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Development of Energy System Modeling to Forecast 2060 Oil and Gas Demand in The Household Sector of East Kalimantan Using Bottom-Up Method

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ABSTRACT - Household sector is significantly influenced by population and economic factors, which are two key variables in energy consumption projections. For example, the selection of East Kalimantan as the location for the Nusantara Capital City through Law Number 3 of 2022 increased the household energy consumption in the area. It was observed that cooking and electricity needs were dominated by the usage of oil and gas, leading to the need for energy system modeling to design appropriate energy policies, avoid dependence on fossil fuels, and control CO_2 emissions in the future. Therefore, this research aims to forecast oil and gas demand of households up to 2060 based on several scenarios. A bottom-up method was dynamically connected to multiple variables for the forecast due to its ability to provide essential feedback loops, delays, and interactions required for energy system. The results showed that Business as Usual (BaU) scenario led to 28,96 million Barrel Oil Equivalent (BOE) and 8,09 million tons of emission in 2060 while Indonesian Capital City (IKN) scenario had 35,65 million and 9,8 million tons respectively. It was further reported that low carbon (LC) scenario produced 3,5 million tons of emissions.

Keywords: CO_2 emission, energy system modeling, energy transition, oil and gas demand, system dynamic.

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INTRODUCTION

Population growth, advances in economic activity, and improvements in the lifestyles of people are causing an increase in energy demand (BPS Indonesia 2018). This has led to the general application of GRDP (Gross Regional Domestic Product) and population as two variables to determine energy consumption. The trend is identified in the increase in the electricity consumption of East Kalimantan due to the growth of GRDP and population, as shown in Figures 1, 2, and 3.

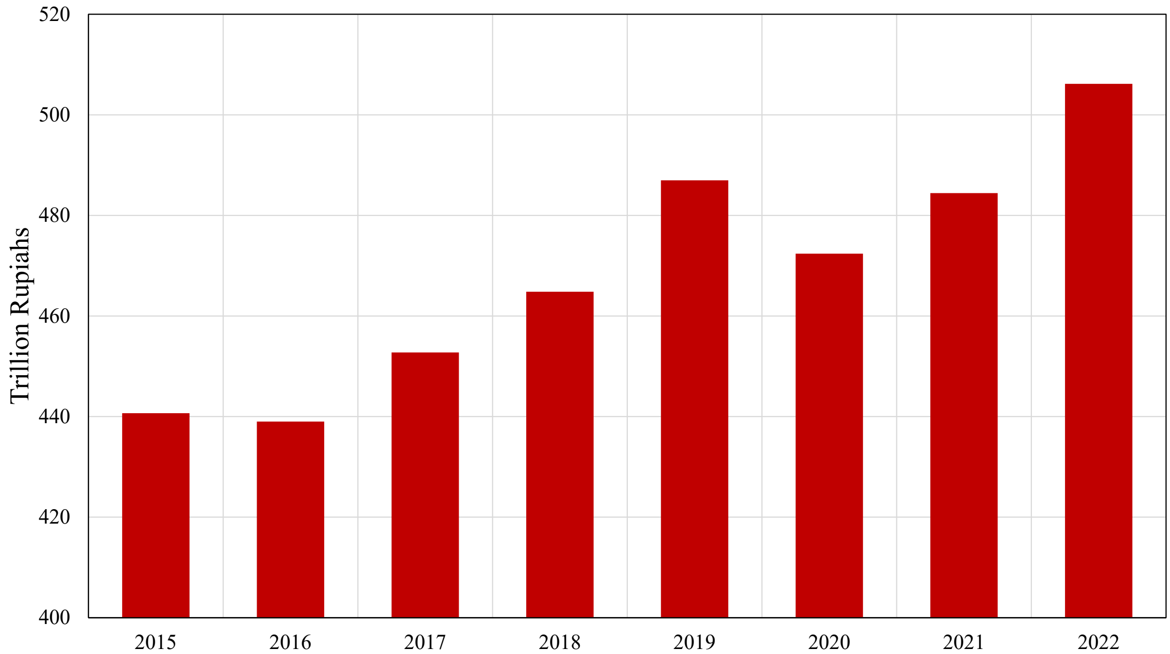

Figure 1
East Kalimantan GRDP (at constant 2010 prices)

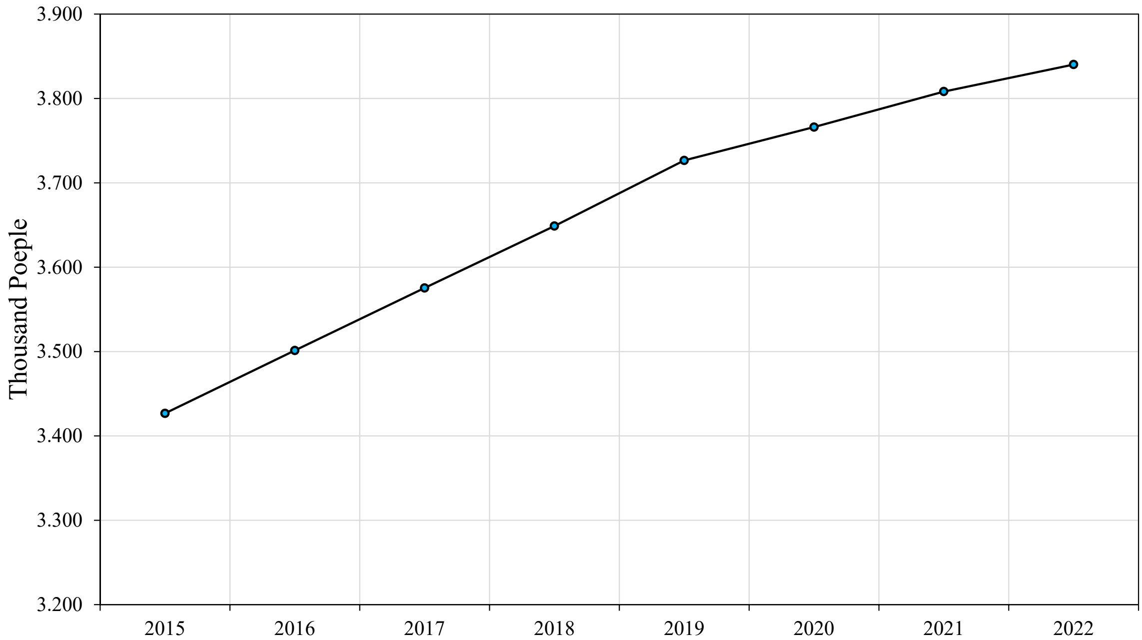

Figure 2
Population of East Kalimantan

GRDP of East Kalimantan during the 2015-2022 period showed dynamic growth (BPS Kalimantan Timur 2019a, 2022, 2024). However, there was a decline in 2016, 2020, and 2021 due to COVID-19. The population also increased in the observation year from 3,05 million in 2010 to 3,77 million in 2020, with an average growth of 2,13%. the growth averaged 0,84% per year after 2020 (BPS Kalimantan Timur 2016, 2020, 2023b, 2024). The trend recorded for the two variables led to an increase in electricity consumption as observed in PLN (State Electricity Company) electricity sales data for the 2015-2022 period. Figure 3 shows that most power plants designed to meet electricity needs use fossil fuels and do not lead to energy availability. The demand for energy in East Kalimantan is generally based on fossil fuels, primarily oil and gas. This trend is a significant concern considering the continuing decline in domestic oil production. Moreover, environmental issues have become a concern for the global community as observed in the efforts to reduce CO_2 emissions by limiting fossil fuel usage and increasing new and renewable energy (NRE) adoption. This shows the need for comprehensive energy planning to develop system modeling and simulation that are capable of maximizing local energy sources in line with Government Regulation No.79/2014 concerning National Energy Policy (Pemerintah Indonesia 2014).

A comprehensive energy system modeling that considers different sectors as the end users is needed. The sectors in East Kalimantan are divided into six, including industry, household, transportation, commercial, non-energy, and others. Household is important because the sector is most affected by population size. Therefore, it is important to project future oil and gas needs in household sector as a basis to formulate appropriate policies.

The projection of future energy needs on a regional basis requires a tool known as energy system modeling. The use of the device has experienced rapid development through the application of different methods, leading to several variations and modifications. Therefore, there is a need for accuracy in selecting a modeling system that is relevant to the conditions and energy characteristics of the modeled area. This led to the recommendation of quantitative and qualitative selection processes as constructive methods due to the possibility of producing different results in each region.

The application of several types of energy system modeling in Indonesia is described in the Indonesian Energy Outlook which is compiled through several scenarios (Dewan Energi Nasional 2016a, 2016b, 2017, 2018, 2019). The development of energy system modeling in the world is grouped into two main fields, namely; Process System Engineering (PSE) and Energy Economics (EE) (Subramanian et al. 2018), and this study is included in the EE field. EE is known as modeling with high-level aggregation technology. Energy system modeling continues to improve and integrate with environment, economics, and policy (Parikh 1981; Seebregts et al. 2002), and its adjustment to the conditions of each country (Munasinghe & Meier 1988, 1993; Pachauri 1989), especially in developing countries (Bhattacharyya & Timilsina 2009, 2010; Subramanian et al. 2018). This study develops energy system modeling by forecasting household sector energy consumption using the Energy Demand Management (EDM) approach (Suganthi & Samuel 2012), dynamically (Sani et al. 2018) with the bottom-up method. The combination of top-down methods with IO models at the beginning of modeling, and bottom-up in building the model is a part that has never been done in energy modeling, especially in East Kalimantan.

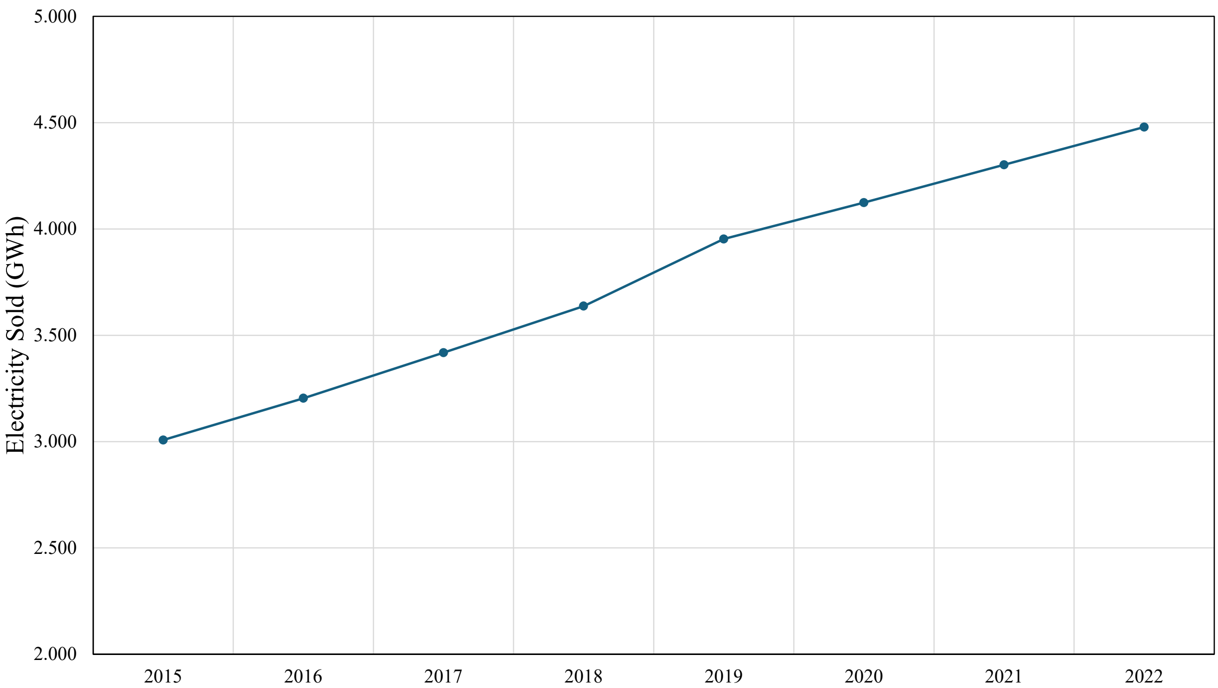

Figure 3
PLN electricity sold for East-North Kalimantan

Regional macroeconomic analysis is the basic description of the interaction between households and other business sectors before modeling. It is based on IO (Input Output) and a table analysis (Yusgiantoro 1991). Therefore, this research aimed to design future energy demand in household sector through four stages, including (1) regional macroeconomic analysis using IO table, (2) selection of qualitative energy system modeling, (3) modeling and simulation through Business as Usual (BaU) scenario, and (4) conclusions based on the results obtained in the previous stages. The process was initiated through qualitative modeling selection. This was achieved by combining two energy system modeling methods, including top-down using IO method and bottom-up through system dynamics. The combination is a novelty in energy system modeling and has not been applied in any region in Indonesia. The flow diagram of the research is generally presented in Figure 4.

The preparation stage focused on the collection of energy data and the application of IO table analysis to determine East Kalimantan energy landscape. The next stage was the qualitative selection of the appropriate energy system modeling method through a series of comparisons with several existing systems. Subsequently, modeling and forecasting were conducted using the selected modeling method and the final stage was to draw some conclusions based on the results.

This research is expected to serve as a reference for other regions in Indonesia in building energy system modeling and predicting future oil and gas demand on a regional scale using a bottom-up method. The results would also serve as input for the government in designing appropriate policies to meet energy needs of household sector in the future as well as to control CO_2 emissions. The focus on East Kalimantan energy system was due to its uniqueness based on varied and abundant energy resources.

East Kalimantan is known as the national energy barn due to the existence of coal potential with 38.380 million tons of resources (39% national) and 11.780 million tons of reserves (37% national). Moreover, oil has P3 reserves with 263 MMSTB (6% national), natural gas has P3 reserves of 5,7 TCF (11% national), and coalbed methane gas potential is 89,5 TCF, (Donanita et al. 2022). There is also potential for new renewable energy in addition to fossil fuels, including 2.119 MW hydropower, 3.112 KW mini and macro hydro, 13.479 MW solar power, 212 MW wind power, and bioenergy with a potential of 1.086 MW (Dewan Energi Nasional 2022). The biodiesel production capacity of the area was also estimated to be 2.547 KL (13% National). Therefore, modeling is important in building a system to estimate future energy demand in household sector using bottom-up and demand-side methods.

The development of the modeling is intended to continue the efforts of Sani et al. (Sani et al. 2018) who designed the national energy mix using system dynamics with top-down and supply-side methods to correct the current national and regional energy modeling. Therefore, the main objectives are: 1). to select the proper energy system modeling and accommodate bottom-up by conducting literature research and qualitative comparisons; 2). Develop models and simulations through BaU scenario to determine oil and gas needs in household sector by 2060 and 3). Model development through several other scenarios.

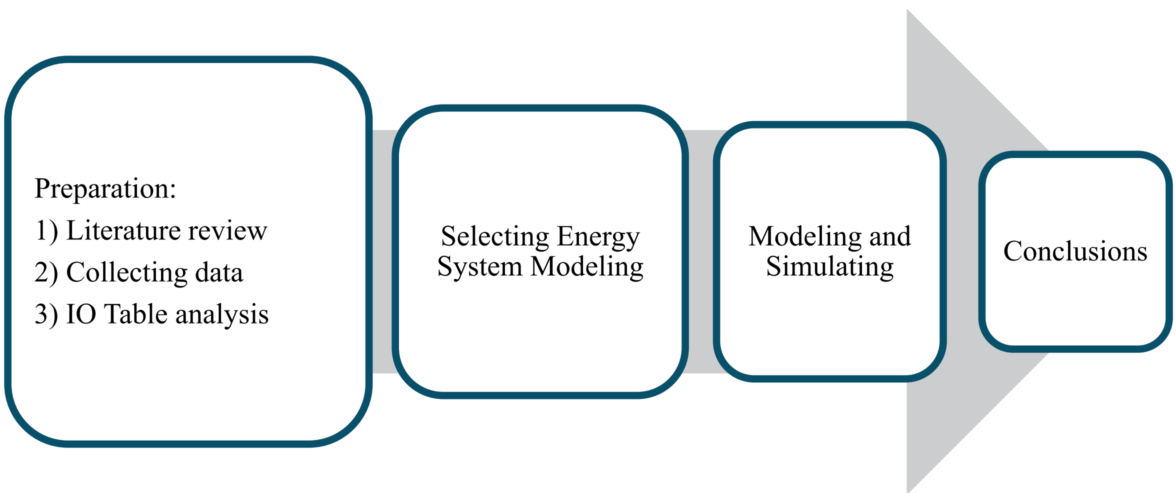

Figure 4
Research flow chart

METHODOLOGY

Energy system modeling has been in existence since the 1950s and applied using the accounting method in the US (United States). It was rapidly developed due to the global energy crisis of the 1970s. (Forrester 1989). Moreover, the modeling selection process is qualitative as observed in comparative research related to energy system modeling (Bhattacharyya & Timilsina 2009, 2010; Subramanian et al. 2018), demand forecasting (Suganthi & Samuel 2012), and system dynamics (Sani et al. 2018). Furthermore, the process was simplified by screening several existing energy system modeling methods specifically those commonly used in developing countries. This was based on the desired modeling, bottom-up, and demand forecasting methods.

The discussion led to the assessment of the system dynamics considered most relevant for this research. This was based on the belief that dynamic energy behavior, indirect biased influence of a policy such as delay, inconsistent consumption patterns, and multiple effects of the interactions between variables could only be adjusted through system dynamics. Therefore, system dynamics was selected for the modeling process using bottom-up and demand forecasting methods.

The preparation stage was initiated through the analysis of the 2016 East Kalimantan IO table published by East Kalimantan BPS (Central Statistics Agency) in August 2021 (East Kalimantan Central Statistics Agency 2021) to serve as the reference in compiling modeling and simulation scenarios. The data were obtained from several sources, including BPS, National Energy Council (DEN), East Kalimantan Mining and Mineral Service, East Kalimantan Provincial Government, Ministry of Energy and Mineral Resources of Indonesia, State Gazette of the Republic of Indonesia, and Energy Information Agency.

The next stage was the modeling and simulating of oil and gas demand for East Kalimantan household sector based on the growing energy consumption influenced by the increase in GRDP per capita. The flowchart of the modeling is presented in Figure 5. Furthermore, energy demand was calculated using Barrel Oil Equivalent (BOE).

The flowchart includes several variables considered and calculated to obtain oil and gas demand in household sector. The process was initiated by calculating the macro variables such as GRDP influenced by GVA (Gross Value Added) of household sector, population, elasticity, intensity, and GRDP per capita. All the variables changed dynamically and were interconnected. This affected the growth rate of energy demand in the sectors and was applied to form an appropriate system. The output of the system was the amount of energy consumption in BOE and GVA in Billion Rupiah. These variables were calculated and validated using actual data through matching. Matching was achieved through sensitivity analysis of the GRDP per capita growth rate in the period 2015-2022.

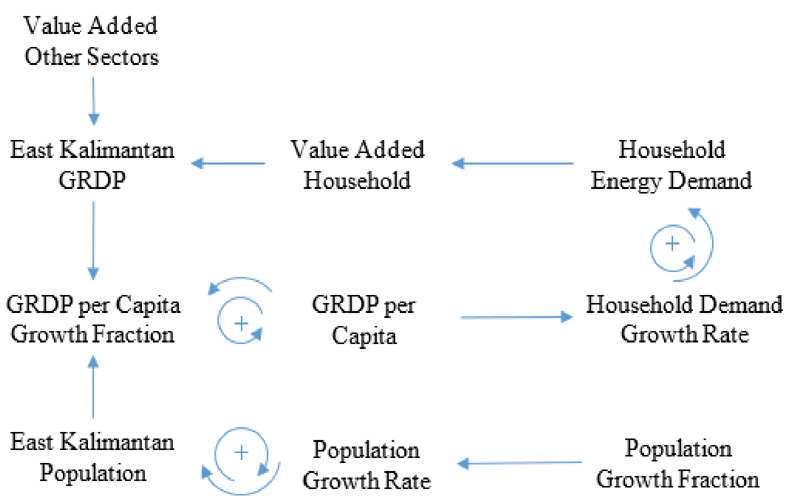

Figure 5
Flowchart of energy demand modeling

Population

The average population growth rate of East Kalimantan between 2010 and 2020 was 2,05% and the value was assumed to be the same in the following years. The curve in Figure 6 compares the modeling and actual data using 2015 with a population of 3,427 million as the base year up to 2022 in line with the available data (BPS Kalimantan Timur, 2019a, 2022, 2024).

Number of households

The population of East Kalimantan was divided based on two social classes, urban and rural communities. Moreover, the rural communities were further divided into two, including electrified and non-electrified areas. The number of urban residents increased from 66% in the base year of 2015 to 68,9% in 2020 and 70,1% in 2022, as shown in Figure 7. Meanwhile, the number of people in each household (RT) or Family Group (KK) was 4,02 (BPS Kalimantan Timur, 2019b).

Household energy consumption

Household energy consumption was divided into two based on needs, including cooking and electrical equipment such as air conditioners, refrigerators, televisions, etc. The average energy consumed for cooking in East Kalimantan per year was 1,332 BOE/KK with the percentage of the type of energy utilized presented in Table 1 (BPS Kalimantan Timur 2023a). Furthermore, the average electricity consumption per household was found to be 1,870 kWh with the distribution presented based on groups in Table 2.

Table 1
Energy type utilization for cooking

Energy Types	2015	2016	2021
Electricity (%)	0,63	1,04	0,35
LPG (%)	91,55	93,71	96,28
Kerosene (%)	1,73	1,09	0,15
Charcoal (%)	0,30	0,27	0,00
Wood (%)	4,89	3,10	1,85
Other (%)	0,90	0,79	1,36
Total	100	100	100

Table 2
Average household electricity consumption

Electricity Consumption	Average per year	
	Urban	Rural
kWh per KK	2.879,41	860,42

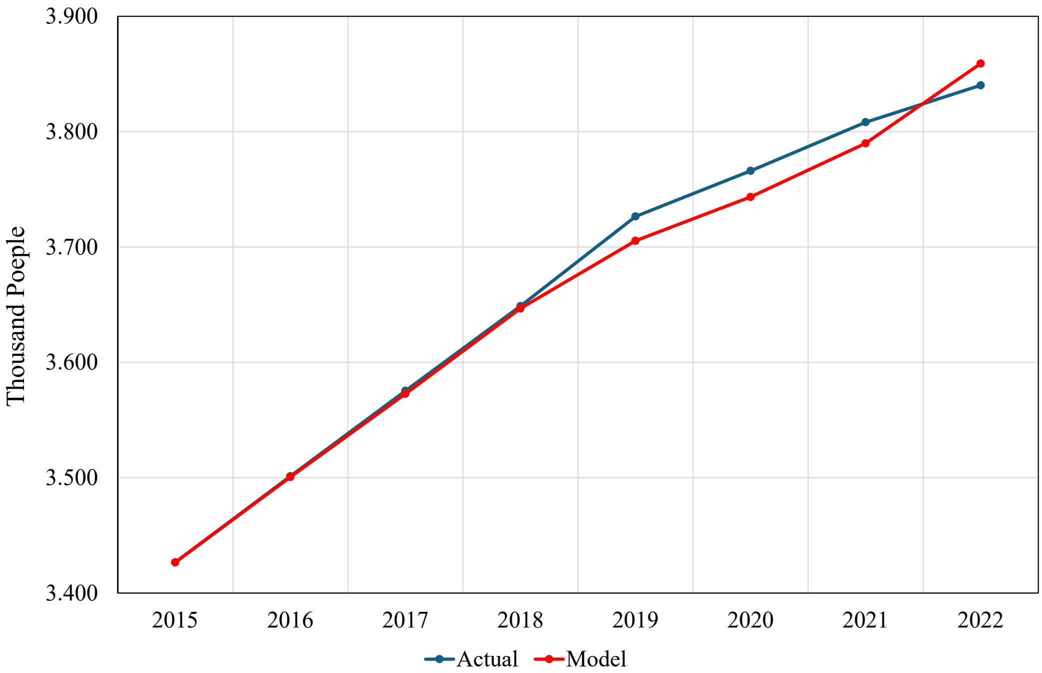

Figure 6
Population of East Kalimantan

The electricity consumption of a region depends on the available sources and facilities. This availability is statistically reflected through the electrification ratio. The data collected from BPS and PLN showed that the electrification ratio of East Kalimantan from 2015 to 2022 did not reach 100% (PT PLN 2016, 2017, 2018, 2020, 2021, 2022, 2023).

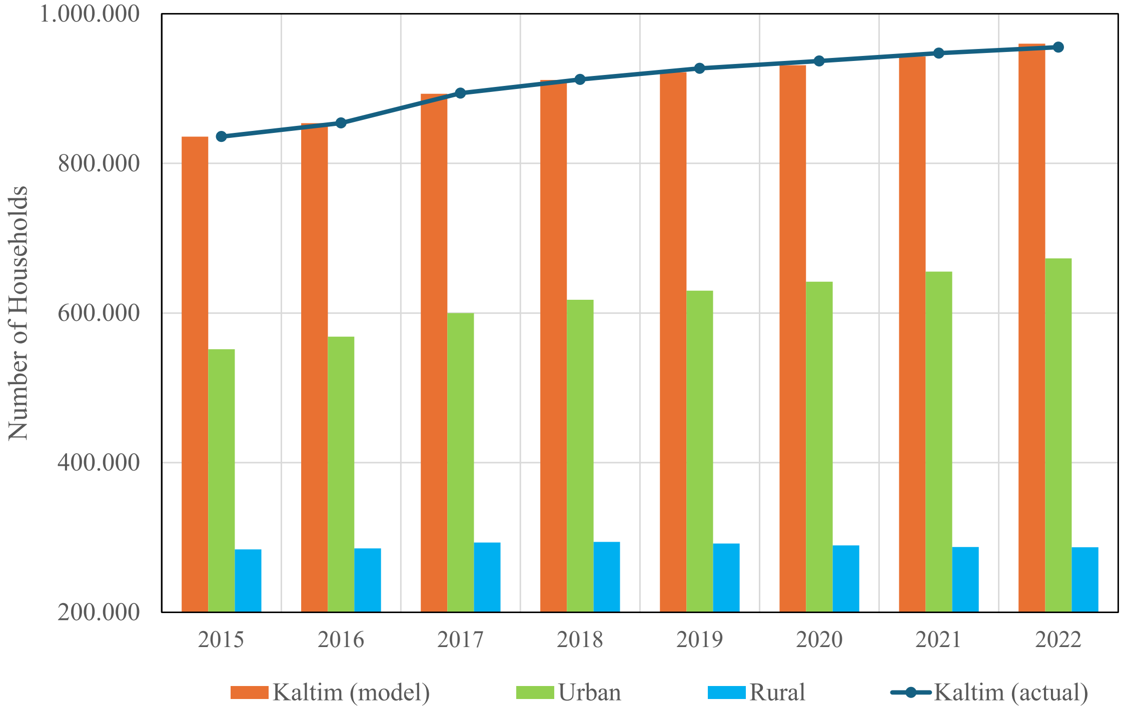

Figure 7
Number of households in East Kalimantan

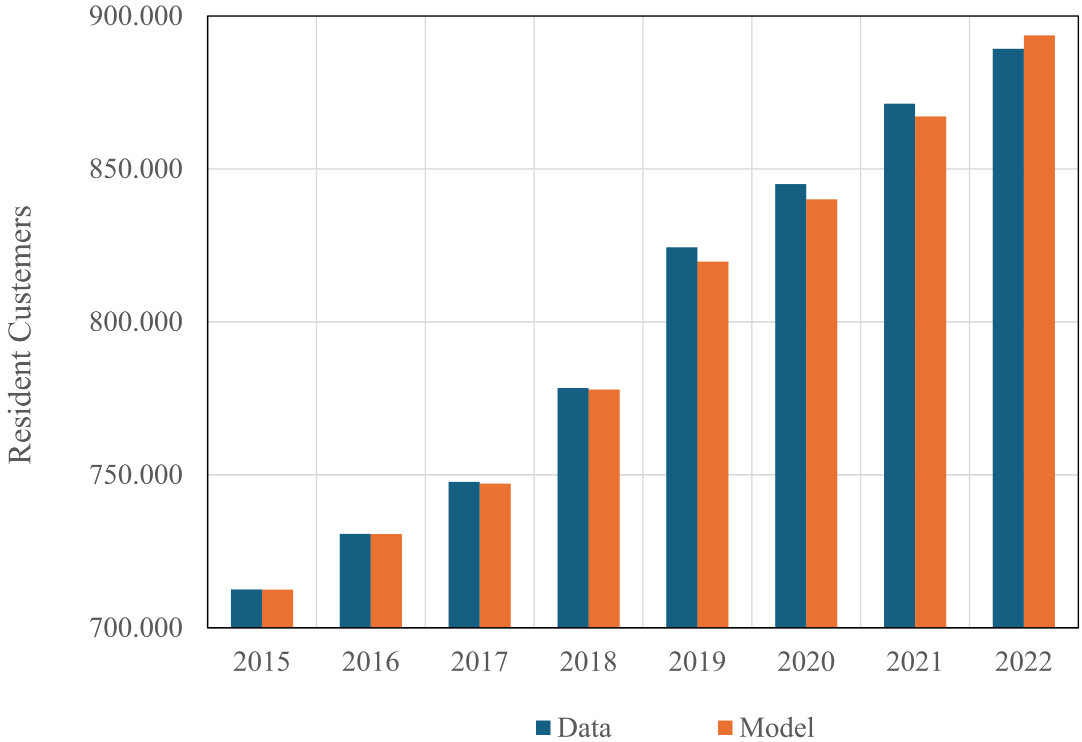

Figure 8
Number of household electricity customers

A higher electrification ratio represents the existence of more electricity customers. It was also observed that an increase in the number of customers could be due to the population growth of the area. Therefore, number of electricity customers in East Kalimantan (KK) is presented in Figure 8.

The average electricity consumption by a customer was calculated based on the unit of electricity sold (kWh/customer). Therefore, Figure 9 shows electricity consumption data per customer group for East and North Kalimantan regions which are presented as one in PLN statistics book.

Energy elasticity

The average energy elasticity used in the modeling was calculated based on economic growth in each sector (GVA) and region (GRDP). This is generally presented in the following equation:

$$\varepsilon = (\Delta EC/EC)/(\Delta GDP/GDP) \quad (1)$$

Where, is energy consumption and is the changes in gross income. The growth of sectoral GVA was used to determine the development of energy sector in the modeling. Therefore, Equation (1) was modified as follows:

$$\varepsilon_{sector} = \frac{(\Delta GVA_{sector}/GVA_{sector})}{(\Delta GDP/GDP)} \quad (2)$$

Where, $(\Delta GVA_{Sector} \ / \ GVA_{sector})$ is the economic growth in the sector for the observation year, 2010 to 2015. The average elasticity was calculated as 1,00 and assumed to be constant to the end of the forecast.

Energy intensity

Energy Intensity (EI) was used to represent energy required to provide one unit of GVA. The International Energy Agency (2019) measured EI as energy use per unit of GRDP. The variable was generally described through the following equation:

$$EI = Energy\ Consump/GVA \quad (3)$$

Where, EI is energy intensity in BOE/Billion Rupiah, Consump is energy consumption in BOE, and GVA is the gross value added in Billion Rupiah. IE calculated for the first modeling year was 116 BOE/Billion Rupiah.

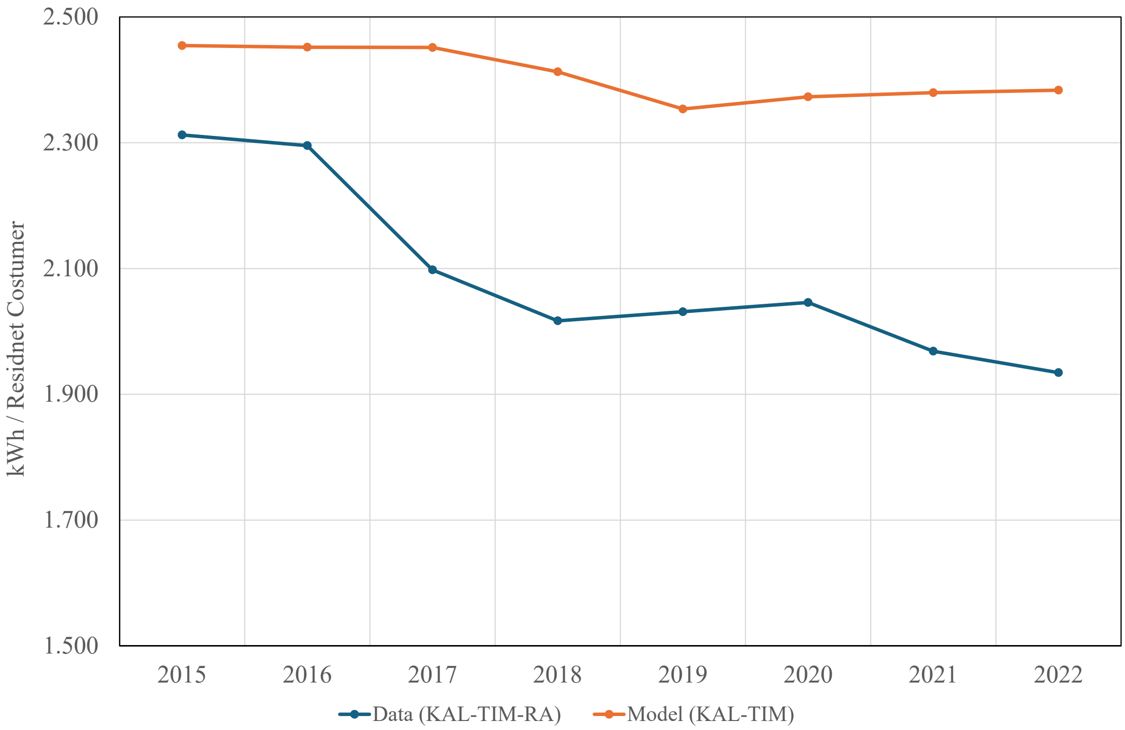

Figure 9
Average electricity consumption

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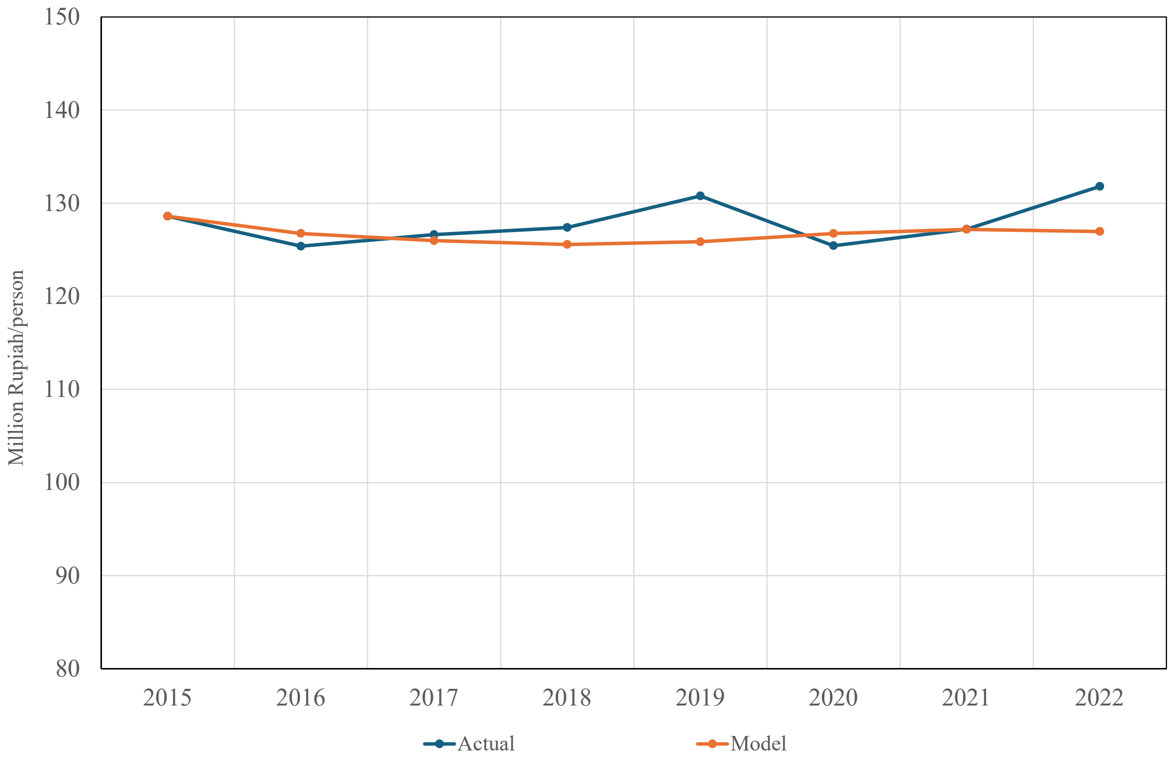

Figure 10
East Kalimantan GRDP per capita

GRDP per capita

The modeling significantly considered GRDP per capita at constant prices. The increase in GRDP was also determined based on the dynamic accumulation of GVA for all energy user sectors. This was achieved by adjusting the average growth of GRDP East Kalimantan between 2010 and 2022. The comparison curve of the modeling results and actual data for GRDP per capita from 2015 to 2022 is presented in Figure 10.

Table 3 shows the basic assumptions used in developing a modeling based on BaU scenario. The arguments associated with these assumptions have been previously explained.

Population growth, elasticity, and the number of people in each household were determined based on observations of actual BPS data from 2010 to 2020. Meanwhile, EI, GRDP, and GRDP per capita change dynamically following the system modeling developed.

Table 3
Basic assumptions of the modeling

Assumptions	2015	2025	2040	2060
Population (Million People)	3,427	4,104	5,581	8,410
Growth (%)	2,24	2,05	2,05	2,05
Number of people in each household	4,02	4,02	4,02	4,02
Elasticity	1,00	1,00	1,00	1,00
Energy Intensity (BOE/Million Rupiah)	116	126	144	189
GRDP (Trillion Rupiah)	441	519	714	1.164
Growth (%)	1.17	1.99	2.26	2.64
GRDP per Capita (Million Rupiah/person)	129	126	128	138

RESULTS AND DISCUSSION

Energy modeling and forecasting results for East Kalimantan household sector by 2060 are presented in this section. The basic model was developed based on BaU scenario followed by several other scenarios as comparative material.

GRDP

GRDP was calculated based on the accumulation of economic activities of all sectors in nominal rupiah in Figure 11. The curve shows the projection results based on the BaU scenario assuming no change in energy prices, which is the most difficult exogenous factor to control, especially in war conditions. The assumption also influences other variables as part of an integrated energy system.

GRDP per capita

GRDP per capita fluctuated annually but generally increased as presented in Figure 12. The modeling results based on BaU scenario showed 138 million per capita in 2060. This was a 10 million increase from the 2015 base year.

Energy consumption

The projection of household sector energy demand based on BaU scenario is presented in Figures 13 and 14 while the types of energy used for cooking are listed in Table 3. Energy consumption for cooking was calculated in Barrel Oil Equivalent while electricity was determined in gigawatt Hours (GWh).

Table 4
Forecast of household sector energy consumption

(1.000) BOE	2015	2025	2040	2060
Coal	638	829	1.305	2.565
Gas	2.424	4.189	5.465	28.651
Oil	116	99	155	305
NRE	151	49	23	61
Total energy	3.328	5.165	10.794	31.583

CO_2 emissions

CO_2 emissions in household sector were calculated based on the type of energy used and found to be directly proportional to fuel oil usage. The greenhouse gas inventory calculation and reporting manual designed by Ministry of Energy and Mineral Resources required the determination of emissions using tons of CO_2 (Ditjen Gatrik, 2018). The modeling results presented through the curve in Figure 15 showed that the emission produced in 2015 was 0,865 million tons and projected to be 8,02 million in 2060.

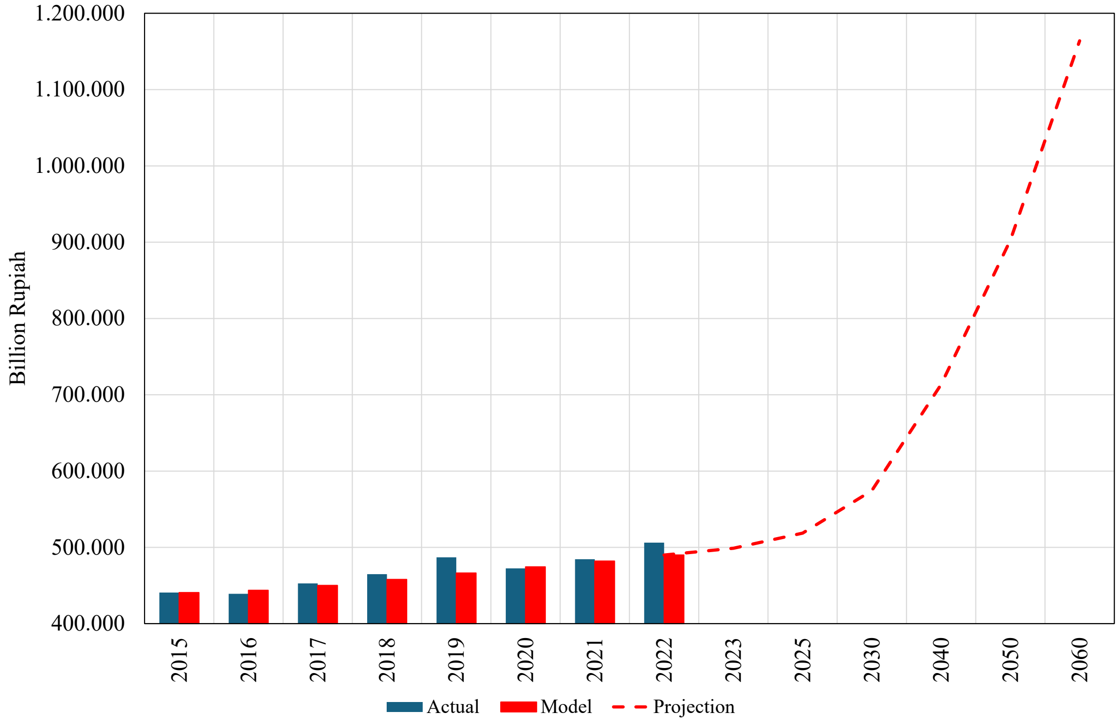

Figure 11
GRDP based on BaU scenario

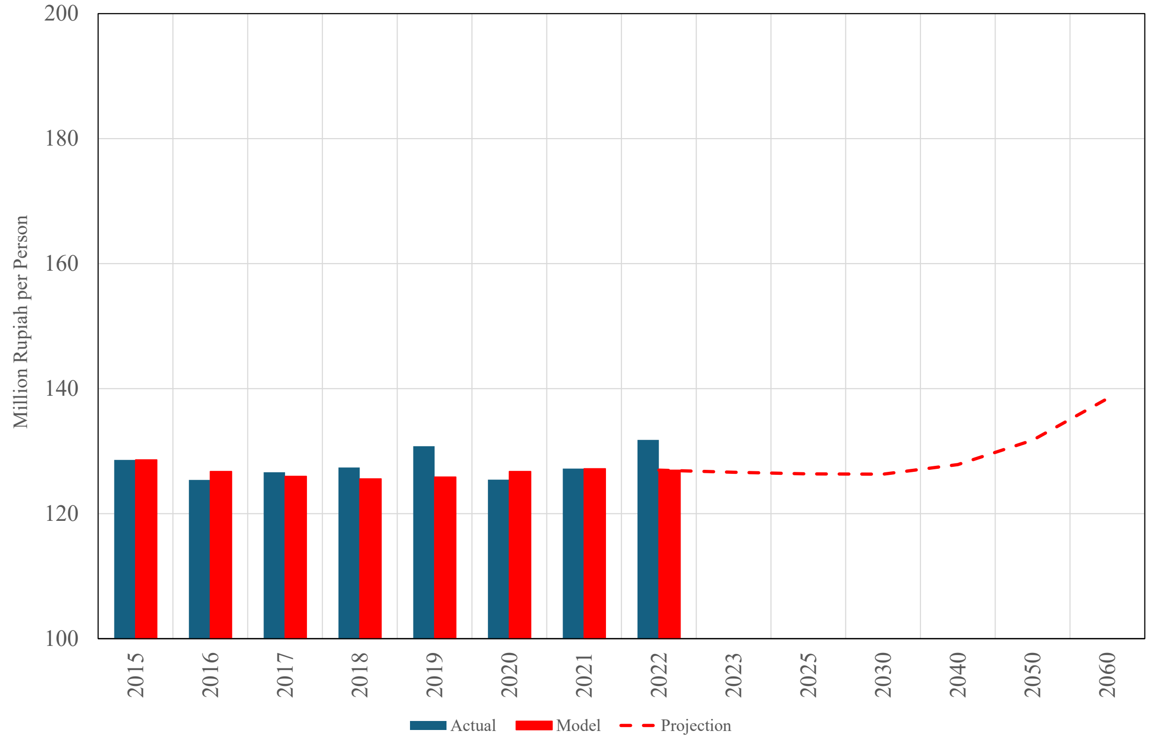

Figure 12
GRDP per capita based on BaU scenario

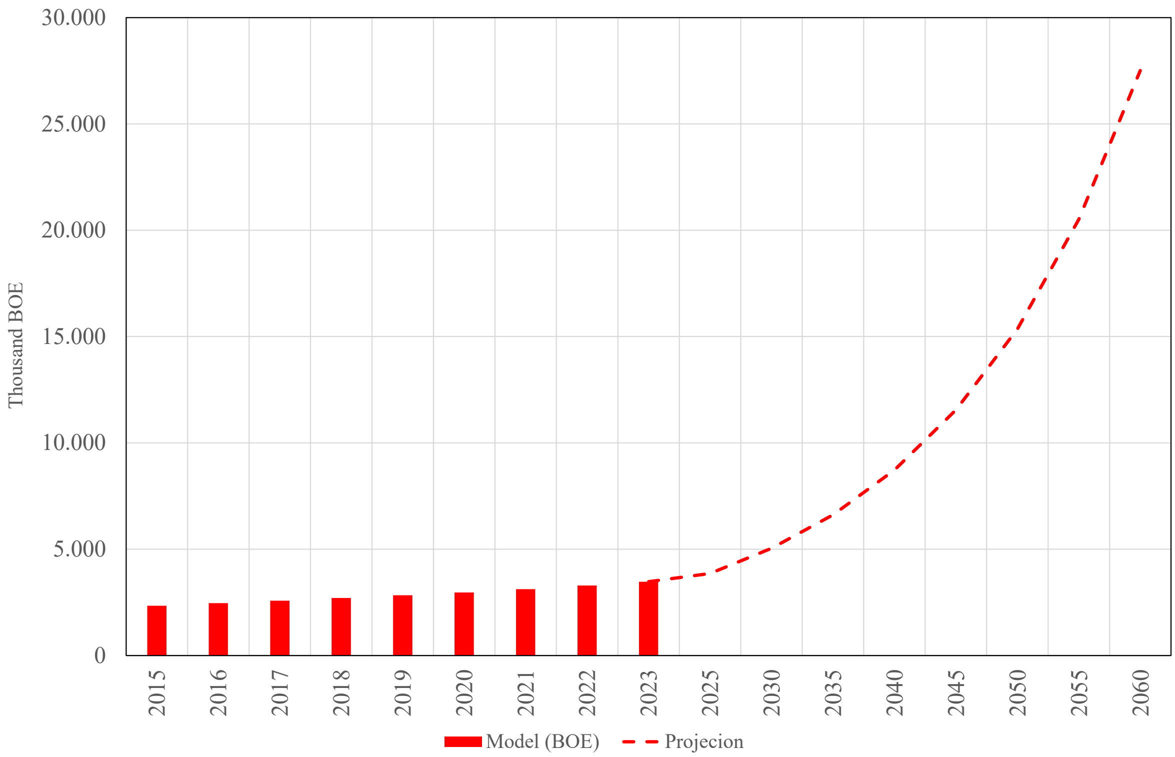

Figure 13
Household energy consumption for cooking

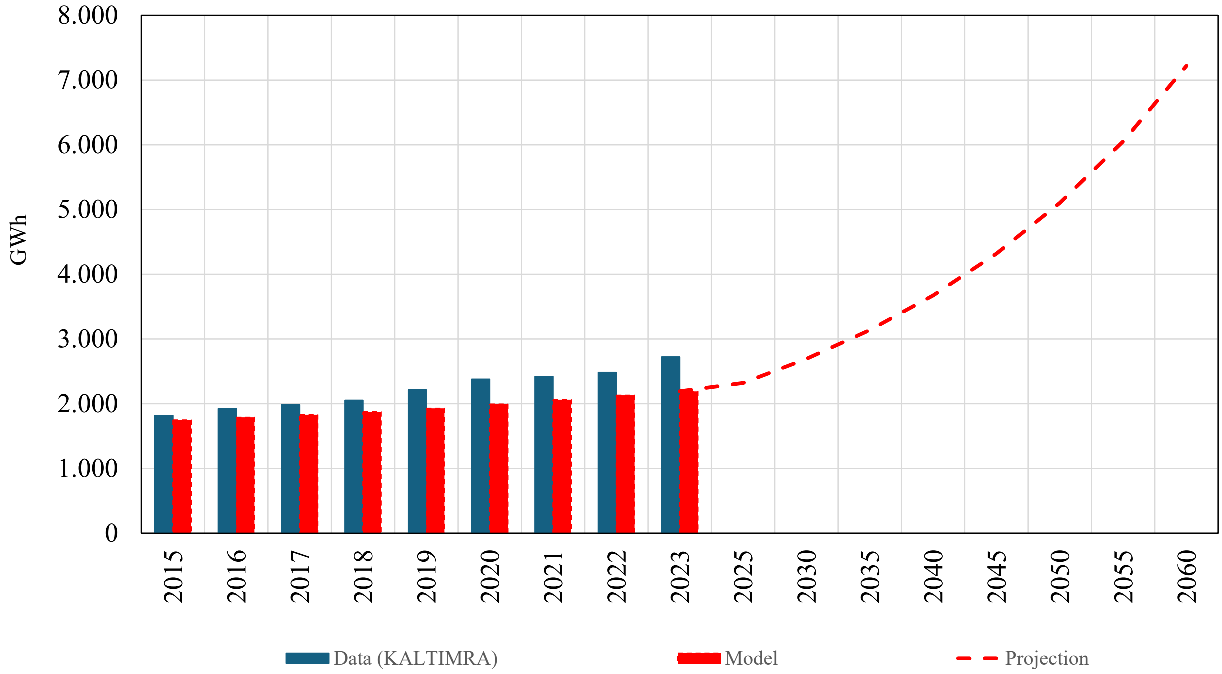

Figure 14
Household electrical energy consumption (GWh)

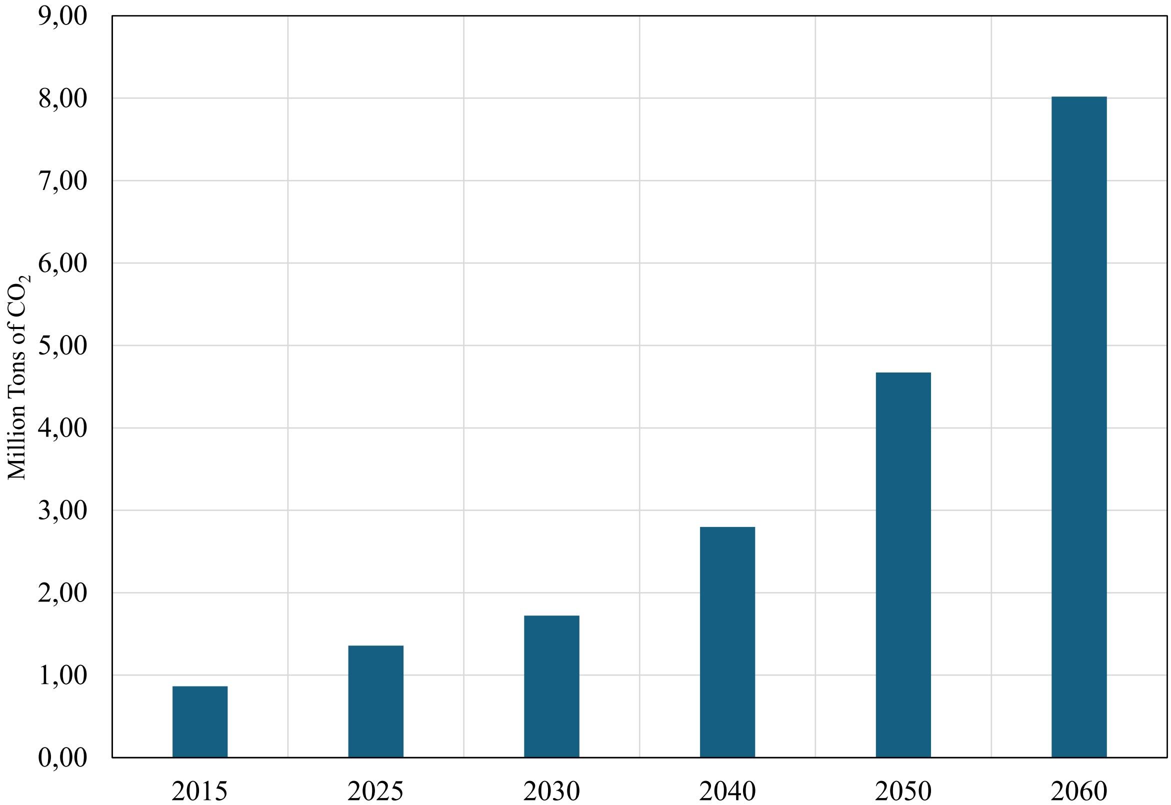

Figure 15
Household sector CO_2 emissions

Scenario comparison

Several other scenarios were developed and compared based on economic and population growth. The scenarios were based on the placement of IKN in East Kalimantan through Law Number 3 of 2022 concerning IKN (Pemerintah Indonesia, 2022b). The area was also designated to achieve Net Zero Emission (NZE) by 2060 through Presidential Regulation Number 112 of 2022 concerning the Acceleration of Renewable Energy Development for Electricity Supply (Pemerintah Indonesia, 2022a). It was also considered part of the area for Carbon Capture and Storage (CCS) technology (Pemerintah Indonesia, 2024).

The implementation of CCS technology is an alternative to mitigate the impacts of climate change. Moreover, Indonesia is pursuing the ENDC (Enhanced Nationally Determined Contribution) target, reducing emissions to 31,89% in 2030 with its efforts and 43,20% with international support. At the International Conference on Climate Change in Egypt (COP 27 in Sharm El Sheikh) and COP 28 in Dubai at the end of 2023 (Syarif, 2024).

East Kalimantan had CO_2 storage capacity of 130 million tons (Iskandar & Usman, 2011)particularly in Depleted oil and gas reservoir. These depleted oil and gas reservoirs are appropriate Candidates for co2 storage. However, the capacity of this geological formation has not Been estimated yet. The objective of this study is to estimate the storage capacity of depleted Oil and gas reservoirs in indonesia using the methodology, developed by carbon Sequestration leadership forum (cslf, which could be used to increase oil production through CCS-Enhanced Oil Recovery (EOR) (Iskandar & Syahrial, 2009). It was observed that the area had the potential to reduce CO_2 emissions through CCS while increasing oil and gas production (EOR) from mature fields such as Kutai Basin (Syahrial & Purnomo, 2009). Therefore, low carbon (LC) scenario was considered relevant to the modeling developed in this research.

The average GRDP growth in IKN scenario was assumed to be 6% per year from 2023. The average population growth rate from 2020 to 2025 was 2,58% while the projection from 2025 to 2030 was 4,02% and from 2030 to 2035 was 2,01% (BPS Kalimantan Timur, 2023c).

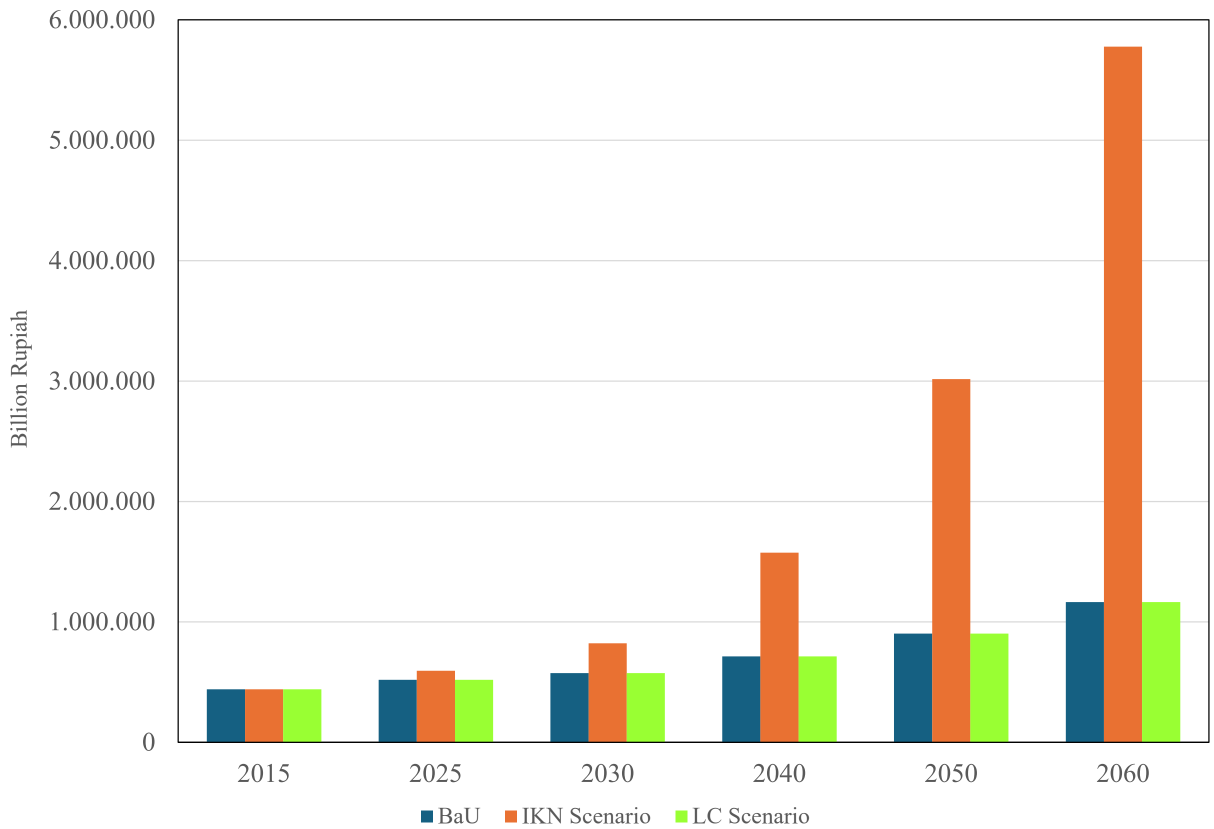

Figure 16
GRDP by scenario

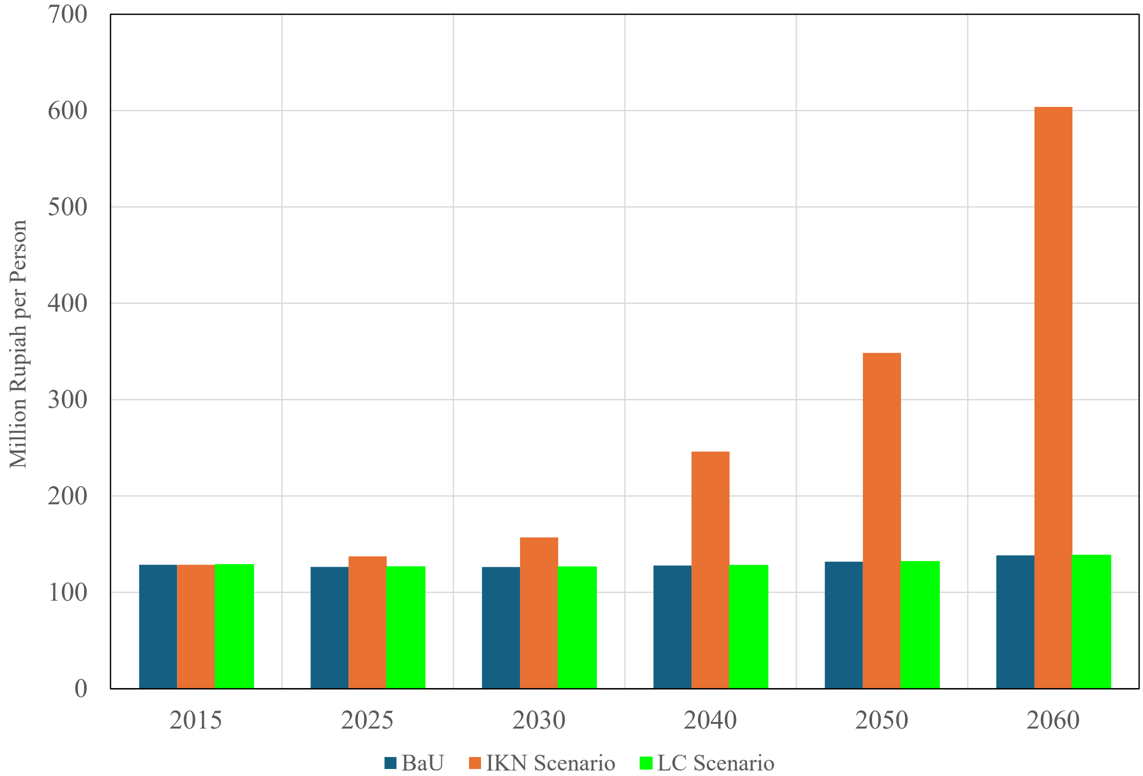

Figure 17
GRDP per capita by scenario

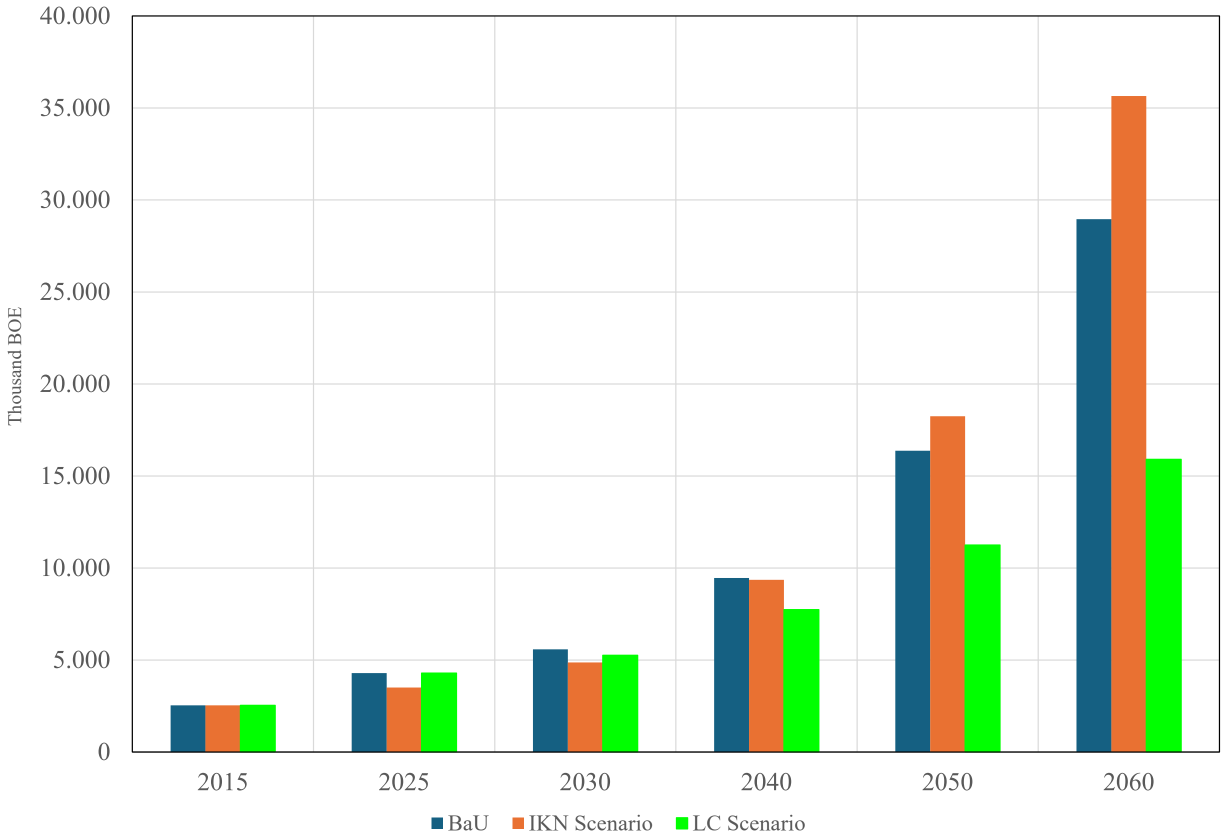

Figure 18
Oil and Gas Demand by Scenario

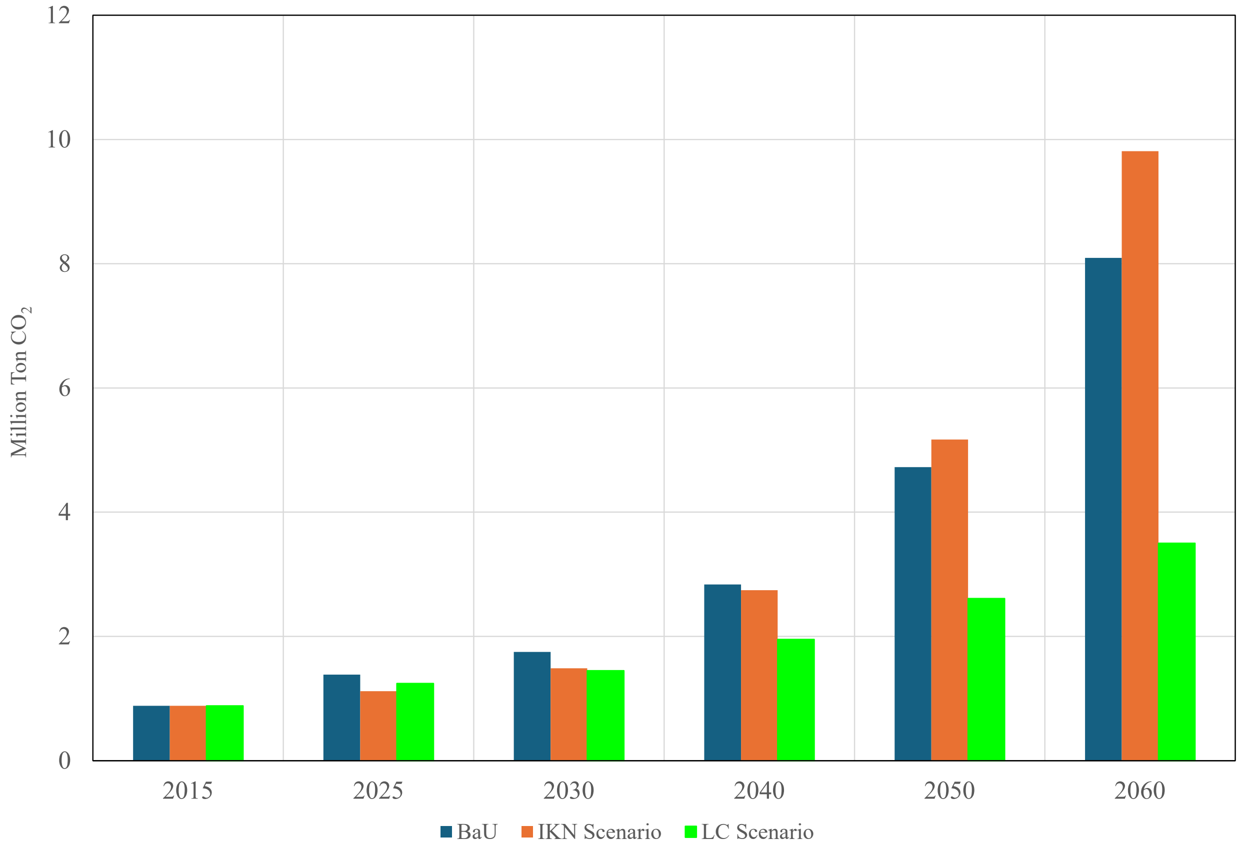

Figure 19
CO_2 emissions by scenario

LC scenario was a development of BaU through the optimization of energy transition process towards net zero emissions by 2060. This is designed to be achieved by (1) cooking using electric stoves with solar panels, (2) a 2% reduction in the usage of coal in power plants, and replacement with 0,5% gas and 1.5% NRE per year in addition to the utilization of B20, and (3) 10% reduction in CO_2 emissions through CCS-EOR technology. The comparison of the modeling system based on the scenario is presented in Figures 16 to 19.

Figure 18 shows that IKN leads to the consumption of more oil and gas than other scenarios. This is due to the increase in economic growth and population, as projected by BPS, which is an effect of IKN placed in the area. Energy demand of household sector is projected to be 38,5 million BOE by 2060 while BaU and LC scenarios produce 31,6 million BOE. This increase is directly proportional to CO_2 emissions produced which is 9,8 million tons as presented in Figure 19. A summary of all the comparison results for the scenarios is listed in Table 5.

LC scenario had similar GRDP and energy consumption values as BaU because, in principle, the assumptions made in both scenarios were the same but the types of energy used were different. This led to the production of fewer emissions in LC scenario due to energy transition process through implemented. There was more than a 50% reduction in CO_2 emissions from 8 million tons to 3.5 million tons by 2060 compared to BaU.

The modeling results showed that household sector could reduce emissions through renewable energy. Therefore, LC scenario, a derivative of NZE policy, is considered quite relevant on a regional scale due to its massive role in reducing emissions. This shows that local governments can implement energy transition policies through gas and ensure a gradual reduction of coal usage. The use of renewable energy and CCS-EOR technology to supply domestic energy demand instead of coal can reduce CO_2 emissions but the process requires preparing the infrastructure. At least 3 aspects of challenges need to be considered, namely engineering, economics, and regulation. CCS development requires expensive investment costs, for example, the Quest CCS project in Canada requires USD 1,35 billion for a capacity of 1,2 million tons of CO_2 per year. (Suryani 2024).

Table 5
Comparison of scenarios

Scenario	GRDP per Capita (Million Rupiah/Person)	
	2025	2060
BaU	126,348	138,405
IKN Scenario	137,323	603,761
LC Scenario	126,348	138,405
Scenario	**Total Energy Demand (Thousand BOE)**	
	2025	**2060**
BaU	5.165	31.583
IKN Scenario	4.191	38.506
LC Scenario	5.165	31.583
Scenario	**Oil and Gas Demand (Thousand BOE)**	
	2025	**2060**
BaU	4.288	28.957
IKN Scenario	3.505	35.647
LC Scenario	4.286	15.909
Scenario	**CO_2 Emission (Million Ton)**	
	2025	**2060**
BaU	1,384	8,094
IKN Scenario	1,119	9,813
LC Scenario	1,244	3,500

Scenario-based energy demand projections as done above are in principle built on many assumptions, so the more accurate the analysis of events, the better the projection results. However, there is always a gap of uncertainty in forecasting and it is highly dependent on regulations. System dynamics is quite relevant to be applied to control the uncertainty space in forecasting because it is supported by features in the system. However, adjustments still need to be made along with changes in energy-related policies and their implications on a local and global scale.

CONCLUSIONS

In conclusion, some of the submissions from the results and discussion are as follows: 1). System dynamics was the most relevant modeling to determine East Kalimantan energy usage in household sector based on bottom-up method; 2). The application of BaU scenario showed that oil and gas demand for the sector was projected to be 28,957 million BOE, 92% of the total energy demand, by 2060 and the emission was projected to be 8 million tons of CO_2. 3). IKN scenario led to 35.647 thousand BOE and 9,8 million tons of CO_2 while LC scenario had 15.909 thousand and 3,5 million, respectively. The lower emissions were due to the implementation of several low-carbon policies.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
BOE	*Barrel Oil Equivalent*	*Barrel*
CCS	*Carbon Capture Storage*	
CO_2	*Carbon dioxide*	
ε	*comparison between the growth rate of energy consumption and the economic growth rate*	*dimension less*
EOR	*Enhanced Oil Recovery*	
GDP	*Gross Domestic Product*	Rupiah
GRDP	*Gross Regional Domestic Product*	Rupiah
GVA	*Gross Value Added*	Rupiah
EI	*Energy Intensity*	BOE/ Rupiah
KL	*Kilo Liter*	Litre
KW	Kilo Watt	Watt
kWh	Kilo Wat Hour	Watt
MBOE	*Million Barrel Oil Equivalent*	Barrel
MMSTB	*Million Stock Tank Barrel*	Barrel
MTOE	*Million Ton Oil Equivalent*	Ton
MW	Mega Watt	Watt
MWh	Mega Watt Hour	Watt
TCF	*Trillion Cubic Feet*	ft^3
TOE	*Ton Oil Equivalent*	Ton

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