter 3: mobile combustion Tier 1 method. The total GHG emissions of conventional gasoline-burning vehicles were expressed in $CO_{2\text{-eq}}$ which is a term for various greenhouse gases in this case including CO_2, CH_4, and N_2O. The results of the calculation of each GHG emission that has been carried out for both motor vehicles and cars will be equivalent as GWP (CO_{2eq}).

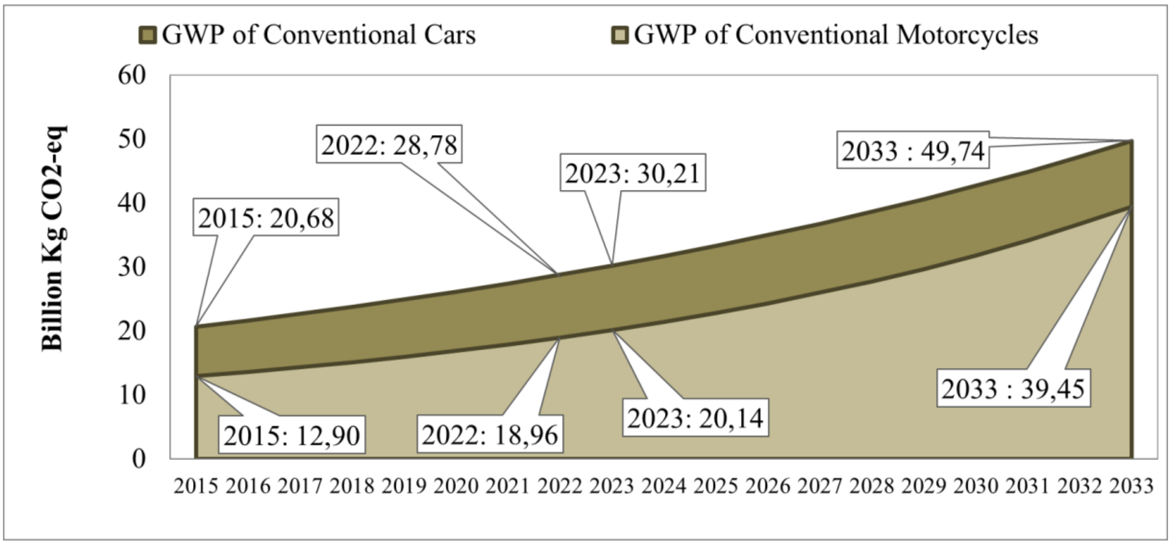


Figure 6. Conventional vehicle GWP

The BAU simulation results in Figure 4.18 show that greenhouse gas (GHG) emissions from conventional vehicle use in Java in 2015 for cars reached 20.68 billion kg CO2eq. This amount has been increasing along with the number of vehicles, reaching 28.78 billion kg CO2eq by 2022. Furthermore, modeling projections of the number of conventional cars indicate that GHG emissions will reach 30.21 billion kg CO2eq in 2023 and will continue to rise, reaching 49.74 billion kg CO2eq by 2033.

For motorcycles, GHG emissions in 2015 were 12.90 billion kg CO2eq. This amount has also been increasing with the growing number of motorcycles, reaching 18.96 billion kg CO2eq by 2022. According to modeling projections, GHG emissions from conventional motorcycles will reach 20.14 billion kg CO2eq in 2023 and will continue to increase, reaching 39.45 billion kg CO2eq by 2033.

3.4. GHG Emissions Modeling Results Electric Vehicle Plan (EVP) Scenario

The Electric Vehicle Plan model assumes that the trend of conventional vehicles will continue to rise throughout the modeling year but the increase will be affected by the transition to electric vehicles due to subsidy policies. The number of electric vehicles is calculated based on the percentage obtained from the representation of questionnaire results for respondents who want to shift to electric vehicles and secondary data accumulated with the existing number of electric vehicles in 2022. The EVP scenario calculates GHG emissions based on the power plant that provides the energy source for electric vehicles.

3.4.1 Electric Vehicle Growth

Electric Vehicles in the modeling are projected based on the existing number of electric vehicles in 2022 and accumulated with the percentage of vehicle growth.

Table 12. Electric vehicle growth projections

Year	Motorcycle	Car	Percentage Growth of Vehicles[1]
2023	82.257	24.500	219%
2024	189.068	56.313	130%
2025	369.542	110.066	95%
2026	34.728	189.050	72%
2027	1.017.775	303.138	60%
2028	1.534.643	457.083	51%
2029	2.316.697	690.013	51%
2030	3.522.312	1.049.098	52%
2031	5.391.994	1.605.970	53%
2032	8.311.365	2.475.486	54%
2033	12.901.362	3.842.586	55%

Source: [1]Asian Development Bank, 2022

The number of electric vehicles in 2022 for motor vehicles was 25,782 units and cars were 7,679 units. Projections of electric vehicles in 2033 carried out by accumulating the percentage growth of electric vehicles show an increasing trend every year until in 2033 there are 12.901.362 units of electric motors and 3.842.586 units of electric cars.

3.4.2 Electric Vehicle Energy Demand

Energy demand for electric vehicles is sourced from power plants. The calculation of energy demand is calculated using 2 scenarios, which are the existing scenario based on the new energy in 2022 assumed to remain the same through 2033 and the "National Energy Policy (NEP)" scenario which is the Indonesian Government's target based on Government Regulation No. 79 of 2014 concerning the National

Energy Policy. Emissions are generated from coal, oil and natural gas power plants. Energy demand is calculated based on distance traveled and energy consumption (TJ/km) of vehicles, both motorcycles and cars.

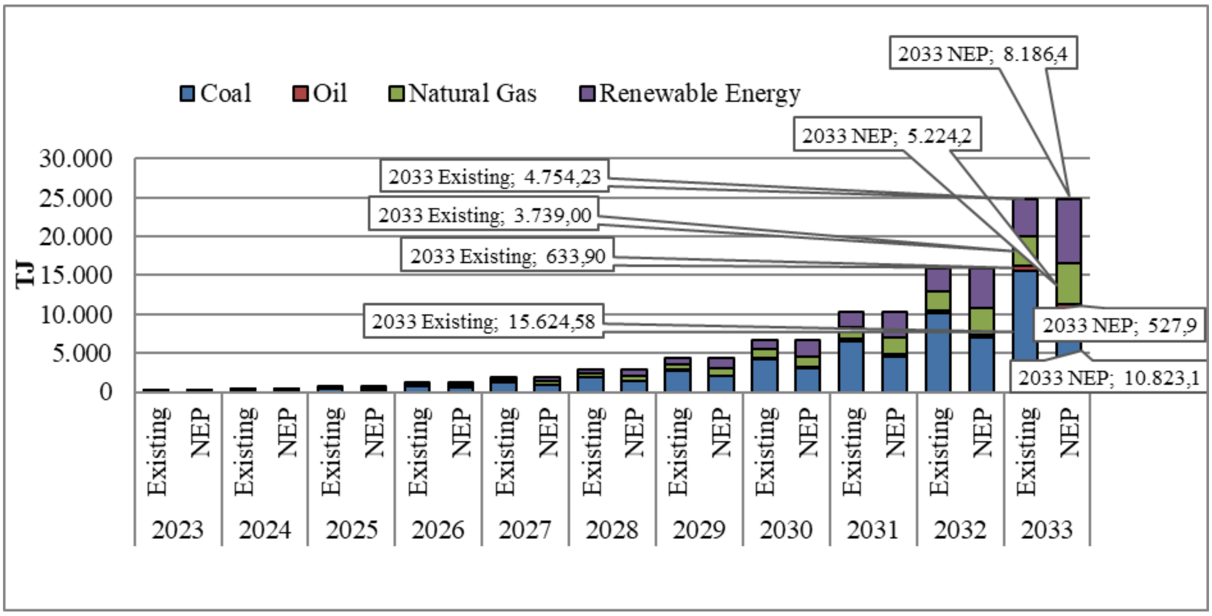


Figure 7. Electric vehicle energy usage

Energy use in two different scenarios (Figure 5) shows that the trend of energy use will increase every year according to the number of electric vehicles until 2033. Based on the graph, there is a difference between energy consumption based on actual conditions and government targets. For example, the energy consumption of coal plants in 2033 under actual conditions will require 15,624 TJ, while if the percentage of coal-fired power plants can meet the government's target, the energy consumption of coal plants will only be 10,823 TJ. This difference in energy use will affect the emissions produced because each type of power plant has a different emission factor. Overall, the energy use of the EVP scenario has an increasing trend as the number of electric vehicles available, which is 157 TJ in 2022 and has increased by 24,751 TJ in 2033, the difference between EVP with Existing energy and EVP with KEN energy is the percentage of each power plant.

3.4.3 Electric Vehicle Greenhouse Gases Emission

The calculation of GHG emissions of electric vehicles uses the guidelines of the "IPCC 2006 chapter 2: stationary combustion" with the Tier 2 method. Emissions are calculated based on the energy used according to the type of power plant and associated with the emission factors in the IPCC. The results of the calculation of each GHG emission that has been carried out for both motor vehicles and cars will be equivalent as GWP (CO_{2eq}).

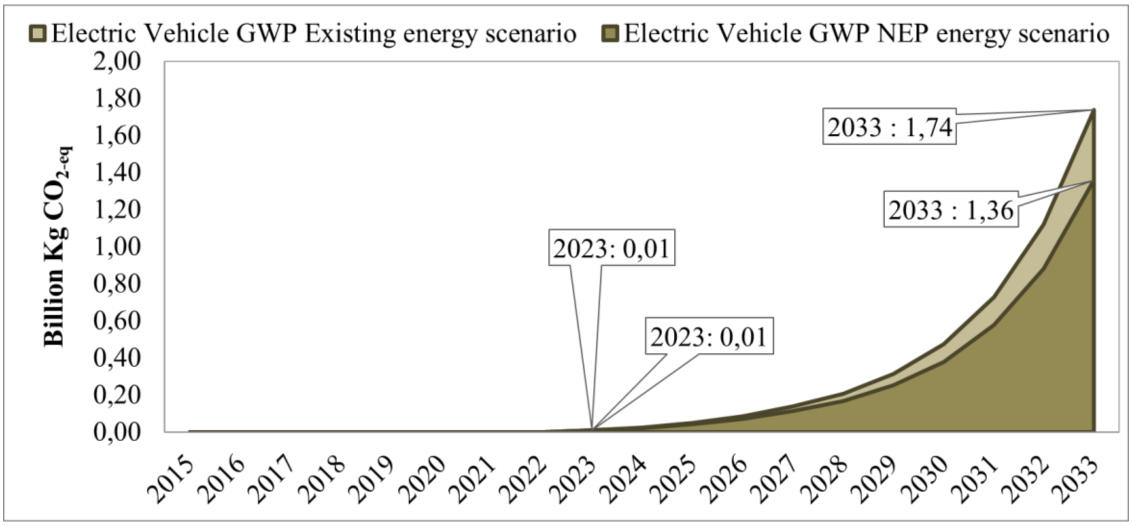


Figure 8. Electric vehicles GWP

Based on the results of the analysis, GHG emissions generated by the use of electric vehicles were generated starting in 2022 as the initial existing condition of the number of electric vehicles and modeled from 2023 to 2033. The calculation results show an increasing trend from 2023 to 2033, which is in line with the number of electric vehicles that were calculated. Emissions of electric vehicles on the Java island in 2022 based on the existing power plant scenario is 11,08 million Kg CO_{2eq} where there is an increasing trend for 10 years based on modeling projections with total emissions in 2033 reaching 1,73 billion Kg CO_{2eq}. Emissions from the use of electric vehicles on the Java island in 2022 based on the NEP scenario are 9,72 million Kg CO_{2eq} which has an increasing trend for 10 years based on modeling projections made with total emissions in the year reaching 1,35 billion Kg CO_{2eq}. In 2033 emissions with the NEP scenario which is the target of Indonesia's energy use is 27.9% lower than the existing energy scenario, this can happen because based on the difference in energy used as described in Figure 5 where the Indonesian government's target prioritizes the use of renewable energy in power plants so that if the target can be met then there is great potential for fewer emissions generated from the use of electric vehicles.

3.5. Emission Reduction of Electric Vehicle Usage

To calculate the emission reduction that occurs in the electric vehicle shift, it is necessary to equalize the number of vehicles in order to obtain equivalent emission comparison results. Equalization was conducted by reducing the number of conventional vehicles during the modeling year by the number of electric vehicles during the modeling year. In 2015 to 2021, there has not been a reduction in emissions due to the new electric vehicle transition in 2022 to 2033.

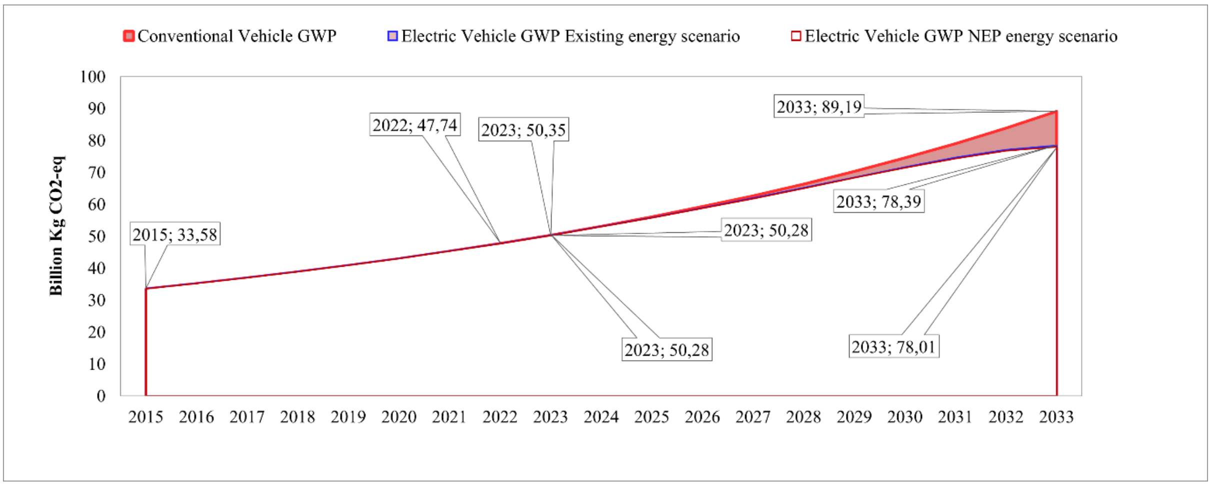


Figure 9. Emission reduction of electric vehicle Switch

The modeling results show that there is a decrease in GHG emissions from conventional vehicles due to the shift to electric vehicles. Both types of power plants modeled in the EVP scenario can reduce conventional vehicle GHG emissions under BAU scenario by 10,8 billion kg CO_{2eq} (12,11%) by the year 2033 using existing power plants, while using power plants targeted by the government (NEP) can reduce emissions by 11,1 billion kg CO_{2eq} (12,54%) by the year 2033. The reduction in emissions occurs under the assumption that there is a shift towards vehicles due to the subsidy of electric vehicles, which currently subsidizes electric vehicles in the form of a discount of Rp. 7.000.000 for electric motor vehicles and the elimination of PPnBM of 11% of the vehicle price for electric car vehicles. Based on the results of emission reduction modeling, the subsidy cost that needs to be incurred by the government based on the subsidy given to all electric vehicles is Rp. 20.097 per kg $CO_{2\text{-}eq}$ if based on the existing scenario while if based on the NEP scenario the subsidy cost is Rp. 19.415. This is still far below the standard when compared to the recommended carbon price based on IPCC 2006 which ranges from US$ 20 - US$ 80 for each ton of CO_2.

Referring to the results of the analysis, until 2033 based on the EVP model scenario, it can reduce emissions by ± 10,8 billion kg CO2eq or around 12% of the BAU scenario. If referring to the Enchanced Nationally Determined Contribution (ENDC) document of the Republic of Indonesia in 2022, GHG emissions as Indonesia's existing scenario in 2030 are 2.869 Mega Ton (MT) for all sectors and 1.669 Mega Ton (MT) for the energy sector. NDC itself is a document containing a country's climate commitments and actions communicated to the world through the United Nations Framework Convention on Climate Change (UNFCCC). When compared with the results of the emission reduction analysis in 2030, the shift to electric vehicles can contribute to GHG decarbonization in Indonesia by 0,766% based on the amount of GHG in all sectors and 1,318% based on the amount of GHG in the energy sector. Compared to the target set by the government in the ENDC document for the energy sector, which is around 12,5%, the emission reduction studied in this research has a positive impact on meeting the target. However, this study is limited to the transportation sector on the scale of Java Island, if it is studied on the scale of Indonesia and with the improvisation of electric vehicle policies, it is not impossible that the percentage of decarbonation from electric vehicle switching can increase.

4. Conclusions

The results showed that the number of conventional vehicles on the island of Java until 2033 was 164,173,172 units which increased by 219% from 2015 which amounted to 52,074,157 units for motor vehicles. As for car vehicles on the island of Java until 2033 is 20,463,091 units which has increased by 140% from 2015 which amounted to 8,509,551 units. As for electric vehicles in 2023 there is a potential of 82,257 motor vehicles and 24,500 car vehicles that will switch to electric vehicles which continue to increase until 2023 amounting to 12,901,362 units of motor vehicles and 3,842,586 units of car vehicles. Emission is calculated based on 2 scenarios, the first is the BAU scenario where emission analysis is calculated by counting conventional emissions from 2015 to 2033. The second scenario is EVP where in 2023 it is assumed that there is a transition to electric vehicles until the modeling year, 2033. Based on the modeling results, GHG emissions from conventional vehicles will increase along with the trend of vehicles increasing every year. The existence of an electric vehicle subsidy policy program to encourage the shifting from conventional vehicles to electric vehicles is expected to reduce GHG emissions by around 12% by 2023 with a subsidy cost that needs to be allocated by the government of Rp. 20.097 per kg CO2-eq if based on the existing scenario while if based on the NEP scenario the subsidy cost is Rp. 19.415. Based on the GHG emission reduction figures that have been described in this study, it can be concluded that the transition from conventional vehicles to electric vehicles can contribute to reducing GHG emissions, so the Indonesian government is expected to be more vigorous in promoting electric vehicles by increasing existing policies and subsidies to encourage more significant growth in electric vehicles.

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