Appendix

Overview, Design concepts and Details (ODD) of Participatory Energy System Dynamics Model (P/ESDM)

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The overview, design concepts, and details (ODD) protocol by Grimm et al. (2006) and Grimm et al. (2010) is partly used to describe Participatory Energy System Dynamics Model (P/ESDM) as follows:

A.1 Purpose

The Participatory Energy System Dynamics Model (P/ESDM) was developed to address the pressing need for practical and achievable energy security strategies in Indonesia. The P/ESDM was designed to support evidence-based policymaking in Indonesia's energy sector to assess strategies for energy security. The P/ESDM provides a framework to evaluate the feasibility and effectiveness of various policy scenarios. P/ESDM is composed of five interconnected modules, i.e demographic and macroeconomic dynamics, final energy demand and associated emissions, total energy supply, policy interventions, and impact assessments. The P/ESDM captures the emergent properties of Indonesia's energy system by simulating the complex interactions between demographic growth, energy demand, energy supply, and environmental impacts. The P/ESDM facilitates learning by providing a dynamic platform for analyzing the complexities of the energy system and understanding how policy decisions influence long-term sustainability and cleaner energy outcomes.

Eight policy scenarios were explored, including oil production, crude oil export restrictions, refinery expansion, electric vehicle promotion, biodiesel adoption, renewable energy growth, coal production management, and urban gas network development. This model also assessed the relationships between energy production, energy demand, and environmental consequences such as greenhouse gas (GHG) emissions and land-use changes. By simulating eight distinct policy scenarios, including renewable energy growth, electric vehicle promotion, and coal production management, the model provides actionable insights into the pathways for energy security. The emergent behaviors in the model arise from the feedback loops within the system. P/ESDM shows the dynamic nature of energy production, supply, and demand in response to policy interventions in Indonesia. The P/ESDM model shows how different policy interventions, such as renewable energy development and increased biodiesel mix can lead to shifts in the energy mix. The P/ESDM shows how policies promoting increased biodiesel mix, renewable energy development, and electric vehicles, highlight potential environmental sustainability.

The collaboration among government agencies, industry stakeholders, and researchers was conducted by integrating expert knowledge into model development and scenario analysis. By achieving these objectives, the P/ESDM serves as a strategic tool for guiding Indonesia's energy policies toward sustainable and cleaner energy. The participatory nature of the P/ESDM sets it apart, as stakeholders from technical ministries, academic institutions, and industry experts were actively involved in its design and implementation. Stakeholders contribute insights that refine P/ESDM, ensuring more realistic and actionable outcomes. Through focus group discussions and collaborative workshops, stakeholders contributed to defining the model's structure, selecting relevant data, and formulating policy scenarios. The participatory modeling approach enables continuous dialogue between policymakers, industry representatives, and researchers. These interaction dynamics ensure that the P/ESDM captures the complexities of energy policy formulation and implementation in Indonesia. By incorporating stakeholder feedback, the P/ESDM bridges the gap between theoretical modeling and practical energy policy planning, enabling more inclusive and adaptive decision-making. This process not only enhanced the transparency and credibility of the model but also ensured that it captured a wide range of perspectives, making it a valuable tool for policymaking.

The P/ESDM enables policymakers to anticipate future trends in energy supply, energy demand, demography, economics, and environmental impacts under various policy scenarios. The P/ESDM's predictive capabilities include forecasting energy supply and demand. The P/ESDM projects the evolution of Indonesia's energy mix based on historical data and policy interventions. It predicts changes in oil production, crude oil export restrictions, refinery expansion, electric vehicle promotion, biodiesel adoption, renewable energy growth, coal production management, and urban gas network development over time.

The model runs the business as usual and optimistic simulations with varying assumptions to test the resilience of policy decisions under different policy scenarios. This predictive capability helps policymakers design flexible strategies for a cleaner energy transition in Indonesia. By leveraging predictive analytics, the P/ESDM provides actionable insights that support Indonesia's long-term energy planning and sustainability goals.

A.2 Demography and macroeconomic module

Table A.1 Demography and macroeconomic module

Definition: This module represents population growth and macroeconomic indicators such as GDP and energy intensity. It provides the foundation for understanding how demographic changes and economic growth drive energy demand.

Variable name	**Brief descriptions**
Population	The population of Indonesia, encompassing the number of urban and rural households. Calculated as “population increase = Population growth rate*Population”, stated in people.
GDP	Indonesia’s total GDP, representing the sum of industrial GDP, transportation GDP, commercial GDP, and other sector GDP, stated in billion IDR.
GDP by sector	GDP for each sector, including industrial, transportation, commercial, and other sectors. Calculated as “GDP by sector increase = GDP by sector*GDP by sector growth rate*Sector elasticity to total GDP”, stated in billion IDR.
Electrification ratio	Assumed urban electrification ratio multiplied by the number of urban households, stated in dimensionlessly (Dmnl).

The diagram in **Figure A.1** illustrates the relationship between population growth and Gross Domestic Product (GDP) in Indonesia. It highlights how changes in the number of households (HH) and the distribution of urban and rural households directly influence population growth. For instance, an increase in urban households may lead to a higher demand for infrastructure and public services, affecting resource allocation and development policies. Additionally, the diagram depicts how the electrification ratio serves as a crucial indicator in assessing the level of economic and social development across different regions.

The diagram also incorporates key economic sectors, including industry, transportation, commerce, and government consumption. Each sector contributes differently to total GDP, depending on its elasticity to GDP fluctuations. For example, the industrial sector may exhibit higher elasticity to GDP compared to the commercial sector. The diagram further accounts for GDP growth rates and how each economic sector contributes to this growth.

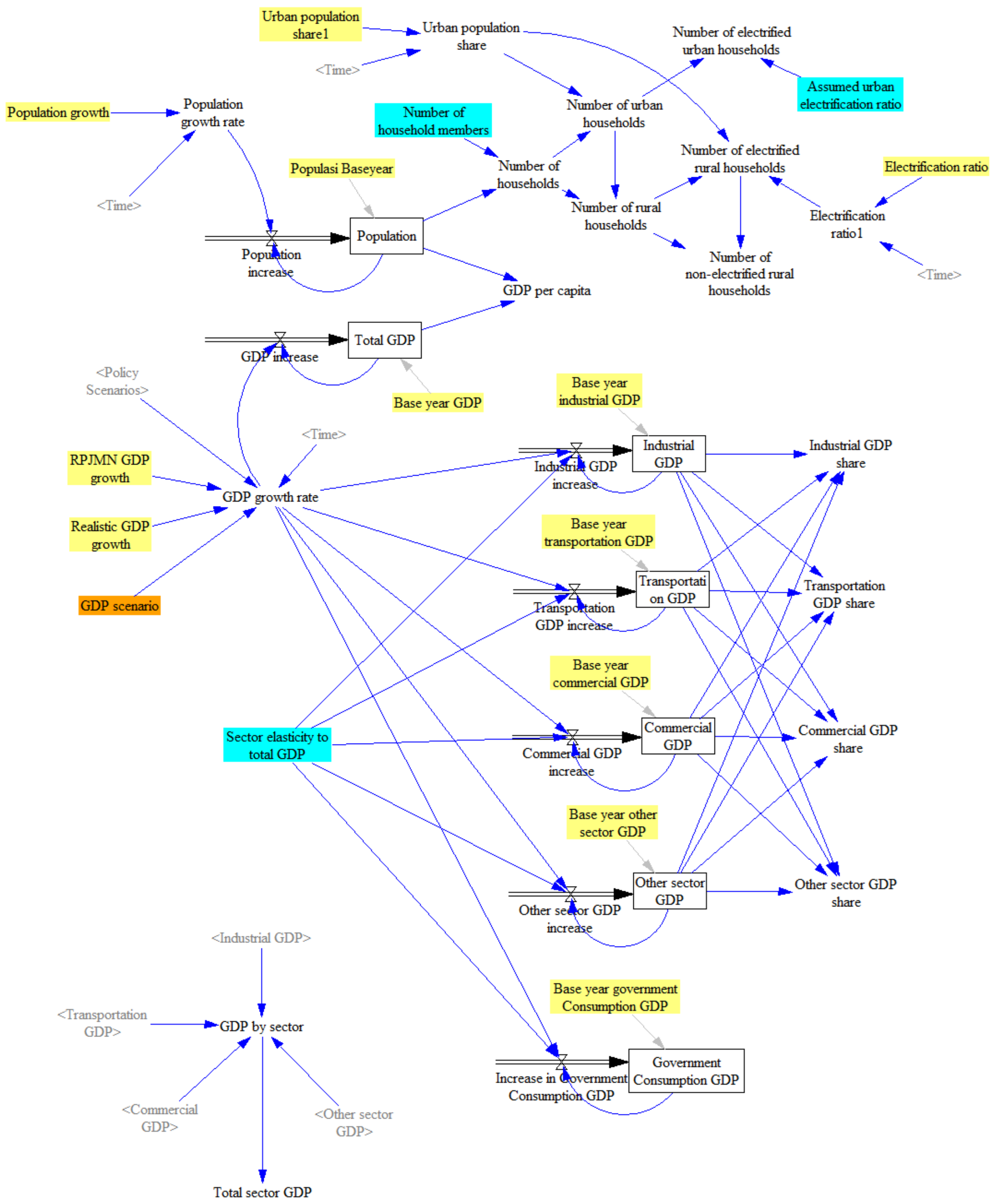

Figure A.1 Demography and macroeconomic module

A.3 Final energy demand and total emissions module

Table A.2 Final energy demand and total emissions module

Definition: This module estimates the energy consumption across different sectors (transportation, industrial, residential, commercial, and other sectors) and calculates total emissions based on energy use.

Variable name	**Brief descriptions**
Sub-module: Transportation demand	
Car shares by technology	The share of cars by technology, including ICE, HEV, PHEV, and BEV, stated in Dmnl.
Share of BEV electric cars	The share of BEV electric vehicles in Indonesia, stated in Dmnl.
Car shares by fuel type	The share of cars by fuel type in Indonesia, stated in Dmnl.
Road vehicle stock	The stock of road vehicles, including cars, buses, trucks, and motorcycles, stated in units.
Non-road vehicle stock	The stock of non-road vehicles, including passenger trains, freight trains, passenger aircraft, freight aircraft, and ASDP sea vessels, stated in units.
Energy intensity	The energy intensity of road vehicle stocks (cars, buses, trucks, motorcycles), stated in SBM/Million Passenger Km
Energy demand	Energy consumption by road vehicles (cars, buses, trucks, motorcycles), stated in SBM
CO2 emissions	CO2 emissions, calculated as "Transportation Sector Energy Demand by Energy Type*Emission Factors*Conversion to Million Tons CO2 Eq", stated in Million Ton CO2 Eq.
GHG emissions in the transportation sector	GHG emissions from the transportation sector, calculated as "CH4 Emissions+CO2 Emissions +N2O Emissions", stated in Million Ton CO2 Eq.
Sub-module: Industrial demand	
Industrial activity by subsector	Industrial activity by subsector, calculated as "Industrial GDP*Industry Subsector Share", stated in billion IDR.
Total energy demand in the industrial sector	Total energy consumption from direct process heating, indirect process heating, and machine drivers, stated in SBM.
Energy intensity for direct process heating	Energy intensity for direct process heating (fuel, other energy, and electricity), stated in SBM/billion IDR.
Energy intensity for indirect process heating	Energy intensity for indirect process heating (fuel and other energy), stated in SBM/billion IDR.
Energy intensity for process cooling	Energy intensity for process cooling, stated in SBM/billion IDR.
Energy intensity for machine drivers	Energy intensity for machine drivers, stated in SBM/billion IDR.
GHG emissions in the industrial sector	GHG emissions from the industrial sector, calculated as "CH4 Emissions+CO2 Emissions +N2O Emissions", stated in Million tons CO2 Eq.
Sub-module: Residential demand	
Urban cooking share	Urban cooking share in Indonesia, including lighting, air conditioning, refrigerators, TVs, rice cookers, and other appliances, stated in Dmnl.

Variable name	Brief descriptions
Rural cooking share	Rural cooking share in Indonesia, including lighting, air conditioning, refrigerators, TVs, rice cookers, and other appliances, stated in Dmnl.
Number of urban and rural households	The number of urban and rural households, stated in households.
Household energy intensity	Household cooking energy intensity, stated in SBM/household
Urban and rural electricity demand	Urban and rural electricity consumption for lighting, air conditioning, refrigerators, TVs, rice cookers, and other appliances, stated in Million SBM.
GHG emissions in the residential sector	GHG emissions from residential sector, calculated as “CH4 Emissions+CO2 Emissions +N2O Emissions”, stated in Million Ton CO2 Eq
Sub-module: Commercial demand	
Private commercial electricity demand	Electricity consumption in Indonesia from the private commercial subsector, stated in million SBM
Private commercial energy demand	Total energy consumption in Indonesia from the private commercial subsector, stated in million SBM
Government commercial electricity demand	Electricity consumption in Indonesia from the government commercial subsector, stated in million SBM
GHG emissions in the commercial sector	GHG emissions from commercial sector, calculated as “CH4 Emissions+CO2 Emissions +N2O Emissions”, stated in million Ton CO2 Eq
Sub-module: Other demand	
Electricity demand in other sectors	Electricity consumption outside transportation, industrial, residential, and commercial sectors, stated in Million SBM.
GHG emissions in the other sector	GHG emissions from other sector, calculated as “CH4 Emissions+CO2 Emissions +N2O Emissions”, stated in million Ton CO2 Eq
Feedstock energy demand	Feedstock energy consumption in Indonesia, stated in million SBM
Total final energy demand	Total final energy demand, calculated as the sum of electricity, coal, natural gas, fuel oil, biofuel, LPG, renewable energy, and other refinery product demands, stated in million SBM
Total GHG emissions	Total GHG emissions, calculated as the sum of emissions from transportation, industrial, residential, commercial, and other sectors, stated in million Ton CO2 Eq.

A.3.1 Sub-module: Transportation demand

The diagram in **Figure A.2** presents an energy-based vehicle transition model, focusing on transportation electrification policy scenarios. The model classifies vehicles based on their propulsion technology, including internal combustion engine (ICE) vehicles, hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs).

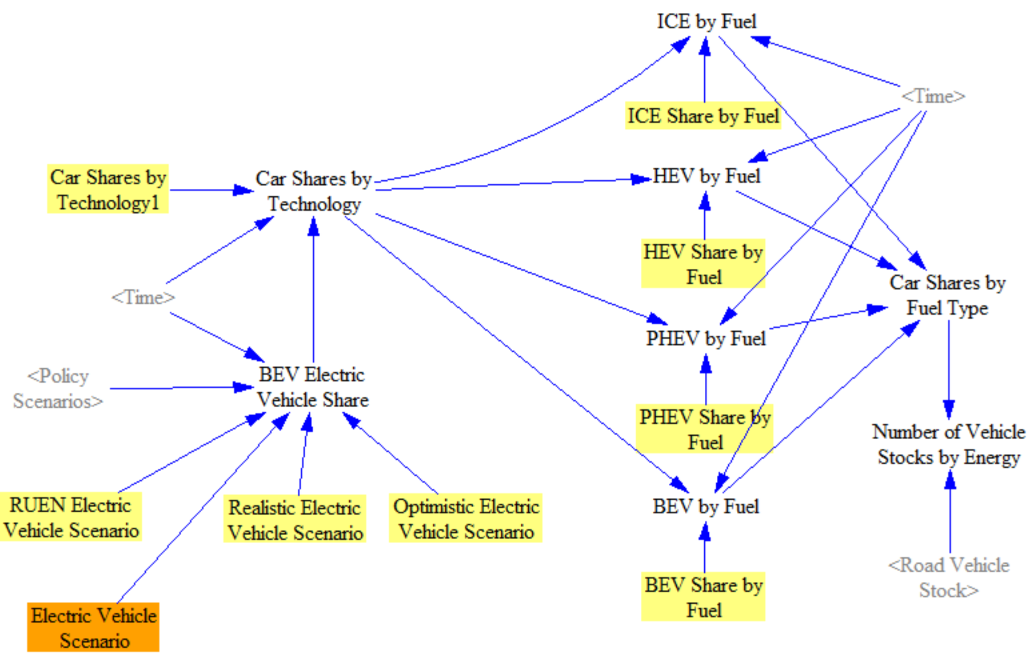

Figure A.2 Tranportation demand sub-module

The policy scenarios implemented in this model include the RUEN Electric Vehicle Scenario, the Realistic Electric Vehicle Scenario, and the Optimistic Electric Vehicle Scenario. Each scenario contributes to the BEV Market Share variable, which represents the market penetration of electric vehicles based on the adopted policy framework. This variable is also influenced by time factors and broader policy scenarios, determining the acceleration of electric vehicle adoption.

Conversely, the market share of fossil fuel and hybrid vehicles, such as ICE, HEV, and PHEV, is also considered in the model. Each vehicle type has a Share by Fuel variable, which reflects its distribution within the national vehicle mix. The Car Shares by Technology and Car Shares by Fuel Type variables serve as accumulation points for different types of vehicles available in the market, capturing the ongoing transition from fossil-fuel-powered vehicles to electric vehicles.

A.3.2 Sub-module: Industrial demand

Figure A.3 illustrates the industrial activity transition model based on time and economic factors such as industrial Gross Domestic Product (GDP). This model focuses on how industrial activities evolve over time and how the contributions of industrial subsectors are calculated. The key variable in this model is Current Industrial Activity1, which represents the current state of industrial activity. Changes in this activity are influenced by the Activity Addition variable, reflecting the growth or decline of industrial activities over time. This process is controlled by the annual conversion factor, which represents the rate of change within a year.

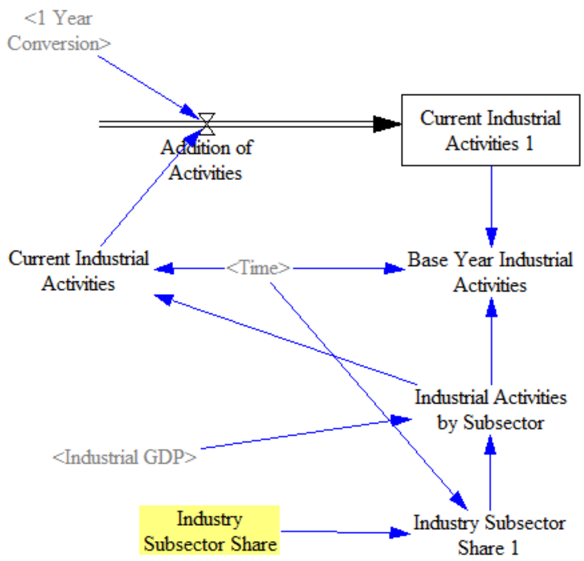

Figure A.3 Industrial demand sub-module

Additionally, the model links Current Industrial Activity with the Baseyear Industrial Activity value, which serves as a reference for comparing changes from the base year to the current period. Industrial activity is also categorized into multiple subsectors through the Industrial Activity by Subsectors variable, allowing for a more detailed analysis of industrial activity distribution across various fields.

The contribution of industrial subsectors in this model is measured using the Industrial Subsectors Share variable, which is calculated based on industrial GDP. This variable indicates how each subsector contributes to overall industrial activity within a given period. This share is then updated in the Industrial Subsectors Share1 variable reflecting the latest industrial distribution based on growth or changes in the industrial subsectors.

A.3.3 Sub-module: Residential demand

Figure A.4 shows the dynamic system of household energy consumption in urban and rural areas, focusing on different types of energy used for cooking and lighting. The model connects key variables affecting household energy market share, including the use of Dimethyl Ether (DME), gas pipeline networks (jargas), and electricity access.

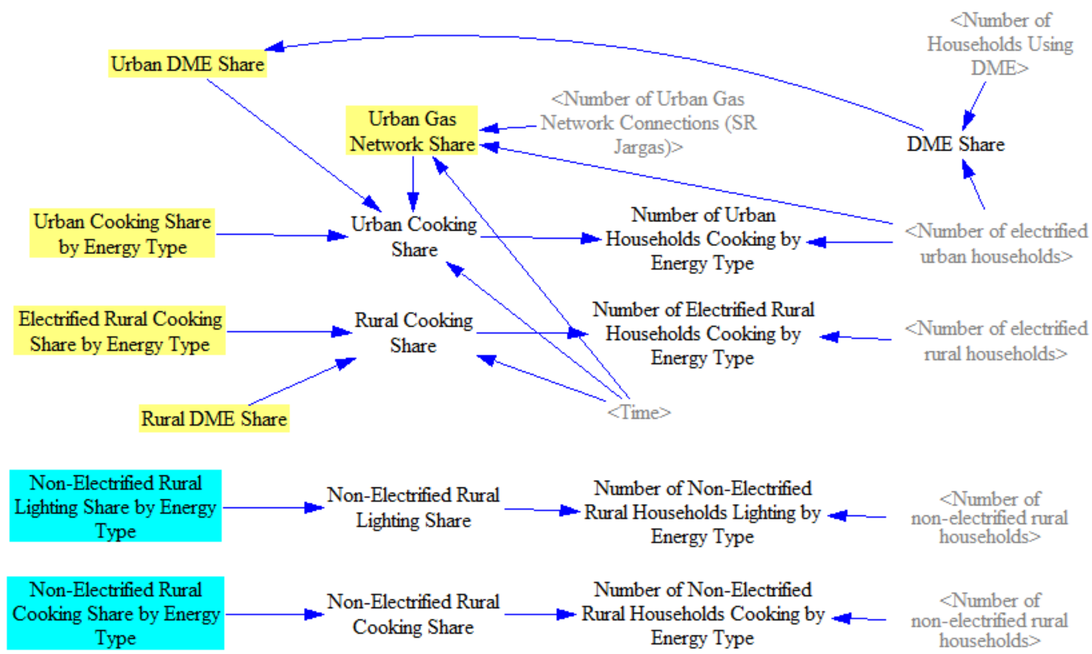

Figure A.4 Residential demand sub-module

In urban areas, the share of cooking energy is determined by the Urban Cooking Share variable, which is influenced by the Urban Gas Pipeline Share and Urban DME Share. The number of urban households using specific energy sources is calculated through the Number of Urban Households Cooking by Energy variable, which also depends on the number of electrified households.

Meanwhile, in rural areas, there are two main groups: electrified households and non-electrified households. For electrified households, cooking energy consumption is determined by the Electrified Rural Cooking Share by Energy variable, which then defines the number of households using each energy type. For non-electrified households, the key variables are the Non-Electrified Rural Lighting Share by Energy and Non-Electrified Rural Cooking Share by Energy, which indicate how remote households meet their energy demands.

Furthermore, the model accounts for the overall use of DME through the DME Share variable, which is calculated based on the number of households using DME in both urban and rural areas. This variable is influenced by the market share of DME in each region and the number of households relying on DME as their primary energy source.

A.3.4 Sub-module: Commercial demand

In the commercial sector, energy consumption is influenced by fuel usage composition, represented by the Commercial Fuel Shares variable, as well as baseline energy consumption determined by the Baseyear Commercial Energy Consumption variable (**Figure A.5**). Energy intensity in this sector is measured through two key parameters: Baseyear Commercial Oil Fuel Intensity, which reflects oil fuel consumption, and Baseyear Commercial Other Energy Intensity, which includes energy from other sources. Over time, the commercial sector's growth is indicated by GDP expansion through the 2019 Commercial GDP Addition variable, which contributes to the Cumulative Commercial GDP value. Moreover, electricity consumption in the commercial sector is highly dependent on supply from the PLN, which is calculated based on the Baseyear Electricity Consumption by PLN Customers variable.

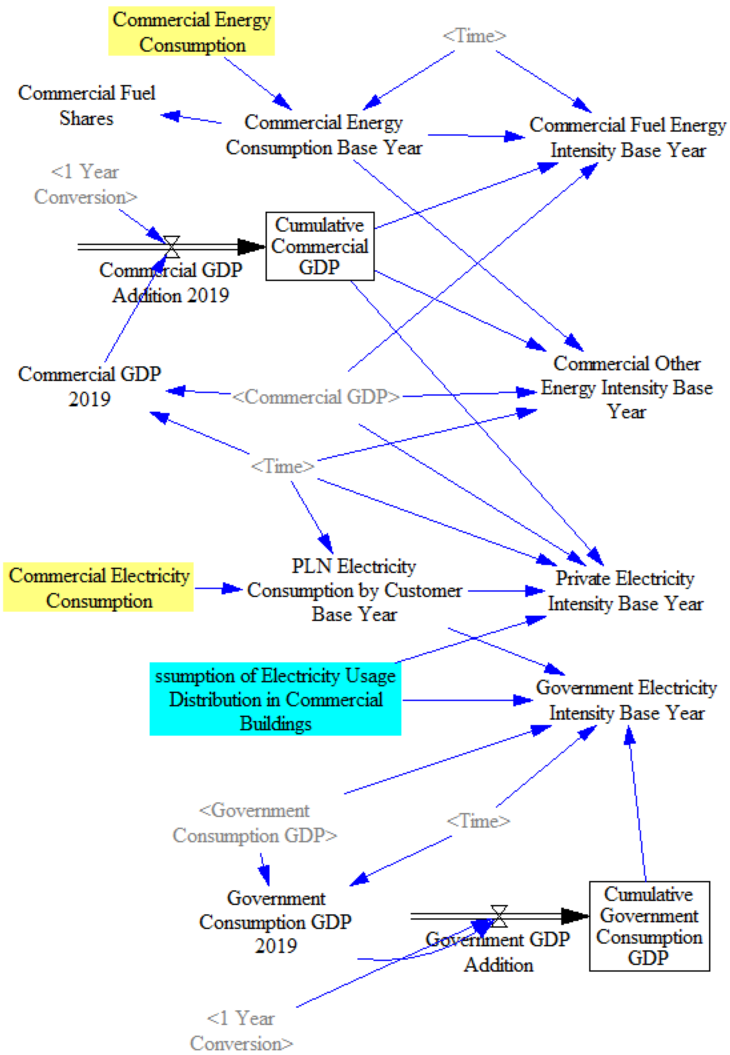

Figure A.5 Commercial demand sub-module

Regarding electricity consumption in the commercial sector, there is a strong correlation between the amount of electricity consumed and the assumed distribution of electricity used in commercial buildings, represented by the Commercial Building Electricity Use Distribution Assumption variable. The electricity intensity for private and government sectors is also considered through the Baseyear Private Electricity Intensity and Baseyear Government Electricity Intensity variables, which describe electricity usage per economic activity unit in each sector.

On the other hand, the government sector also experiences growth, represented by the Government GDP Addition variable, which ultimately contributes to the Cumulative Government Consumption GDP value. Similarly, energy consumption in the government sector is closely related to the electricity intensity used by various government institutions, as reflected in the Baseyear Government Electricity Intensity variable.

A.3.5 Sub-module: Other demand

The GDP of other sectors grows over time, represented by the Other GDP Addition variable, while the accumulation of this growth is reflected in the Cumulative Other GDP variable (**Figure A.6**). As this sector expands, its baseline energy consumption is determined by the Baseyear Energy Consumption of Other Sectors, which represents the amount of energy used under initial conditions.

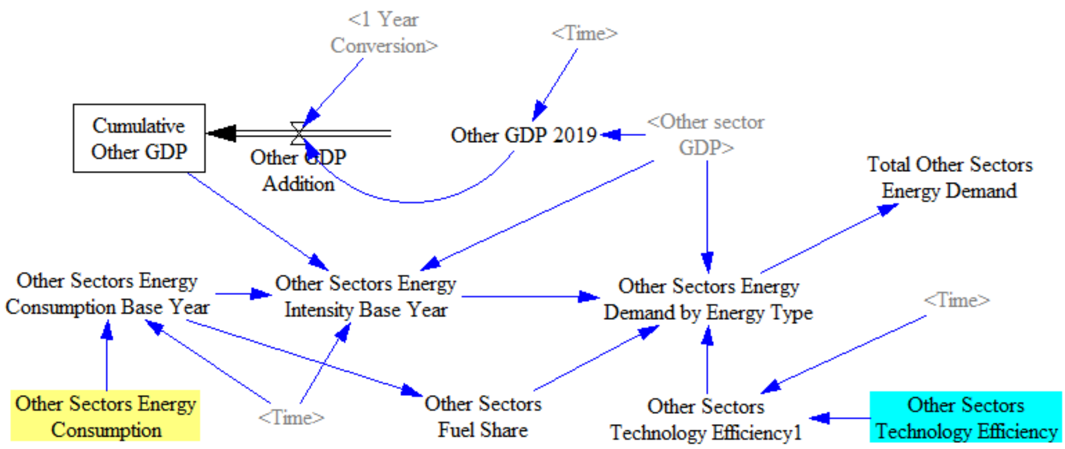

Figure A.6 Other demand sub-module

Energy intensity in other sectors is measured through the Baseyear Energy Intensity of Other Sectors variable, which indicates the level of energy consumption relative to the sector's economic activity. Additionally, energy consumption is influenced by the fuel composition used, represented by the Fuel Share of Other Sectors variable. Considering the different types of energy utilized, the energy demand of other sectors is calculated based on the Energy Demand of Other Sectors by Energy Type variable, which contributes to the total energy demand of this sector. Technological efficiency plays a crucial role in determining the energy demand of other sectors. The Technological Efficiency of Other Sectors variable represents the improvements in energy efficiency over time, which can help reduce overall energy consumption. With advancements in technology, it is expected that energy demand in other sectors can be better managed, even amid economic growth.

Figure A.7 illustrates the flow and interconnection of energy demand based on end-use sectors and fuel types. The model begins by mapping energy demand across different sectors, including industry, transportation, residential, commercial, and other sectors. Each sector has its energy consumption level, which is aggregated into the Final Energy Demand by Sector variable. From this point, the total national energy demand is summed into the Total Final Energy Demand variable, representing the overall energy demand across all economic sectors.

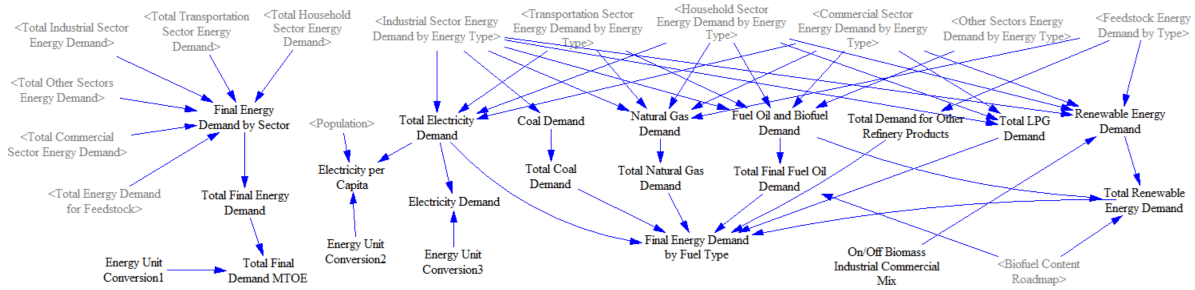

Figure A.7 Final energy sub-module

Once the total energy demand is calculated based on end-use sectors, the model categorizes this energy demand by fuel type. The fuel types classified in this model include electricity, coal, natural gas, petroleum fuels, biofuels, liquefied petroleum gas (LPG), and new and renewable energy (NRE). Each fuel category has a dedicated variable to compute its total demand, which subsequently contributes to overall national energy consumption. The model also highlights the interaction between petroleum fuels and refinery products, reflecting the complexity of the energy supply chain, where one fuel type can be influenced by the availability and production of other fuels.

Furthermore, the model demonstrates a strong interconnection between the industrial sector and energy demand for raw materials. This indicates that the industrial sector plays a crucial role in shaping national energy demand, both for production needs and as raw materials in various manufacturing processes. Meanwhile, the biofuel content roadmap within the model suggests the influence of external factors, such as policy interventions, that could impact the national energy mix, particularly in enhancing the role of renewable energy and reducing dependence on fossil fuels.

The model categorizes GHG emissions by major sectors, including industry, transportation, residential, commercial, and other sectors (**Figure A.8**). Each sector's emission contribution is calculated separately and then aggregated into the GHG Emissions Demand by Sector variable. After the total emissions from each sector are calculated, the model consolidates them into the Total GHG Emissions Demand variable, representing the overall GHG emissions from all economic activities. With this structure, the model can be used to analyze how each sector contributes to total national emissions and how changes in energy consumption or specific policy measures may affect overall emission levels.

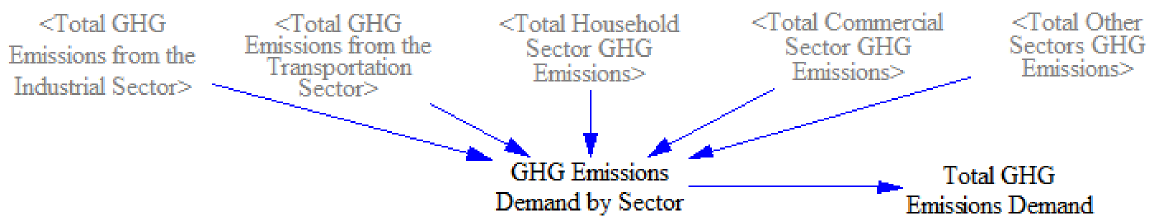

Figure A.8 GHG emissions sub-module

A.4 Total energy supply module

Table A.3 Total energy supply module

Definition: This module captures the production of energy from various sources, including renewable and non-renewable energy. It includes resource constraints, production costs, and energy trade dynamics. Energy source from power generation, oil refinery, biofuel, gas and DME, coal conversion, and mining.

Variable name	**Brief descriptions**
Sub-module: Power generation	
Total power generation	Total power generation from domestic production and imports, stated in GWh.
Power generation by type	Total power generation based on types of domestic production, stated in GWh.
Electricity imports	Total electricity imports, stated in MWh.
Power plant capacity by type	Power plant capacity based on types available in Indonesia, stated in GW.
Power plant efficiency	Calculated value of power plant efficiency, stated in Dmnl.
Addition of Surya Nusantara rooftop solar	Additional rooftop solar capacity considering the number of households, workers, subsidy savings, and investment value, stated in GW.
Addition of power plants	Additional capacity from geothermal (PLTP), wind (PLTB), solar (PLTS), PV rooftops, hydro (PLTA), biopower (PLT Bio), nuclear (PLTN), and diesel (PLTD) power plants, stated in GW.
Power plant GHG emissions	GHG emissions from power plant, calculated as "CH4 Emissions+CO2 Emissions +N2O Emissions", stated in million Ton CO2 Eq
Sub-module: Oil refinery	
Oil refinery capacity	Total oil refinery capacity, stated in million SBM.
Oil refinery capacity additions	Additional oil refinery capacity, stated in million SBM.
Refinery capacity production	Refinery production capacity at Balongan 1&2, Balikpapan 1, Balongan 3, Balikpapan 2, Cilacap, Plaju, Tuban, and Bontang, stated in million SBM.
Sub-module: Biofuel	
Green diesel production capacity	Green diesel production capacity from coprocessing, standalone green diesel, and revamping, stated in million KL.
Biorefinery production capacity	Biorefinery production capacity in Indonesia, stated in Dmnl.
Blending share of biogasoil	Biogasoil blending share derived from biofuel and green diesel content, stated in Dmnl.
Biodiesel production	Total biodiesel production meeting biodiesel demand and exports, stated in million SBM.
CPO feedstock requirement for biodiesel	CPO feedstock required for biodiesel based on biodiesel production and efficiency, stated in million tons.
Biodiesel plant investments	Total investment in biodiesel plants, stated in trillion IDR.
Bioethanol production	Bioethanol production capacity based on feedstock demand,

Variable name	Brief descriptions
capacity	stated in Dmnl.
Sub-module: Gas and DME	
LPG plant capacity	LPG plant capacity, including base year and additions, stated in million SBM.
LPG plant capacity additions	Additional LPG plant capacity based on addition rates, stated in million SBM/year.
DME production	DME production derived from plant capacity and additions, stated in million tons.
DME capacity additions	JAdditional DME plant capacity based on production scenarios, stated in million tons.
LPG plant efficiency	Efficiency of LPG plants, calculated from base year and efficiency improvements, stated in Dmnl.
LPG and DME production	Total LPG and DME production, calculated as the sum of LPG and DME outputs, stated in million SBM.
Total LPG production	Total LPG production from natural gas input and plant efficiency, stated in million SBM.
LNG plant capacity	LNG plant capacity, including base year and additions, stated in million SBM.
Gas regasification LNG production capacity	LNG regasification production capacity based on refinery input and power plant requirements, stated in million SBM.
Sub-module: Coal conversion	
Briquette production capacity	Briquette production capacity in Indonesia, stated in million SBM.
DME Syngas, methanol Synfuel, capacity	Capacity derived from DME plants, coal gasification, methanol plants, and coal liquefaction, stated in Dmnl.
DME plant capacity and efficiency	Capacity and efficiency of DME plants, stated in Dmnl.
Capacity and efficiency of coal gasification	Capacity and efficiency of coal gasification plants, stated in Dmnl.
Capacity and efficiency of methanol plant	Capacity and efficiency of methanol plants, stated in Dmnl.
Coal liquefaction	Coal liquefaction calculated from Synfuel demand, stated in million SBM.
Sub-module: Mining	
Coal production	Coal production calculated from historical growth and new additions, stated in million tons.
Natural gas production	Natural gas production from additional capacity, exploration scenarios, and routine/new gas programs, stated in million SBM.
Sub-module: Total primary energy	
Primary energy supply by fuel type	Primary energy supply by gasoline, biogasoline, gasoil, biogasoil, aviation fuels, electricity, coal, natural gas, LPG, and biomass, stated in million SBM
Total primary energy supply	Total primary energy supply from all fuel types, stated in million SBM.
Total greenhouse gas (GHG) emissions	Total GHG emissions from energy supply, stated in million Ton CO2 Eq.
GHG emissions per capita	Total GHG emissions from energy supply divided by population, stated in million Ton CO2 Eq.

A.4.1 Sub-module: Power generation

Figure A.9 shows the power generation system based on plant type, generation capacity, and factors influencing electricity demand and distribution. Total electricity production is affected by electricity imports and Transmission and Distribution Loss, which represents energy losses during the transmission and distribution process. These losses have a direct impact on the availability of electricity for end consumers.

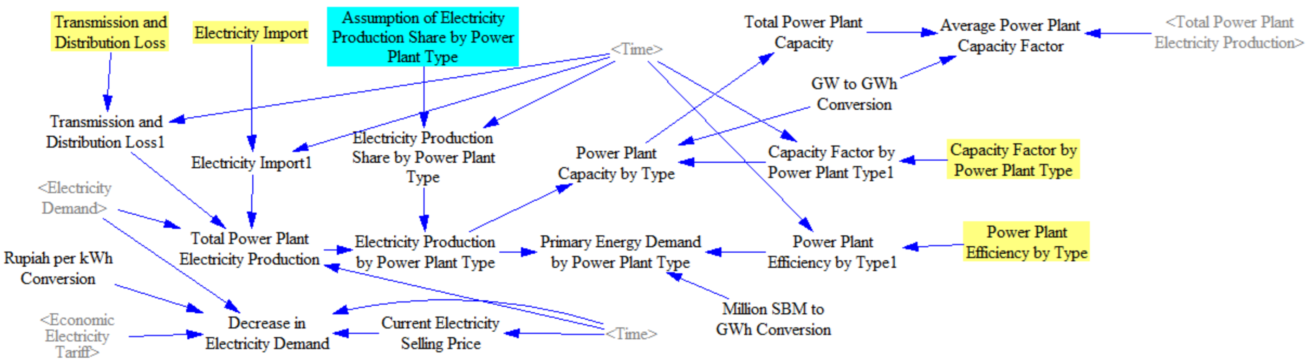

Figure A.9 Power generations sub-module

Additionally, power generation is determined by the Assumed Share of Electricity Generation by Plant Type, which defines the contribution of each power plant type within the electricity system. Each type of power plant has a Total Power Plant Capacity, which is influenced by individual plant capacity and the average capacity factor. This capacity factor, represented by the Capacity Factor by Plant Type, indicates the extent to which a power plant operates relative to its maximum capacity.

Technological efficiency in the power generation process is also a critical factor. The Power Plant Efficiency by Type variable affects the amount of primary energy required to generate electricity, which is then converted into energy units such as GWh or million BOE (Barrels of Oil Equivalent). As efficiency improves, the primary energy required can be reduced, thereby enhancing the effectiveness of energy resource utilization. Beyond production, electricity demand is also influenced by economic factors such as the Current Electricity Selling Price and Economic Electricity Tariff. If electricity prices rise, a potential decrease in Electricity Demand may occur, which can impact overall production requirements.

A.4.2 Sub-module: Oil refinery

Refinery capacity is affected by capacity additions over time, which depend on the Refinery Capacity Addition Rate (**Figure A.10**). These additions reflect refinery expansion and development projects, ultimately determining the Planned National Refinery Capacity (RPMN). Refinery capacity is also linked to its initial condition, represented by the Baseyear Refinery Capacity. This capacity then determines the amount of crude oil input that can be processed by the refinery, as set by the Baseyear Refinery Input and Refinery Input Share. Through this process, refineries produce petroleum fuel products according to the projected production in the baseline scenario (Baseyear Refinery Fuel Production).

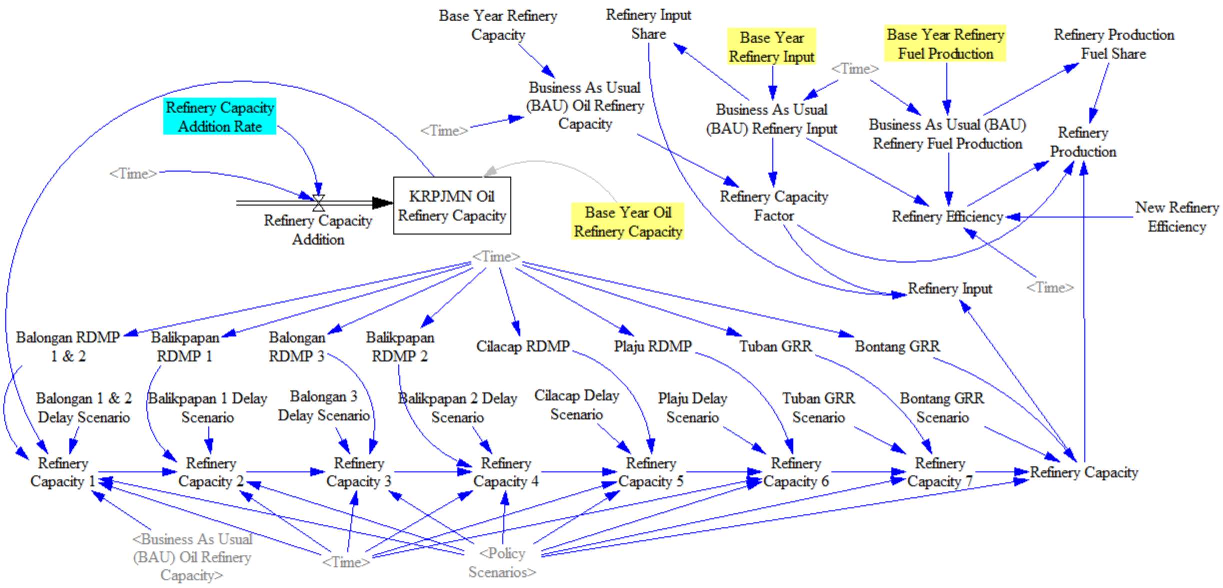

Figure A.10 Oil refinery sub-module

The refinery capacity factor plays a crucial role in determining system performance. Refinery efficiency in converting crude oil into finished products also contributes to output levels. In this diagram, various Refinery Development Master Plan (RDMP) projects—such as Balongan, Balikpapan, Cilacap, and Plaju, as well as Grass Root Refinery (GRR) projects in Tuban and Bontang, demonstrate how refinery development can enhance national oil production capacity.

However, various policy scenarios influence refinery capacity, including potential project delays (Delay Scenario), which may affect refinery capacity availability within a given period. Different simulation scenarios, such as the Business as Usual (BAU) Scenario, Optimistic Scenario, and Simulation Scenario depict varying projections in refinery capacity development and future oil production.

A.4.3 Sub-module: Biofuel

Figure A.11 illustrates the dynamics of green diesel production based on various policy scenarios. Green diesel production can be carried out through three main approaches: Coprocessing Green Diesel, Stand-Alone Green Diesel, and Revamping. These approaches are influenced by the implemented policy scenarios and technological advancements over time.

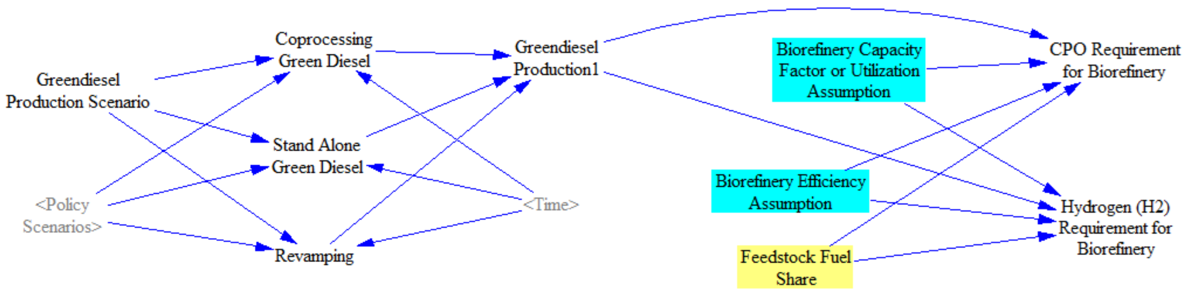

Figure A.11 Biofuel sub-module

In the context of biorefinery, **Figure A.11** also showed that green diesel production also depends on biorefinery facilities' capacity factor or utilization rate, represented by the Assumed Biorefinery Capacity Factor or Utilization Rate. This factor determines the demand for key feedstocks, such as crude palm oil (CPO) and hydrogen (H_2), required to support the production process. Additionally, the efficiency level of the production process plays a crucial role in determining feedstock requirements and production output, as represented by the Assumed Biorefinery Efficiency. On the other hand, the Feedstock Fuel Share influences the input-output balance within the biorefinery system.

A.4.4 Sub-module: Gas and DME

Figure A.12 depicts the relationship between LPG and DME (Dimethyl Ether) production capacity under various policy scenarios. LPG production depends on LPG plant capacity, which can be expanded through plant capacity additions. This variable is influenced by the LPG Plant Capacity Addition Rate and the initial installed capacity. Additionally, the LPG plant capacity can be increased from the base year condition, subsequently impacting the overall production of LPG and DME. The efficiency of the LPG plant is also a key component in determining production performance, as higher LPG plant efficiency contributes to the overall optimization of LPG production.

In this sub-module, there are two main scenarios for LPG-DME blending: a scenario with 20% DME blending and a scenario with 100% DME substitution. The chosen scenario affects the number of households (HHs) using DME and the overall DME production level. The decision regarding the DME production scenario also involves policy simulations, which include the Business-as-Usual (BAU) Scenario, the Optimistic Scenario, and the Simulation Scenario. Furthermore, the DME Capacity Planning aspect determines the increase in DME production capacity over a certain period. This entire sub-module provides insights into how changes in capacity, efficiency, and policy scenarios influence overall LPG and DME production within a broader energy system.

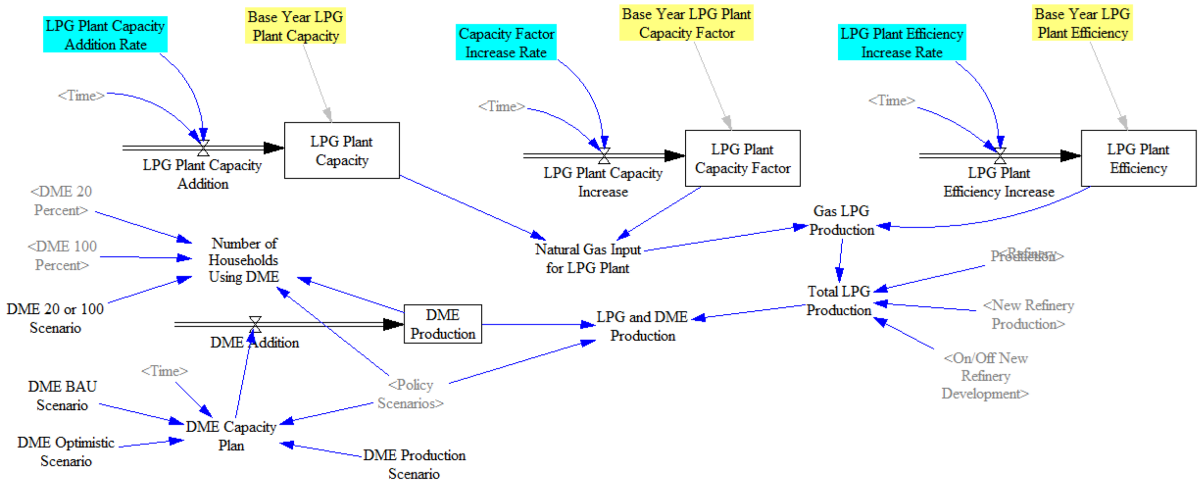

Figure A.12 Gas and DME sub-module

A.4.5 Sub-module: Coal conversion

Figure A.12 illustrates the relationship between coal demand and various conversion processes that produce energy products such as briquettes, DME (Dimethyl Ether), methanol, and synfuel (synthetic fuel). The capacity and efficiency factors of each plant play a crucial role in determining the coal requirements for each conversion process. On the left side of **Figure A.12**, briquette production is influenced by the Assumed Capacity Factor and the Utilization Rate of the Briquetting Plant, along with its efficiency. These factors determine the amount of coal required for briquette production. The higher the plant capacity and efficiency, the more optimized the coal utilization in the production process.

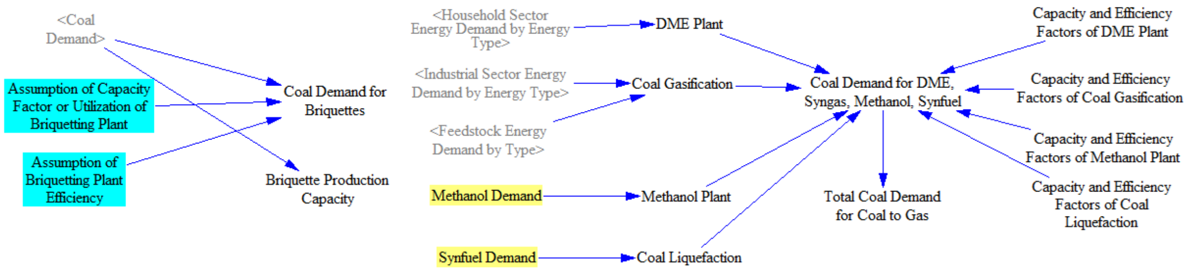

Figure A.13 Coal conversion sub-module

On the right side, there are various coal-to-energy conversion pathways. Coal is utilized in coal gasification processes to produce energy feedstocks that are subsequently used for DME, methanol, and synfuel production. Coal liquefaction also contributes to synfuel production. The total coal demand for all these processes is categorized as Total Coal Demand for Coal-to-Gas Conversion. Each plant within the conversion pathway has specific capacity and efficiency factors that influence the overall coal requirements and production output. The capacity and efficiency of the DME plant, coal gasification plant, methanol plant, and coal liquefaction plant are key variables in determining the effectiveness of this coal-based energy conversion system.

A.4.6 Sub-module: Mining

A.4.6.1 Coal

Coal resources are derived from baseyear data and can increase according to the Coal Resource Growth Rate (**Figure A.14**). In this process, the concept of the Coal Recovery Replacement Ratio plays a crucial role in determining the growth of coal reserves. Additionally, coal reserves are influenced by historical data and annual conversions, which transform resources into mineable reserves. Coal production in this diagram consists of various scenarios, such as BAU Coal Production, Baseyear Coal Production, and RUEN Coal Production. Coal production can grow based on historical trends and specific policies, such as RDMP.

Moreover, coal production scenarios consider the potential for increased production, taking into account reserve factors and annual conversions that affect future production levels. The relationship between reserves and production is also represented by the R-to-P Ratio Coal, which measures how long coal reserves can sustain current production levels. If production increases significantly without corresponding reserve additions, this ratio will decline, potentially driving policies to enhance exploration and investment in new resource exploitation.

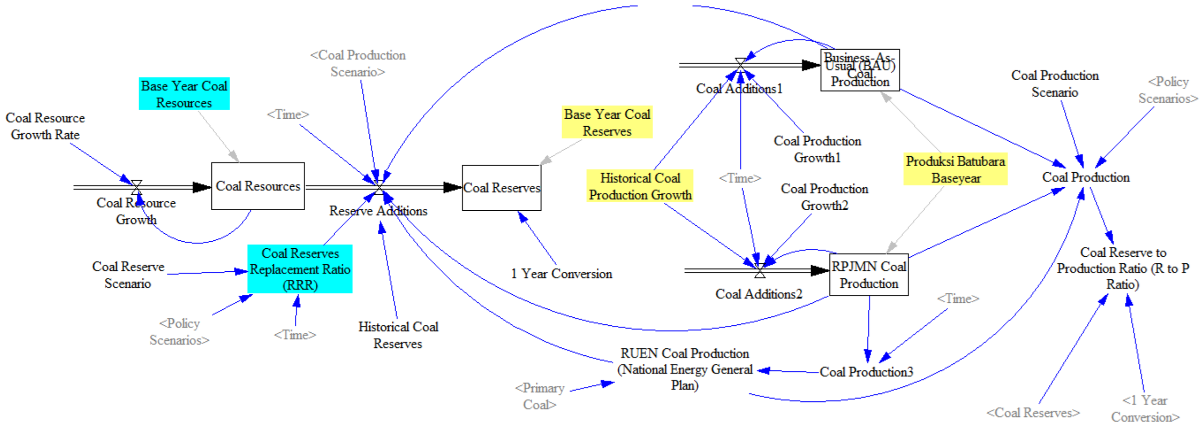

Figure A.14 Coal mining sub-module

In the policy scenarios presented in **Figure A.14**, three main approaches are considered. The Business-as-Usual (BAU) Scenario represents the coal industry's trajectory if current exploitation and production trends continue without significant policy interventions. The Optimistic Scenario, on the other hand, assumes increased exploration, production efficiency, or policies aimed at extending coal reserve lifespans. Meanwhile, the Simulation Scenario allows for variations in different factors, such as production growth or the implementation of more sustainable energy policies.

A.4.6.2 Natural Gas

Figure A.15 illustrates the relationship between natural gas reserves, natural gas production, and various factors influencing exploration and resource development under different policy scenarios. Natural gas reserves are derived from baseyear data and can increase through various mechanisms, including new gas exploration programs and routine exploration programs. The Natural Gas Reserve Replacement Ratio (RRR) is used to measure the success rate of exploration in restocking reserves.

Natural gas production is influenced by reserve growth and a gradual increase in production capacity. The diagram also includes gas exploration scenarios involving various development projects, such as Masela Gas, IDD Gas, JTB Gas, and Tangguh Gas. Each project has an associated delay scenario, which can impact overall gas production levels. From a policy perspective, this diagram presents various scenarios for increasing gas production, including massive exploration programs and routine exploration programs aimed at updating gas reserve data. Additionally, the relationship between natural gas production and the R-to-P Ratio Gas provides insights into the sustainability of reserves at current production rates, making it a crucial indicator in national gas resource management strategies.

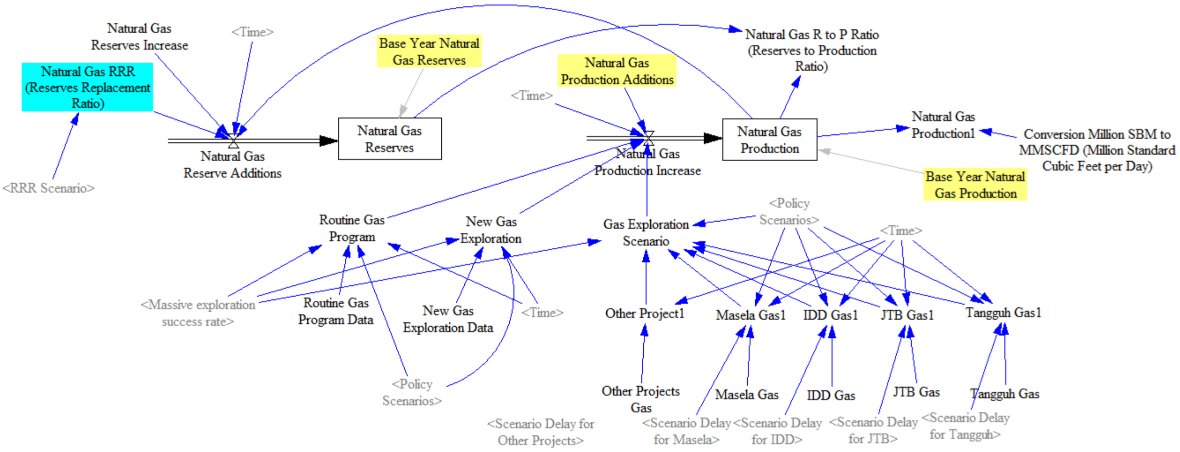

Figure A.15 Natural gas mining sub-module

A.4.6.3 Petroleum

Figure A.16 depicts the dynamics of petroleum reserves and production under various policy scenarios, exploration activities, and production enhancement strategies. Petroleum reserves are derived from baseyear data and can increase through new exploration initiatives, routine exploration programs, and the implementation of Enhanced Oil Recovery (EOR) technology. The Oil Reserve Replacement Ratio (RRR) is used to measure the success of exploration efforts in replacing depleted reserves.

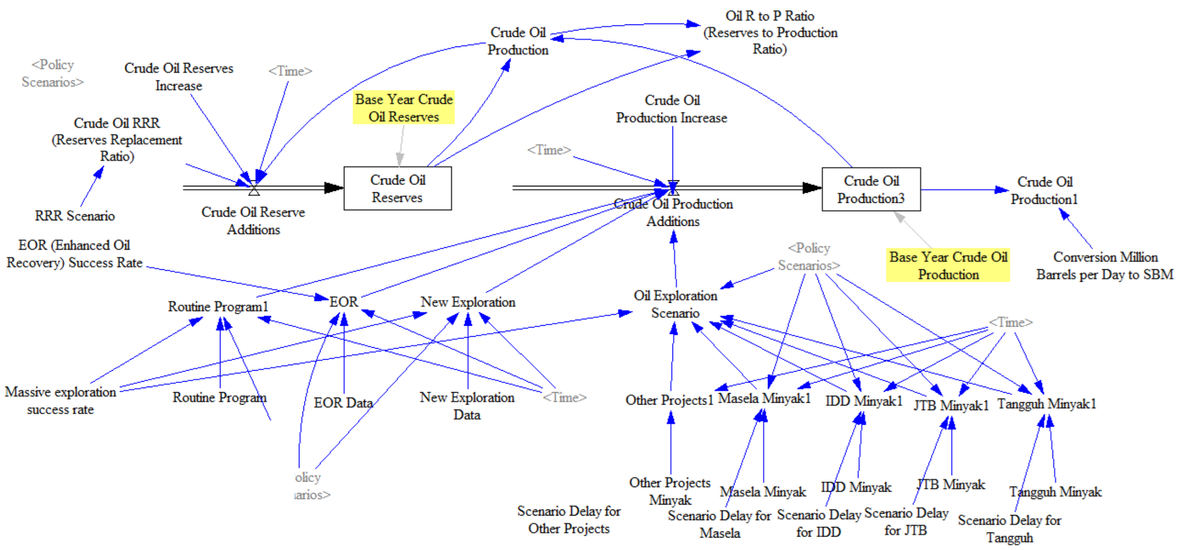

Figure A.16 Petroleum mining sub-module

Petroleum production is influenced by reserve growth and a gradual increase in production levels. This diagram also includes oil exploration scenarios involving several development projects, such as Masela Oil, IDD Oil, JTB Oil, and Tangguh Oil. Each project has an associated delay scenario, which can impact overall oil production. Various oil exploration and development policies play a critical role in boosting production, including massive exploration programs, routine exploration activities, and the adoption of EOR technology. The R-to-P Ratio Oil is used to illustrate the relationship between oil production and the sustainability of petroleum reserves at current production rates. Additionally, this sub-module shows oil production conversion into million barrels per day (SBM).

A.4.7 Sub-module: Total primary energy

Figure A.17 illustrates the flow of primary energy demand from various energy sources, including both fossil fuels and new and renewable energy (NRE), as well as their relationships with domestic consumption, imports and exports, and further processing at refineries. On the left side, coal as a primary energy source includes coal demand for power generation, briquettes, and total coal-to-gas conversion. The available coal production is partially allocated to meet domestic demand and exports. This diagram also shows the relationship between coal and overall primary energy needs.

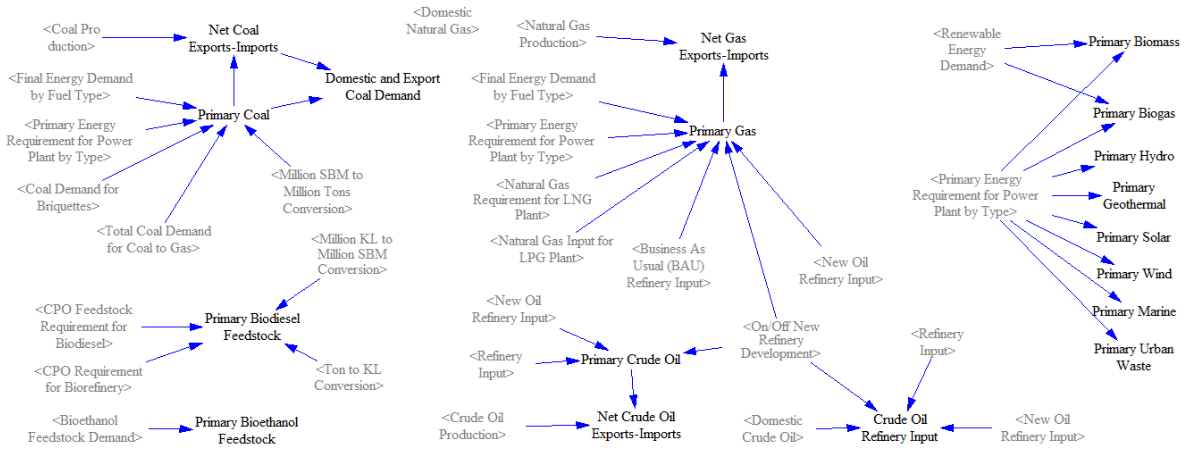

Figure A.17 Total primary energy sub-module

At the centre of the sub-module, natural gas as a primary energy source originates from domestic natural gas production, which can be consumed directly or further processed into Liquefied Natural Gas (LNG). This gas is then utilized for various domestic needs and exports, while also being integrated into the national energy system through conversion and distribution across different sectors.

On the right side, new and renewable energy (NRE) sources consist of biomass, biogas, hydropower, geothermal, solar, wind, ocean energy, and municipal waste. These energy sources serve as primary energy inputs for electricity generation, forming part of the national energy diversification strategy to reduce dependence on fossil fuels. At the bottom of the diagram, petroleum as a primary energy source comes from both domestic oil production and imports. Crude oil is then processed at refineries to produce various petroleum products used in transportation, industry, and other sectors. The diagram also includes petroleum input to new refineries as part of energy infrastructure development.

A.5 Policy interventions module

Table A.4 The policy interventions module

Definition: This module evaluates the impact of policy measures for renewable energy, and energy efficiency. It allows simulation of various policy scenarios to understand their effects on energy supply, demand, and emissions.

Variable name	**Brief descriptions**
Sub-module: DMO for coal	
Coal DMO policy	Domestic Market Obligation (DMO) policy for coal, stated in Dmnl.
Domestic coal	Domestic coal calculated from coal production influenced by the DMO policy, stated in million SBM.
DMO coal exports	Exported coal under the DMO policy, stated in million tons.
Coal exports	Total coal exports considering net coal exports minus imports, stated in million tons.
Coal trade balance	Coal trade balance calculated as surplus or deficit based on net coal exports minus imports, stated in million tons.
Coal power plant investments	Investments in coal-fired power plants, calculated based on capital costs and plant capacity by type, stated in billion USD.
Sub-module: DMO for gas	
Gas DMO policy	Domestic Market Obligation (DMO) policy for gas, stated in Dmnl.
Domestic gas	Domestic gas calculated from natural gas production with the application of the gas DMO policy, stated in million SBM.
Gas exports	Total gas exports, stated in million SBM.
Gas trade balance	Gas trade balance based on net gas exports minus imports, stated in million SBM.
Investments in gas-using industries	Investments in gas-utilizing industries, taking into account user industry investments, stated in billion USD.
Sub-module: Renewable energy development	
Additions and investments in biodiesel plants	Additions to biodiesel plants and related investments, stated in billion USD.
Additions and Investments in DME plant	Additions to DME plants and related investments, stated in billion USD.
Additions and investments in coal gasification plant	Additions to coal gasification plants and related investments, stated in billion USD.
Sub-module: Electric vehicles	
Increases in EV and non-EV industry capacity	Increase in production capacity of electric vehicles (EV) and non-electric vehicles (non-EV), stated in units.
EV and non-EV sales	Total sales of EVs and non-EVs in Indonesia, stated in units.
Local content incentives	Local content incentives, stated in Dmnl.

A.5.1 Sub-module: DMO for coal

The system begins with the coal DMO policy, which influences the allocation of coal between domestic use and exports (**Figure A.18**). This policy determines how much coal supply is available for the domestic market compared to exports. When the DMO policy is enforced, domestic coal becomes a key factor in meeting national industrial demand, while coal exports directly impact the trade balance and the national coal surplus deficit. Coal price fluctuations are influenced by the correlation model between coal prices and industrial investments. Higher coal prices can drive increased investment in coal-consuming industries, such as manufacturing and coal-fired power plants. Conversely, lower prices may reduce incentives for industries to invest in new projects.

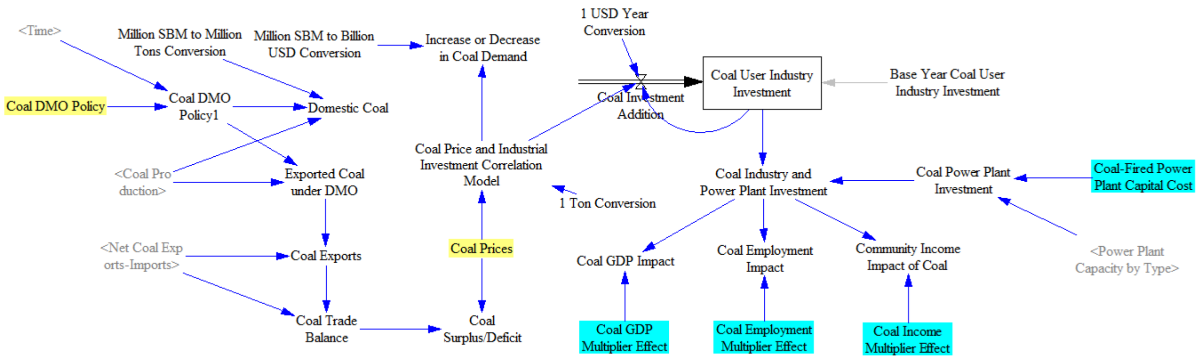

Figure A.18 DMO for coal sub-module

Investment in coal-consuming industries is a key variable in this model, as it is directly related to investments in coal-based power plants and broader economic impacts. This investment affects economic growth by increasing the capacity of power generation and industries that rely on coal. As investment increases, its impact on Gross Domestic Product (GDP) also becomes significant, reflected in the multiplier effect on the economy.

Furthermore, the multiplier effect on employment in the coal sector demonstrates how increased investment can create more job opportunities in the industrial and energy sectors. This contributes to overall income growth, which is analyzed under the variable coal-related income impact. Additionally, the diagram considers the capital cost for coal-fired power plants (CFPPs). This cost is a crucial factor in determining the economic feasibility of coal-fired power investments. The resulting power generation capacity directly affects national energy supply and electricity price stability.

A.5.2 Sub-module: DMO for gas

Figure A.19 illustrates the relationship between the Domestic Market Obligation (DMO) policy for natural gas, gas prices, investment in gas-consuming industries, and the resulting economic impacts. The system begins with the natural gas DMO policy, which determines the allocation of gas for domestic consumption and exports. This policy plays a crucial role in maintaining the balance between domestic gas supply and exports, ultimately affecting the gas trade balance. If gas exports increase, the gas surplus-deficit will fluctuate, which in turn influences gas price volatility in both domestic and international markets.

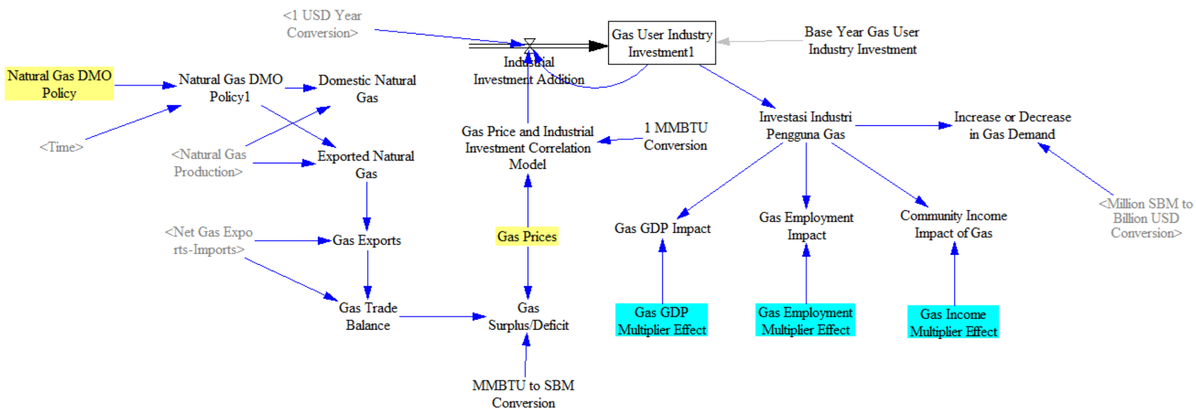

Figure A.19 DMO for gas sub-module

Gas prices are determined through a correlation model between gas prices and industrial investments. An increase in gas prices can impact investment decisions in gas-consuming industries, including the manufacturing and energy sectors. Higher gas prices raise production costs for industries reliant on gas, potentially reducing investment incentives. Conversely, stable or declining gas prices can encourage greater investment in industries that use gas as their primary fuel source.

Investment in gas-consuming industries is a critical factor in this model as it directly contributes to economic growth and employment. Increased investment in this sector generates a multiplier effect on Gross Domestic Product (GDP), reflecting the role of natural gas in national economic development. Additionally, higher investment levels create more job opportunities in related sectors such as petrochemicals and gas-fired power plants, as captured by the gas-related employment multiplier effect.

Another impact is the rise in public income due to the expansion of gas-based industries. This is measured through the income multiplier effect of gas, which demonstrates how increased investment enhances societal welfare by generating employment and increasing household incomes. Furthermore, the sub sub-module considers conversion factors between energy units and economic values, such as the conversion of MMBTU to SBM and billions of US dollars. These conversion factors help assess the broader-scale impact of investments and gas price fluctuations.

A.5.3 Sub-module: Electric Vehicles

The system starts with the vehicle fleet composition, which consists of electric vehicles (EVs) and internal combustion engine vehicles/ICEVs (**Figure A.20**). The number of vehicles on the road is influenced by the sales rate of both EVs and ICEVs. Vehicle sales contribute to tax revenues, including Luxury Goods Sales Tax (PPnBM) and Value-Added Tax (VAT) at both national and regional levels.

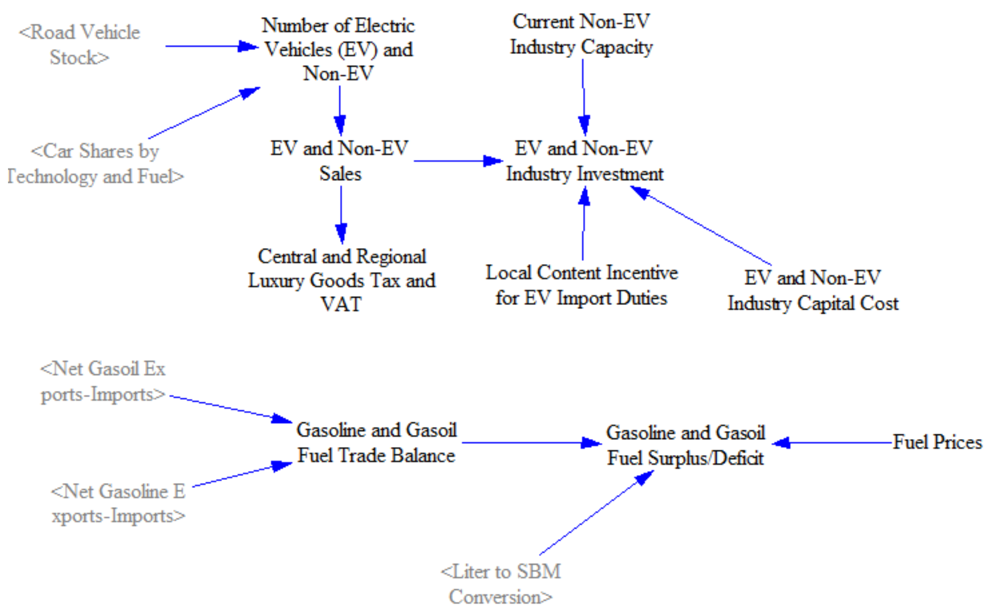

Figure A.20 Electric vehicles sub-module

From an industrial perspective, vehicle sales influence investments in both EV and ICEV manufacturing industries. These investments aim to expand the production capacity of the automotive sector for both electric and conventional vehicles. To support EV investments, several incentives are provided, such as local content incentives (TKDN) and the reduction or elimination of import duties on EVs. Additionally, industrial investment is affected by capital costs, which include development and production expenses for both EVs and ICEVs.

Changes in the number of vehicles on the road have direct implications for the fuel trade balance. If ICEVs remain dominant, fuel consumption will remain high, affecting the net trade balance of fuel, particularly gasoline and gasoil. This trade balance is also influenced by net fuel imports and exports. An imbalance between fuel imports and exports results in either a surplus or a deficit in the fuel trade. If fuel imports exceed exports, a trade deficit occurs, potentially increasing domestic fuel prices. Conversely, a growing EV fleet reduces fuel consumption, contributing to an improved trade balance and reducing fuel deficits. Additionally, the sub-module includes the conversion factor for SBM (Oil Barrel Equivalent) per litre, which is used to measure and compare energy consumption across different fuel types on a standardized scale.

A.6 Impact Assessment module

Table A.5 The impact assessments module

Definition: This module measures the outcomes of energy transitions, such as changes in emissions, energy supply, energy demand, and economic costs. It integrates outputs from the other modules to provide a comprehensive assessment of policy effectiveness.

Variable name	**Brief descriptions**
Sub-module: Land and water	
Land use for energy production	Land use for energy production, including primary gas, coal, oil, biodiesel, bioethanol, and biomass, stated in km².
Land use for power generation	Land used for power generation, stated in m²/MWh.
Total land use	Total land use, calculated as the sum of land used for power plants and land used for energy production, stated in km²
Water use for energy production	Water consumption for energy production, encompassing power plant and non-power plant water use, stated in liters.
Sub-module: Investment	
Impact of investment on GDP	The impact of investments in gas, coal, oil, biodiesel, bioethanol, and biomass plant additions on GDP, stated in billion USD.
Impact of investment on employment	The impact of investments in gas, coal, oil, biodiesel, bioethanol, and biomass plant additions on employment, stated in billion USD.
Impact of investment on community income	The impact of investments in gas, coal, oil, biodiesel, bioethanol, and biomass plant additions on community income, stated in billion USD.

A.6.1 Sub-module: Land and water

Figure A.21 depicts the interconnections between land and water utilization in energy production and various aspects of the energy supply chain, from the exploitation of primary resources to their impact on natural resource efficiency. Primary energy sources, including coal, natural gas, crude oil, bioethanol, and biodiesel feedstocks, serve as the starting point in this system. Each energy type requires different land allocations depending on the extraction and conversion processes. For instance, coal mining demands vast land areas, whereas bioethanol and biodiesel production necessitate large agricultural lands for cultivating energy crops. These primary energy sources are then processed and converted into more representative energy units, such as GWh or million SBM, to depict the system’s total energy consumption.

Land utilization in energy production is represented in this model through the relationship between primary resource demand and land area usage. In the energy production process, land use falls into two main categories: land directly utilized for electricity generation and land required for primary energy production. The land-use intensity in energy production is calculated based on the amount of energy generated per unit of land area utilized. This metric provides insights into the efficiency of different energy sources in utilizing available land.

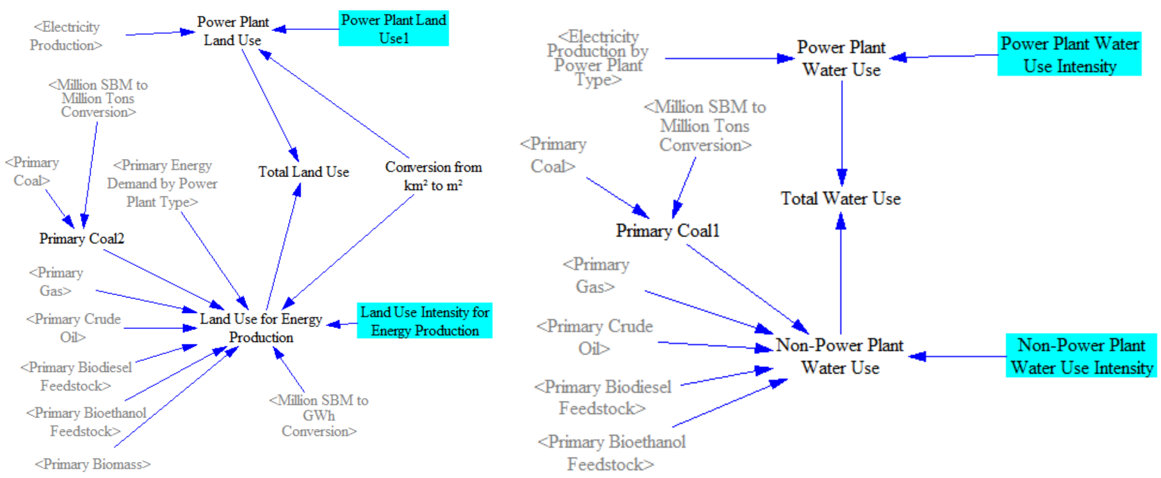

Figure A.21 Land and water sub-module

In addition to land, water utilization is another critical factor in energy production. Water is essential in various stages, including thermal power plant cooling, coal-washing processes, and oil and gas exploration. In this model, water usage is categorized into two segments: water used in electricity generation processes, and water consumption in energy production not directly related to power generation. Each category is associated with water-use intensity indicators, which measure the volume of water consumed per unit of energy produced. These indicators are crucial for evaluating water efficiency and assessing the environmental impact of energy production.

A.6.2 Sub-module: Investment

Figure A.22 illustrates how investment in three key sectors (renewable energy power plants, dimethyl ether (DME) plants, and coal gasification projects) contributes to economic and social growth through multiplier effects on GDP, employment, and public income. In the first section of the sub-module, investment in renewable energy power plants begins with capacity expansion based on the chosen technology. This investment process requires capital costs, which are a primary determinant of the project’s financial feasibility. The impact of this investment extends beyond increased electricity generation capacity, as it also positively influences the economy by increasing GDP in the energy sector, creating jobs, and increasing public income in the energy workforce. Each economic factor is linked to a multiplier effect, reflecting the broader economic impact of renewable energy investments.

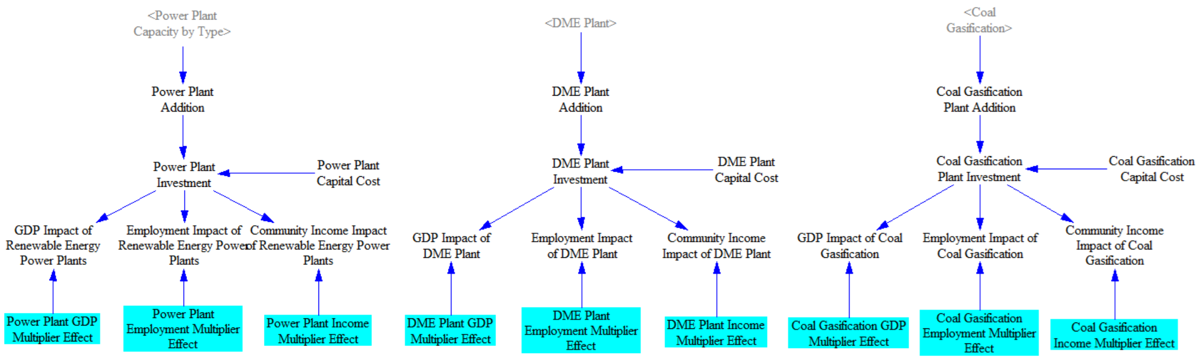

Figure A.22 Investment for power plant, DME plant, and coal gasification plant addition sub-module

The second section of the sub-module highlights investment in DME plant development. Similar to renewable energy projects, investment in DME production facilities is driven by the need for alternative energy sources as substitutes for conventional fuels. The capital cost of DME plant investment is a crucial factor in determining project viability. The economic impact of this investment is assessed through its contribution to energy sector GDP, job creation in the DME industry, and increased public income for workers involved in the DME supply chain. The multiplier effect of this investment indicates that expanding DME production capacity can generate long-term economic benefits.

The third section of the sub-module presents the dynamics of coal gasification investments. Expanding coal gasification capacity serves as a strategy to enhance the value-added potential of domestic coal by converting it into higher-value downstream products. Similar to renewable energy and DME investments, coal gasification projects require substantial capital costs. However, their economic impact includes growth in the energy sector GDP, job creation in the coal processing industry, and increased public income for workers involved in coal gasification operations and supply chains. The multiplier effect in this sector highlights that investments in coal gasification technology contribute to energy diversification and strengthen national energy security.

Figure A.23 also illustrates the relationship between investment in biodiesel, biorefinery (green diesel), and methanol production based on crude palm oil (CPO) and their economic and social impacts. Each investment sector has a significant multiplier effect on GDP, employment generation, and public income growth. In the first section, biodiesel demand drives the expansion of biodiesel production capacity, requiring substantial investment in plant construction and operations. This investment directly contributes to economic growth by increasing GDP through the expansion of the renewable energy and chemical industries. Additionally, the development and operation of biodiesel plants generate significant employment opportunities, both in manufacturing and feedstock supply chains. As employment increases, public income rises, ultimately fostering local economic growth and strengthening purchasing power.

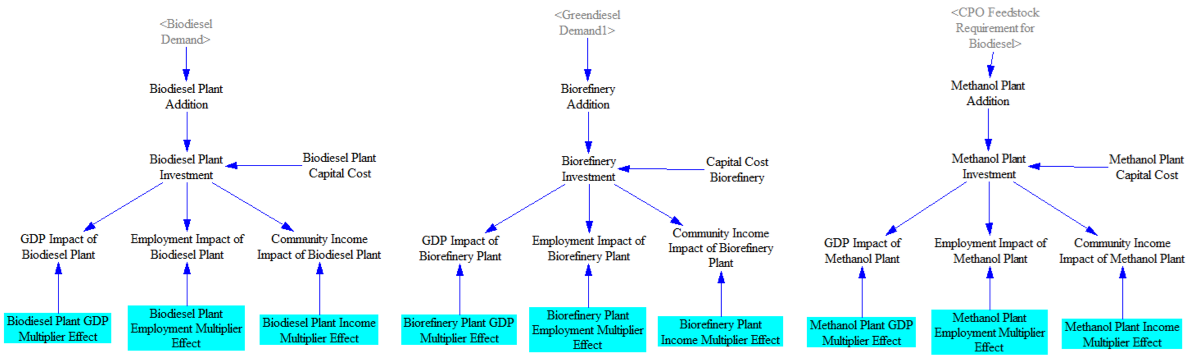

Figure A.23 Investment for biodiesel plant, biorefinery, and methanol plant addition sub-module

Next, the sub-module illustrates how green diesel demand stimulates investment in biorefinery development. Similar to the biodiesel industry, biorefinery capacity expansion necessitates substantial capital investments for facility construction and advanced production technology. This investment positively impacts GDP by driving growth in the renewable energy sector, ultimately reducing reliance on fossil fuels. Moreover, biorefinery industry expansion creates new job opportunities across manufacturing, processing technology, and raw material distribution. As employment increases, public income rises, further strengthening overall economic well-being.

The final section of the sub-module focuses on investment in methanol production facilities based on CPO, driven by the increasing demand for CPO as a feedstock for biodiesel production. Investment in this industry contributes to economic growth by adding value to the palm oil supply chain and the energy sector. Additionally, increasing methanol production capacity creates new employment opportunities, enhancing labour absorption in the palm oil processing and renewable energy sectors. As more workers are employed, public income increases, further supporting regional and national economic growth.

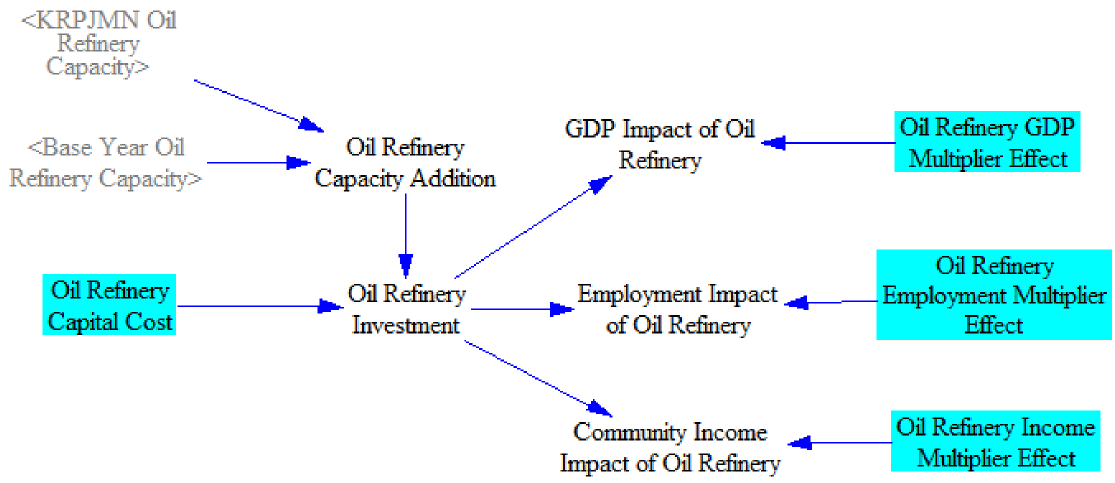

Figure A.24 Oil refinery investment sub-module

Figure A.24 illustrates the relationship between investment in refinery capacity expansion and its economic impact. Refinery capacity expansion can be planned based on the National Medium-Term Development Plan (RPJMN) or determined by the baseline refinery capacity in a specific year. This expansion requires substantial investment, known as capital cost, which includes the construction and development expenses for the refinery.

Investment in refineries has broad economic impacts. One of the primary effects is the increase in GDP through the growth of the energy industry. This GDP growth reflects the refinery sector's contribution to the national economy, both through fuel production and its ripple effects on related industries. This impact generates a multiplier effect on GDP, indicating that every investment in the refinery sector significantly contributes to overall economic growth.

Beyond GDP, refinery investment also plays a crucial role in job creation. The construction, operation, and maintenance of refineries require a large workforce, both in direct sectors such as engineering and manufacturing and in indirect sectors such as logistics and support services. The increase in employment generates a multiplier effect on job creation, meaning that investment in refineries not only creates jobs in the energy sector but also stimulates growth in associated industries.

Another economic impact is the increase in household income in communities surrounding the refineries. As employment opportunities expand and economic activity intensifies, household income also rises. This has a positive effect on local economic well-being and strengthens purchasing power. Similar to other impacts, this income growth has a multiplier effect, demonstrating that every additional investment in the refinery sector can generate broader economic benefits that enhance overall societal welfare.

Figure A.25 illustrates the impact of policy interventions, introduced in 2021, on the mineral industry and mineral downstream processing. These policies focus on strengthening domestic smelting industries by regulating the use of domestic mineral inputs, which in turn affects mineral production and exports. Extracted minerals can either be allocated for domestic smelting as raw material or exported as unprocessed commodities. However, with the policy intervention, there is a tendency to reduce raw mineral exports to enhance value-added processing within the country.

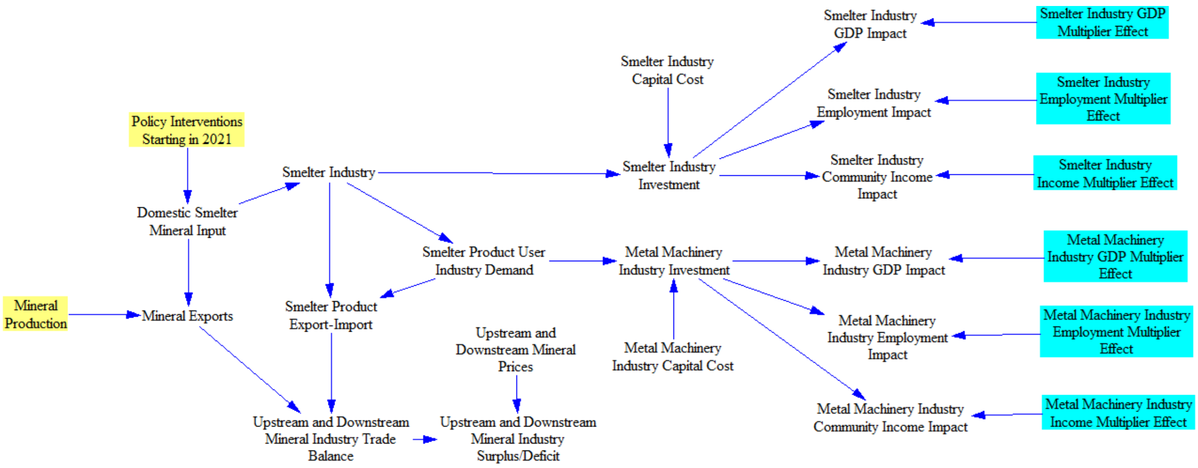

Figure A.25 Investment for smelter industry and metal machinery sub-module

This intervention also affects the trade balance of the mineral industry, both upstream and downstream. As domestic smelting industries increase their mineral consumption, smelter product exports also shift, requiring adjustments in industries that utilize these products. This has implications for mineral prices across various stages of the production chain and may create surpluses or deficits in the upstream and downstream mineral industries.

Investment in the smelting industry is one of the key impacts of this policy. The rise in investment demands significant capital costs, which are expected to generate positive economic effects such as an increase in GDP in the smelting sector, job creation, and higher incomes for workers in the industry. The multiplier effect of this investment is evident in the added value generated across various economic sectors. Beyond smelting, investments also flow into the machine metal industry, which utilizes smelter products. Like the smelting industry, the machine metal industry requires substantial capital investment. Its economic impact includes increased GDP in the machine metal sector, the creation of new jobs, and higher household income for workers involved in this industry. The overall economic multiplier effect highlights that this policy is not only aimed at mineral downstream processing but also seeks to promote the development of metal-based manufacturing industries.

A.7 Process overview and scheduling

The P/ESDM consists of five interconnected modules, as shown in **Figure A.26.** These modules include: (a) Demography and Macroeconomic module; (b) Final Energy Demand and Total Emissions module; (c) Total Energy Supply module; (d) Policy Interventions module; and (e) Impact Assessments module. The development of the P/ESDM followed a participatory process to ensure inclusivity and relevance in addressing energy sector challenges. Participatory approaches to energy modeling have emerged as essential involve stakeholder engagement (McGookin et al., 2021; Metze et al., 2023).

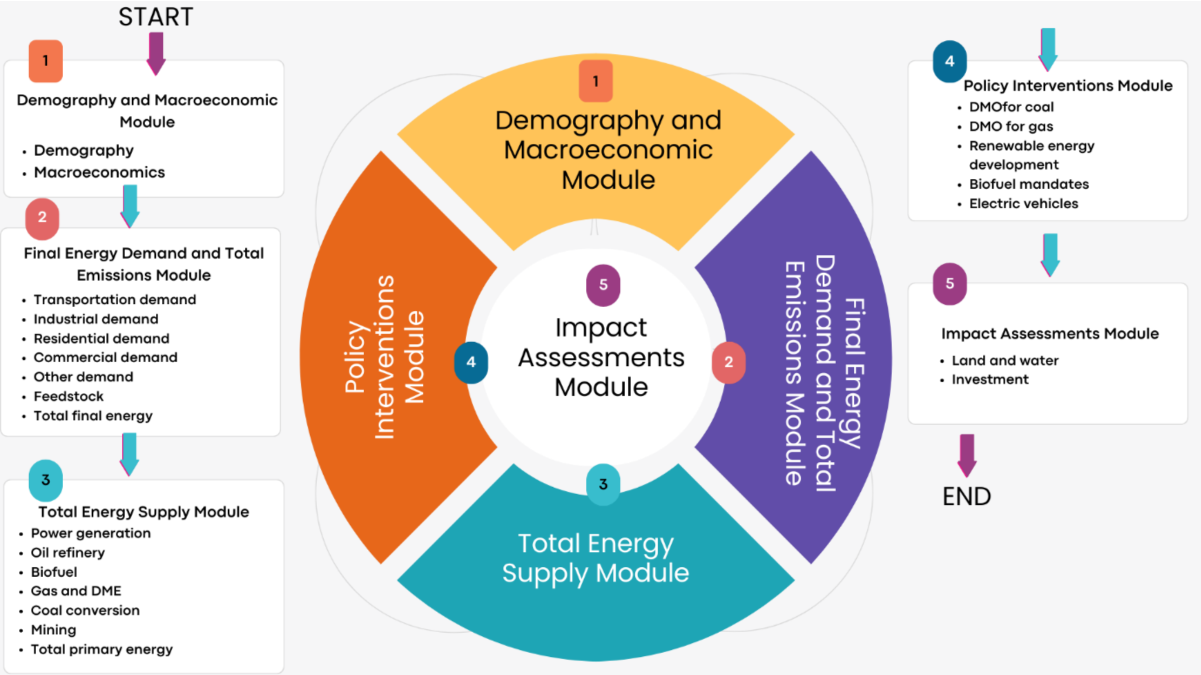

Figure A.26 Process flow of P/ESDM

The P/ESDM is initialized using historical data, expert judgment, and stakeholder consultations to ensure a realistic representation of Indonesia's energy system. The initialization process involves creating a causal loop diagram with historical data on Indonesia's demography and macroeconomics, final energy demand, and total energy supply. In the next step, we create a stock and flow diagram using the system dynamics approach. The model initializes energy policies based on existing regulations, planned policy changes, and stakeholder inputs. Two primary scenarios, Business-as-Usual (BaU) and Optimistic, are used to analyze different energy transition pathways in Indonesia. Initial parameter values and assumptions are validated through participatory discussions with policymakers, stakeholders, and industry representatives. By systematically initializing key variables and policy scenarios the P/ESDM ensures that simulations provide meaningful and actionable insights for cleaner energy.

A.7.1 Preliminary Model Development

The project began with a kick-off meeting on January 7, 2020 (**Figure A.27**). This meeting brought together the Project Management Unit (PMU) of the Partnership for Action on Green Economy (PAGE) under the United Nations Development Programme (UNDP) and the Director of Environmental Affairs from the Ministry of National Development Planning. This collaborative session set the foundation for the dynamic system model's development and outlined the objectives for policy scenario analyses within the energy sector.

On June 8, 2020, the preliminary findings of the P/ESDM and its initial analyses were presented to a wide range of stakeholders, including: The Director of Environmental Affairs, Ministry of National Development Planning; The Secretariat of the Directorate General of New Renewable Energy and Energy Conservation; PMU representatives from the PAGE/UNDP project; Participants of the System Dynamics Bandung Bootcamp; and Energy economists from the Indonesia Institute for Energy Economics. The feedback collected during this session was instrumental in refining the modules and improving the policy scenario analyses.

Figure A.27 Iterative participatory timeline for P/ESDM

A.7.2 Model revisions and refinements

To broaden stakeholder engagement, a follow-up meeting was held on July 23, 2020. This session included representatives from additional directorates within the Ministry of National Development Planning, notably: The Director of Energy, Mineral, and Mining Resources and The Director of Electricity, Telecommunications, and Information. Their contributions provided enhanced insights, resulting in further refinements to the P/ESDM and its policy scenarios.

From October 23 to 25, 2020, discussions were held with The System Dynamics Bandung Bootcamp Team; The National Low Carbon Development Indonesia (LCDI) Secretariat; and The PMU of the PAGE/UNDP initiative. The primary objective of these discussions was to align the P/ESDM with the LCDI dynamic system model developed by the Ministry of National Development Planning. This integration aimed to create a cohesive framework for addressing energy and environmental sustainability goals.

A.7.3 Final Participatory Energy System Dynamics Model (P/ESDM)

The concluding phase took place on November 25, 2020. During this event, the finalized P/ESDM and policy scenario analyses were presented to key stakeholders, including: The Ministry of Energy and Mineral Resources; The Ministry of National Development Planning; Representatives from the PAGE/UNDP project PMU; and other relevant ministries and agencies. This meeting also outlined a roadmap for applying the model and its policy scenario results in strategic decision-making processes. The outcomes were intended to support sustainable energy planning and policy development in Indonesia. The participatory approach ensured that the P/ESDM was robust, inclusive, and aligned with national priorities for energy sector transformation.

A.7.4 Policy scenario

The P/ESDM employs eight energy policy scenarios analyzed under two perspectives: the Business-as-Usual (BaU) scenario and the Optimistic Scenario (**Figure A.28**). This approach allows for a comprehensive evaluation of how different policy choices influence the energy system and related sectors over time. The simulation framework incorporates user-defined parameters via a sub-scenario panel within the P/ESDM interface. This design facilitates scenario customization, enabling stakeholders to examine the long-term implications of various energy policies.

The eight policies and their corresponding scenarios aim to provide a detailed exploration of potential energy futures in Indonesia. These scenarios enable policymakers to identify pathways for achieving sustainability goals, balancing energy security (energy supply and demand), economic growth, and environmental preservation. The design and analysis of scenarios leverage insights from previous stakeholder engagements and model validations.

Policy Scenario

Policies	Business as Usual	Optimistic
Oil production of 1 million barrels per day	Oil and gas production in 2020-2050 is based on the decline rate and routine program.	Oil production will increase to 1 million barrels per day by 2030 due to the strategy to maintain oil and gas production, which includes transforming reserves to production, implementing Enhanced Oil Recovery (EOR), and discovering new oil and gas from new exploration
Redirecting oil exports for domestic needs	The DMO for crude oil production will stay at approximately 90% from 2019 to 2050	DMO for crude oil production will start at 100% in 2025
Constructions of six oil refineries	There are no plans to increase refinery capacity during 2019 – 2050	Development of 4 existing refineries or RDMP and construction of 2 new refineries (GRR) with a total capacity of 300 thousand barrels per day
Electric vehicles	By 2050, the market share of electric vehicles is expected to be 8% for cars, 4% for motorcycles, and 0% for buses.	In 2050, the share of electric cars will be around 50%, electric motorcycles around 100%, and electric buses around 20%.
Increased biodiesel mix	The biodiesel blend rate is set to remain at 30% (B30) from 2020 to 2050, with no developments in green refineries. Additionally, there will be a 10% VAT, and no extra export levy will be imposed if crude palm oil (CPO) prices rise.	The biodiesel blend rate will be 40% (B40) in 2024, while B50 will be implemented in 2025. Green refinery production starts in 2024, with a target of 0.1 million KL from co-processing type and 3.6 million KL from standalone type. VAT 0%, and an additional export levy of US$5/MT (if CPO prices are higher than the reference export levy).
Renewable energy development	Renewable energy power plant capacity is anticipated to grow by about 600 MW annually	Renewable energy power plant capacity increases by an average of around 5 GW/year while diesel power plants are being phased out
Coal production management	Coal production is expected to increase at 3.28%/year, with no additions to proven coal reserves.	Proven coal reserves will increase by 12% per year during the period 2020-2050, and coal production will grow by 0.5% in 2025-2050
Expansions of urban gas networks	The number of city gas customers is projected to reach 887,000 by 2024, with no further growth anticipated.	Urban gas connections reach 4.1 million customers in 2024, 10 million in 2030, and 30 million in 2050

Figure A.28 Energy policy scenarios for P/ESDM

A.8 Adapting P/ESDM for Other Countries

The P/ESDM was designed to analyze Indonesia's energy sector dynamics and policy interventions. However, its framework can be adapted for other countries with different energy profiles, economic structures, and policy landscapes. The adaptability of P/ESDM lies in its modular design, which allows for modifications in key components such as energy supply and demand, policy mechanisms, and economic interactions. This study not only advances the field of energy system modeling but also equips policymakers with a robust tool to navigate the complexities of balancing sustainability goals with economic and energy justice realities. P/ESDM can be accessed at https://github.com/Alyarasya21/P-ESDM.

A.9 References

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., Goss-Custard, J., Grand, T., Heinz, S.K., Huse, G., 2006. A standard protocol for describing individual-based and agent-based models. Ecol. Modell. 198, 115-126.

Grimm, V., Berger, U., DeAngelis, D.L., Polhill, J.G., Giske, J., Railsback, S.F., 2010. The ODD protocol: a review and first update. Ecol. Modell. 221, 2760-2768.

McGookin, C., Ó Gallachóir, B., Byrne, E., 2021. Participatory methods in energy system modelling and planning – A review. Renewable and Sustainable Energy Reviews 151, 111504.

Metze, T.A.P., van den Broek, J., van Est, R., Cuppen, E.H.W.J., 2023. Participatory repertoires for aligning policy and society: An analysis of Dutch stakeholder views on deep geothermal energy. Energy Research & Social Science 98, 103019.