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# Fuel Demand Analysis on the Optimization of Sustainable Electricity System Expansion Planning 2021-2050 in West Kalimantan

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**Abstract**: Fuel demand analysis on the optimization result of sustainable electricity system expansion planning in West Kalimantan within period of 2021-2050 has been carried out using the supply optimization modeling with the least cost principle. Three scenarios have been taken into account i.e.: Scenario-1 considers the business-as-usual demand with externalities and no coal power plant addition, Scenario-2 considers additional energy demand from industrial development policy, and Scenario-3 considers the energy demand on the electricity consumption target per capita as stated in Indonesia National Energy Policy. The result of accumulated fuel demand simulation during the period was 2,592,246 Tera Joule (TJ) for Scenario-1; 3,339,517 TJ for Scenario-2; and 4,140,490 TJ for Scenario-3, respectively.

Keywords: fuel demand, optimization, sustainable, expansion planning, West Kalimantan.

## 1. Introduction

Indonesia's KEN shows the roadmap for Indonesian energy usage until 2050. It is stated that the portion of NRE must be increased to achieve an optimal primary energy mix; it should be at least 23% in 2025 and 31% in 2050, as long as the economy is fulfilled. With regard to the KEN, the priority of national energy plan must be developed based on four principles: a. maximizing the use of renewable energy by considering the economic level; b. minimizing the use of petroleum; c. optimizing the utilization of natural gas and new energy; d. use coal as the mainstay of the national energy supply1). Furthermore RUEN, as a guideline to direct national energy management, emphesizes that the primary energy supply of NRE in the primary energy mix in 2025 should be 92.3 MTOE which is 23.0% of the total energy supply of 400 MTOE. And, in 2050, the total energy supply should be 1012 MTOE, of which 315.7 MTOE (31.2%) will come from primary and renewable energy. Therefore, to fulfil the electricity demand with the target of electricity consumption per capita of 2,500 kWh in 2025 and 7,000 kWh in 2050, the total power generation capacity of 136 GW in 2025 and 443 GW in 2050 is required. Hence, to achieve the target of the NRE mix declared in the KEN, it is estimated that the NRE electricity supply capacity should be around 45.2 GW in 2025 and around 167.7 GW in 20502).

A number of renewable energy sources, including hydropower3), solar4), wind5), bioenergy6), biofuel (biodiesel and bioethanol), and pure plant oil7), have the potential to be developed in Indonesia. Moreover, it has been stated that descriptive and qualitative study has been conducted on Indonesia's geothermal issues and potential, and that this research contributes to academic evidence by focusing on the viewpoints of people who live near geothermal prospective sitespam8).

As Indonesia's largest island, Kalimantan confronts a significant challenge in terms of expanding its electrical infrastructure. The two key concerns that must be emphasized while developing the transmission system are the distributed load and the remote energy source [9]. Given its privileged location over the equator, West Kalimantan has a vast potential for energy resources, particularly solar energy, hydropower, biomass, biogas, coal, and even an area with potential for uranium and thorium[10]. Since 2010, NPP has been a green energy option in the regional development plan[11]. Studies on the suitability of sites for nuclear power plants[12] and the social sustainability of nuclear energy policy have been conducted in West Kalimantan[13]. Despite having an abundance of energy resources, this region faces basic issues with sanitation[14], endemic area of dengue fever[15], forest fire[16], and the accessibility of electricity[17]. Therefore, plans must prioritize citizens' right to live and survive because villagers have the right to prosperity and facilities equivalent to urban dwellers, including energy access fairness[18].

Considering the above mentioned policies, prospects and challenges, designing an adequate fuel demand analysis on optimizing sustainable electricity system expansion planning with a research period 2021-2050 in West Kalimantan being the focus subject of this paper. West Kalimantan has a population of 5.47 million people[19], and has electricity peak load projection reaching 922 MW in 2030[20].

An insight into seeking energy sustainability comes from Japan, one of the least secure developed nations in energy security. Japan has struggled to meet energy demand, prompting research into renewable and nuclear energy choices to assist energy sustainability[21]. Furthermore, several studies have been done to address crises and reduce electricity use during peak hours. Using the CVR method, Rahman (2022) is conducting modeling and experimental research on a smart grid[22]. Data aggregation and analytics enable distribution management to inform the generation section for demand control based on the expected energy consumption pattern. Mendu (2020) investigates the techno-economic performance of several grid-connected and stand-alone integrated energy systems for a school[23].

Modeling and optimization in the electrical power system can be executed using the HOMER Pro. It also enables users to simulate and analyze hybrid configurations, including renewable energy sources (such as solar, wind, and hydro) combined with conventional generators and energy storage options. Another modeling and optimization solver is Balmorel, which could handle optimization problems in many sectors, such as the use of biomass to support transporation[24], the impact of energy use on health[25], the electricity saving model in the household sector[26], and the regional electricity optimization based on renewable energy[27]. Furthermore, many also report applying the Balmoral model[28].

In this study, Balmorel energy model will be used to simulate optimized power generation system development planning in West Kalimantan from 2021 to 2050. Coal, natural gas, biogas, reservoir hydro, river hydro, solar, and nuclear are among the fuels considered for existing and committed power plants. As a result, this study can be used to help with provincial planning and implementation of new and renewable energy development, as well as national energy policies aimed at net zero emissions.

## 2. Methodology

The analysis of simulated fuel demand as the result of optimized power generation system development planning in West Kalimantan in the period of 2021-2050 follow a method as shown in Fig. 1. First step is literature review to collect the previous research as well as the secondary data, and to select the method to analyze the data. The collected data is associated with fuel energy and electricity analysis, such as the availability of power networks, electricity development plans, the potential of new renewable energy, and fuel prices associated with new renewable[29]. The Simple-E (Simple Econometric Simulation System), a spreadsheet Microsoft Excell add-in, is used to simulate the electricity demand forecasting[30]. The second step is optimizing the energy supply based on the least-cost principle and environmental considerations, using Balmorel.

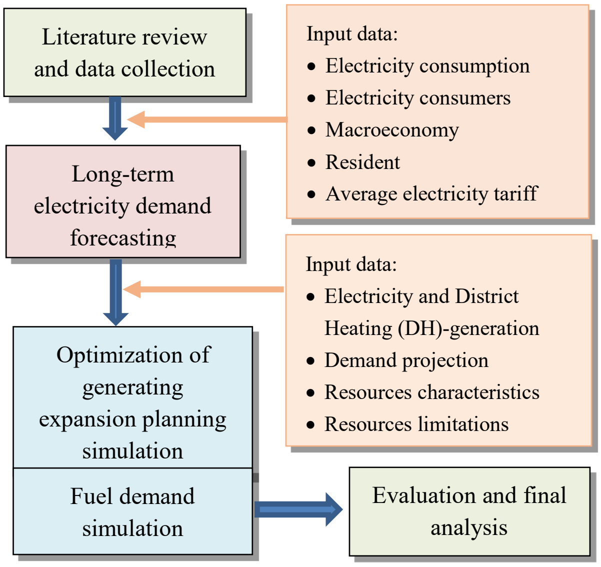


**Fig. 1:** Method for simulation of fuel demand calculation.

Optimization aims to get results that follow the objectives set at the minimum possible cost. For this reason, Balmorel was used in this study. Balmorel works by finding the lowest electricity production and investment price together to get the lowest total cost[31) 32]. The equation used in this simulation is shown in Table 1[33]. The optimization's objective function is minimizing costs

Table 1. Balmorel Optimization Correlation Model[33)]

| Variable | Mathematical Expression | Eq. # |
|---|---|---|
| Cost Involvement | | |
| Electricity generation | $\sum_{g,t} C^{e}_{g,t} * G^{e}_{g,t}$ | (1) |
| Heat generation | $\sum_{g,t} C^{h}_{g,t} * G^{h}_{g,t}$ | (2) |
| Fuel consumption | $\sum_{g,f,t} C^{f}_{g,t} * F^{f}_{g,t}$ | (3) |
| New powerplant investment | $\sum_{g} \langle a * C^{f}_{g} + C^{fLx}_{g} \rangle l_g$ | (4) |
| New transmission investment | $\sum_{x} a * C^{l}_{x} * l_x$ | (5) |
| Unit start | $\sum_{g,t} C^{s}_{g,t} * S_{g,t}$ | (6) |
| Unit online | $\sum_{g,t} C^{O}_{g,t} * O_{g,t}$ | (7) |
| Total | $\min Z_y = (1) + (2) + (3) + (4) + (5) + (6) + (7)$ | (8) |
| Supply and Demand Balance | | |
| Electricity | $\sum_{g} G^{e}_{g,t} + \sum_{X} (1 - lossx) X^{Import}_{x,t} = \sum_{X} X^{Export}_{x,t} + D^{e}_{t}$ | (9) |
| Heat | $\sum_{g} G^{h}_{g,t} = D^{h}_{t}$ | (10) |
| Fuel | $F^{f}_{t} = G^{e}_{g,t} / \eta^{e}_{h} + G^{h}_{g,t} / \eta^{h}_{h} + k^{f}_{g} * K^{f}_{g} * O^{f}_{g,t}$ | (11) |
| Technology Constraint (selected) | | |
| Extraction units | $G^{e}_{g,t} - c^{v}_{g} * G^{h}_{g,t} \leq K^{e}_{g}$ | (12) |
| | $G^{e}_{g,t} \geq c^{b}_{g} * G^{h}_{g,t}$ | (13) |
| Boiler/heat/pumps | $G^{h}_{g,t} = D^{e}_{g,t} / \eta_h$ | (14) |
| Variable RE | $G_{g,t} \leq r^{f}_{t} (K_g + l_g)$ | (15) |
| Hydro water storage | $L_{g,t+1} = L_{g,t} + r^{HY}_{t} * (K_g + l_g) - G^{e}_{g,t}$ | (16) |
| | $\sum^{By\ capacity}_{g \sim f,t} (K_g + l_g) \leq A_f$ | (17) |
| Unit Commitment | | |
| Commitment logic | $S_{g,t} - Dn_{g,t} = O_{g,t} - O_{g,t-1}$ | 18) |
| Minimum fuel | $F^{f}_{g,t} \geq m_g * K^{f}_{g} * O_{g,t}$ | (19) |
| Maximum fuel input | $F^{f}_{g,t} \leq K^{f}_{g} * O_{g,t}$ | (20) |
| Policy Targets | | |
| Minimum fuel | $\sum_{g \sim f} (K_g + l_g) \geq T^{K}_{f}$ | (21) |
| Emission cap | $\sum_{g,f} W^{f}_{w} * F^{f}_{g,t} \leq T_w$ | (22) |
| Full Load Hour Requirement | $\sum_{f} G^{e}_{g,t} \geq FLH_g * (K_g + l_g)$ | (23) |
| Transmission Constraint | $X_{x,t} \leq K^{x} + l^{x}$ | (24) |
| Resource Constrains | $\sum^{By\ fuel}_{g \sim f,t} F^{f}_{g,t} \leq A_f$ | (25) |

corresponding to the generation of electricity and heat (Eq. 1 & Eq. 2), fuel consumption (Eq. 3), new investment (Eq. 4 & Eq. 5), and additional cost (Eq. 6 & Eq. 7) to keep the system operation secure. The solving (Eq. 8) need data as constraints such as energy supply-demand, technology, unit commitment, and government policies. In addition, the availability of energy sources and power transmission is also related to the objective function. Under the conditions of West Kalimantan, this study limits the candidate powerplant variables for optimization simulation, namely PLTS, PLTMG, PLTGU, PLTG, PLTBm, PLTBg, PLTA, PLTM, PLTU-SubC, PLTU-SubC-FGD, PLTN, PLTB, and BESS[33)].

## 3. Potential Energy Sources in West Kalimantan

West Kalimantan Province has immense potential for energy resources, including potential for hydro energy, solar energy, bioenergy, coal, and uranium/thorium. Hydropower potencies are 241 MW[20)] spread over several locations. However, based on data from DJEBTKE-KESDM, the hydro energy potential is 3,780 MW, as presented in Table 2. Further, West Kalimantan has a solar photovoltaic potential of 91,600 MW. West Kalimantan also has a bioenergy potential of 715.6 MW, consisting of 57.0 MW from municipal waste and 658.6 MW from industrial waste. The most bioenergy potential is biomass from scattered palm oil waste which can be used as primary energy source. The large number of crude palm oil plants in West Kalimantan strongly supports utilizing this potential. Based on RUPTL PLN, the bioenergy powerplant in West Kalimantan is 81 MW, and it can be changed according to actual conditions[20)].

Table 2. Renewable energy potential in West Kalimantan[36)]

| Renewable Energy Type | Potency (MW) |
|---|---:|
| Onshore Wind Energy | 554 |
| Offshore Wind Energy | 4,878 |
| Run of River Hydro Energy | 3,780.6 |
| Solar Photovoltaic Energy | 91,600 |
| Bioenergy: | |
| - Municipal Waste | 57.0 |
| - Industrial Waste | 658.6 |

West Kalimantan has potential for nuclear energy in the form of uranium/thorium, which can be used as primary energy for nuclear power plants. According to the geological atlas of mineral and energy resources in West Kalimantan, there is a uranium potential of ± 24,112 tons[20)] in Melawai Regency. However, the PTBGN-BATAN, reported that the uranium potential in West Kalimantan is 17,006 tons $U_3O_8$, and the thorium potential is 4,767 tons[34)]. Related to this uranium potential, Imam Bastori et al. have also researched uranium availability in Indonesia to meet the needs of NPP's fuel. Based on that, Indonesia's uranium reserves are 70,000 tons of $U_3O_8$

(yellow cake), which will be able to meet the needs for 7 units of NPP with each capacity of 1,000 MWe that operating for 40 years[35].

In addtition to NRE, West Kalimantan also has coal reserve. The potential of coal in West Kalimantan is spread around Sintang and Kapuas Hulu regencies. However, further researches need to be carried out to ensure the reserves.

## 4. Scenarios for Fuel Demand Calculation

In this study, three scenarios have been considered to calculate the fuel demand optimization using Balmorel, those are:

1. Scenario-1 (B_X_NC): This scenario was business-as-usual demand calculation by taking into account the externalities ($CO_2$, $SO_2$, NOx, and PM2.5 emissions) and no candidate for coal power plant addition during the period of 2021-2050.
2. Scenario-2 (I_X_NC): The second scenario considered additional energy demand from the result of industrial development policy.
3. Scenario-3 (P_X_NC): In the third scenario, the energy demand was calculated to catch up the target for electricity consumption per capita as planned in KEN.

## 5. Result and Discussion

### 5.1 Fuel Price and Electricity Generation Cost Assumption

Fig. 2 shows the fuel price assumptions used in this simulation. The fuel price for coal, gas, and biomass have considered the transportation cost between regional sites. The municipal waste price is based on Presidential Regulation Number 35 of the Year 2018[37]. Meanwhile, the nuclear fuel of uranium is USD 1,540/kg and the cost of electricity generation refers to the literature[33].

### 5.2 The Calculated Fuel Demand Simulation Based on the Scenario-1

The power generating capacity increases by adding various power plants annually in Scenario-1. The projected peak load of 473 MW in 2021 will rise to 2,084 MW in 2050. The optimization of renewable energy's role in the generation expansion planning in West Kalimantan per year is as follows: PLTS (1,105 MW), PLTMG (30 MW), PLTGU (150 MW), PLTG (60 MW), PLTBm (145 MW), PLTBg (15 MW), PLTA (80 MW), NPP (200 MW), and BESS (184 MW), with import electricity from the Kalimantan Interconnection System (by the PLTA source) is 1,164 MW, the projection of the committed plant capacity is 200 MW, and the existing plant capacity is 10 MW.

The calculated total annual fuel demand during the period of 2021-2050 based on Scenario-1 is shown in Fig. 3, with an average growth rate of about 6.09 %. The hydropower of the reservoir will dominate to fulfill the electricity generation development with an average growth rate of about 18.44 % (from 2031 to 2050). It will be connected to the West Kalimantan electricity system for the first time in 2031, with requires 4,145 TJ. At the end of the research year (2050), the demand for reservoir hydro energy increased drastically to 103,248 TJ.

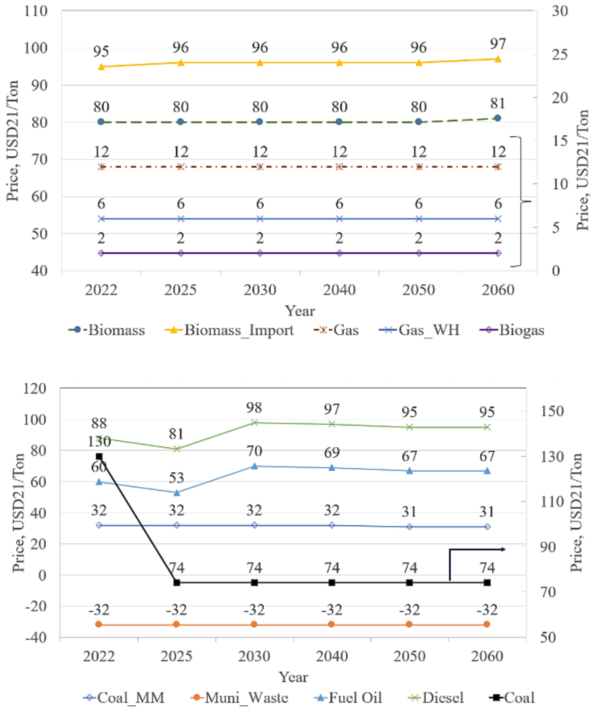


**Fig. 2:** Fuel price assumptions and unit conversion[20) 32) 33) 8)].

Solar power plants had not yet been interconnected with the electricity system at the beginning of the year. However, they are expected to be connected in 2023 with a capacity of 27 MW (511 TJ of solar energy). Next, it has increased and is expected to build a solar energy plant with a capacity of 1,105 MW (with solar energy of 20,792 TJ) at the end of the research year. Therefore, it needs consistent support and realization because the potential for solar energy is enormous in West Kalimantan (91.6 GW) and to support the development of environmentally friendly and low-emission power plants towards the energy transition.

The run-off-river power plants were installed using 9,535 TJ of hydro energy in 2021. After that, there is no growth in hydropower demand; it will decrease in 2029–2030 and rise in 2030, reaching 3,316 TJ in 2050. On the other hand, biogas power plants were not yet interconnected with the electricity system in 2021. They will be connected in 2026 with a capacity of 15 MW and a required biogas energy of 1,014 TJ. In 2050, the demand for biogas will decrease to 953 TJ.

The biomass power plant has been installed using the 1,014 TJ biomass fuel at 2021. Then, starting in 2026, biomass-generating capacity will be significantly increased. In 2050, the need for biomass fuel will be 12,614 TJ to meet a biomass power plant with a capacity

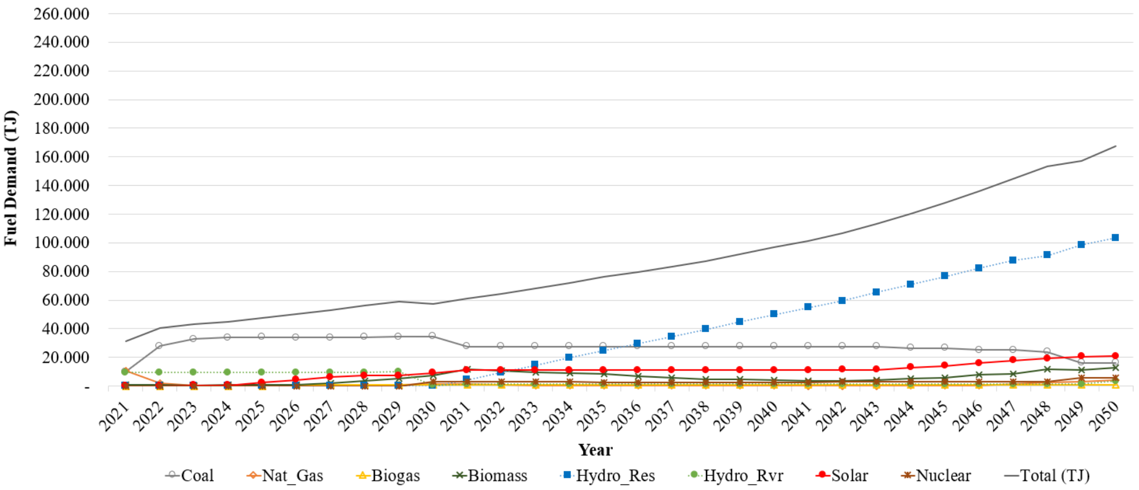
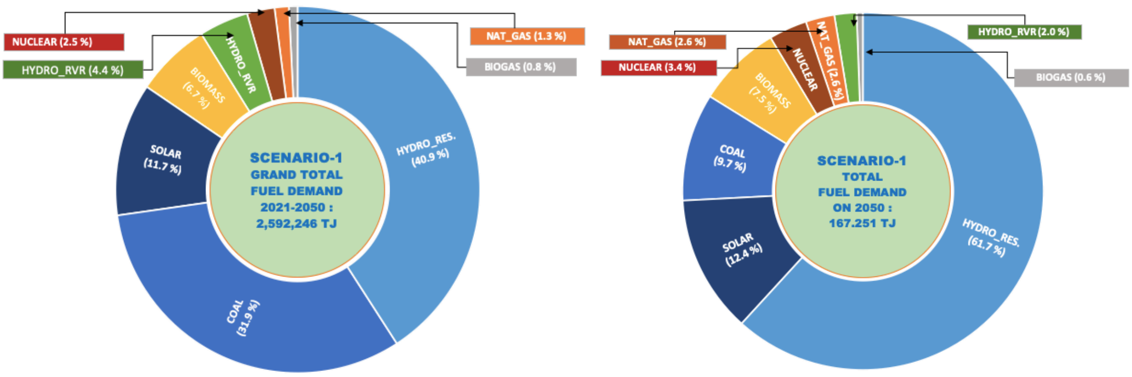


**Fig. 3:** The total fuel demand calculation per year during the period 2021-2050 in West Kalimantan under Scenario-1



**a.** **b.**

**Fig. 4:** The total cumulative calculation for fuel demand under Scenario-1 in West Kalimantan, (a) Total calculation during period 2021-2050, (b) Total calculation in 2050.

of 145 MW. Further biomass energy development needs to be supported and encouraged because West Kalimantan has a reasonably significant biomass potency.

In 2021, nuclear power plants had not yet been interconnected in the electricity system in West Kalimantan. However, they are expected to be connected for 100 MW in 2030 (with a need for uranium nuclear material of 2,978 TJ). After that, the growth of uranium demand is flat and will increase to 5,734 TJ in 2049 (to support the 200 MW nuclear power plant). It certainly needs to be supported and realized because the nuclear power plant produces clean and environmentally friendly energy, and the potential for nuclear fuel is quite large in West Kalimantan (17,006 tons of $U_3O_8$).

For coal fuel demand, at the beginning of the study, there was a significant increase (22,707 TJ ) due to the association for the committed coal power plant of 200 MW in 2022 and another 28 MW in 2023. After that, the growth rate of coal demand is flat because there is a policy of "no additional coal power plant" that does not allow the new coal power plant to be connected to the electricity system. The need for coal fuel decreased to 16,277 TJ in 2050 because some coal-fired power plants were retired. In addition, the need for natural gas fuel was around 10,372 TJ in 2021, but the demand continued to decline because some natural gas power plants were retired. By 2050, the natural gas fuel needed will be 4,336 TJ.

Fig. 4a shows the cumulative calculated fuel demand under Scenario-1 in West Kalimantan during the period 2021–2050, which is 2,592,246 TJ, consisting of a hydro reservoir (40.9%), coal (31.9%), solar (11.7%), biomass (6.7%), hydro of run-off-river (4.4%), nuclear (2.5%), natural gas (1.3%), and biogas (0.8%). Meanwhile, Fig. 4b shows the total calculation of fuel demand under Scenario-1 in West Kalimantan at the end of the research year (2050), which is 167,251 TJ, consisting of hydro reservoirs (61.7%), solar (12.4%), coal (9.70%), biomass (6.7%), nuclear (3.4%), natural gas (2.6%), hydro of run-of-river (2.0%), and biogas (0.6%).

### 5.3 The Calculation Result of Fuel Demand Simulation Based on the Scenario-2

The power-generating capacity increases with the various additional types of power plants each year. As a result, the projected peak load in 2021, 473 MW, will rise to 2,513 MW in 2050 under Scenario-2. The optimization of new renewable energy roles in the generation expansion planning in West Kalimantan per year, with the cumulative configuration projection of capacity plants at the end of the study, is as follows: PLTS (1,080 MW), PLTGU (150 MW), PLTG (90 MW), PLTBm (145 MW), PLTBg (15 MW), PLTA (110 MW), NPP (700 MW), and BESS (232 MW). It still needs to import electricity from the Kalimantan Interconnection System (by the PLTA), which is about 1,186 MW; the projection of the committed plant capacity is 200 MW; and the existing plant capacity is 10 MW.

The cumulative fuel demand and the introduction of the renewable-based powerplant's periodic change to fulfill the total fuel demand under scenario-2 in West Kalimantan are shown in Fig. 5. The cumulative fuel demand will grow at an average rate of 6.70%. The hydropower of the reservoir will dominate the electricity generation development with an average growth rate of 18.47% (from 2031 to 2050). It will be connected to the West Kalimantan electricity system for the first time in 2031 and consume 4,139 TJ of hydro energy. In 2050, the demand for reservoir hydro energy will increase drastically to 103,636 TJ.

In 2021, the solar power plant was yet to be interconnected with the electricity system. However, it is expected to be connected in 2023 with a capacity of 100 MW (equal to 1.892 TJ of solar energy). After that, the growth rate of the need for solar energy has increased quite significantly, and by 2050, it is expected to be possible to build a solar energy plant with a capacity of 1,180 MW (equal to 22,321 TJ of solar energy).

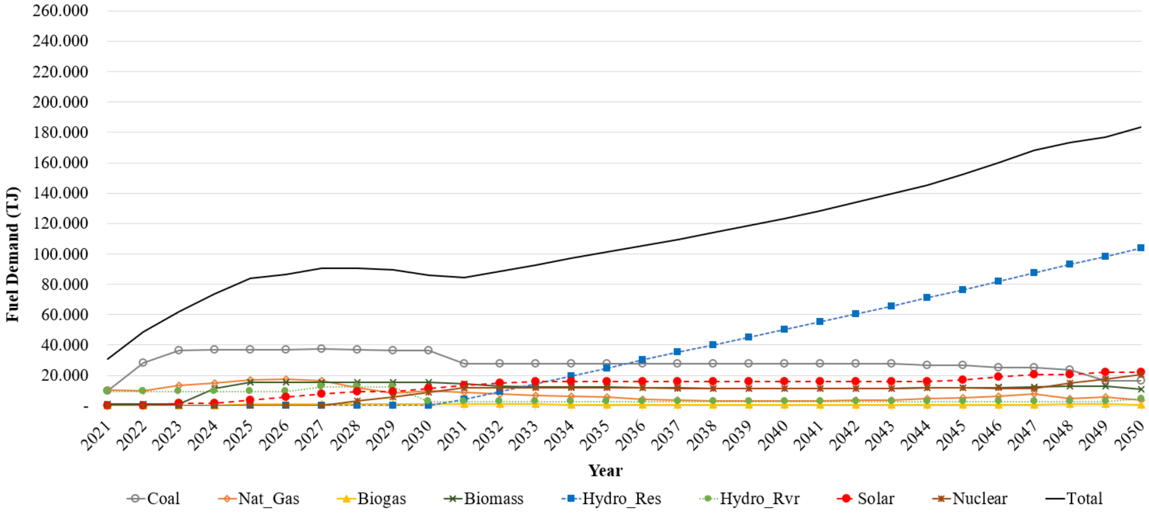
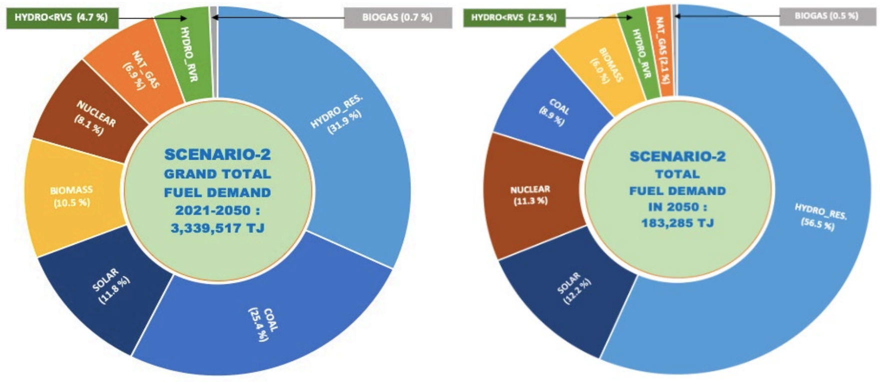


**Fig. 5:** The total cumulative fuel demand calculation during the period 2021-2050 in West Kalimantan under Scenario-2



**a.** **b.**

**Fig. 6:** Total cumulative calculation of fuel demand under Scenario-2 in West Kalimantan, (a) Total calculation during period 2021-2050, (b) Total calculation in 2050

Moreover, biogas power plants were yet to be interconnected with the electricity system in 2021. They will be connected in 2026 with a capacity of 15 MW and required biogas of 1,014 TJ. In 2050, the demand for biogas will decrease to 894 TJ. In addition, 9,535 TJ of hydro run-of-river power plants were installed in 2021. After that, hydro energy demand will not grow until 2026. Then, the demand for hydro run-of-river fuel will increase in 2027–2029. Starting in 2030, the demand for hydropower from run-off rivers will go down to 2,902 TJ by 2049. In 2050, the need for hydro run-of-river energy will rise to 4,560 TJ. Furthermore, a biomass power plant was installed in 2021, using 1,014 TJ of biomass energy. Then, starting in 2024, there will be a significant addition of biomass power plants, and the need for biomass will be 10,985 TJ to meet a biomass power plant with a total of 100 MW in 2050.

The nuclear power plant has yet to be interconnected to the electricity system in West Kalimantan since the beginning of the study. However, it is expected to be connected for 100 MW in 2028 (equivalent to 2,988 TJ of uranium energy). After that, uranium energy demand growth will increase significantly to 20,696 TJ in 2050 (to support the 700 MW nuclear power plant). It certainly needs to be supported and realized because the nuclear power plant produces clean and environmentally friendly energy, and the potential for nuclear fuel is enormous in West Kalimantan (17,006 tons of $U_3O_8$).

The coal fuel demand under Scenario-2 is the same as Scenario-1 due to the policy that "no additional coal power plant" is connected to the electricity system. However, natural gas will still be needed despite the fluctuating demand growth rate. The requirement for natural gas energy was 10,372 TJ in 2021, then will fluctuate until reaching 3,917 TJ in 2050.

Fig. 6 shows the analysis of fuel demand under Scenario-2 in West Kalimantan. Fig. 6a describes the total cumulative fuel demand during the period 2021-2050, namely 3,339,517 TJ, which consists of a hydro reservoir (31.9%), coal (25.4%), solar (11,8%), biomass (10.5%), nuclear (8.1%), natural gas (6.9%), hydro of run-of-river (4.7%), and biogas (0.7%). Meanwhile, Fig. 6b shows the total projected fuel demand in 2050, namely 183,285 TJ, which consists of a hydro reservoir (56.5%), solar (12,2%), nuclear (11.3%), coal (8.9%), biomass (6.0%), hydro of run-of-river (2.5%), natural gas (2.1%), and biogas (0.5%).

### 5.4 The Calculation Result of Fuel Demand Simulation Based on the Scenario-3

The projected peak load in 2021 by Scenario-3 is 606 MW, which will rise to 4,185 MW in 2050. The optimization of new renewable energy roles in the powerplant expansion planning with the cumulative configuration projection of capacity plants at the end of the study (2050) is as follows: PLTS (1,878 MW), PLTGU (450 MW), PLTG (60 MW), PLTBm (145 MW), PLTBg (15 MW), PLTA (210 MW), NPP (2,000 MW), and BESS (416 MW). As in scenario-2, it still entails importing 1,173 MW of electricity from the Kalimantan Interconnection System, the projection of the committed plant capacity is 200 MW, and the existing plant capacity is 10 MW.

Annual supply-demand analysis under Scenario-3 for 2021–2050 in West Kalimantan is shown in Fig. 7. The average growth rate of total energy demand is 7.82%. Based on this scenario, the hydropower of the reservoir will dominate with an average growth rate of 18.47% (from 2031 to 2050). It will be connected to the West Kalimantan electricity system for the first time in 2031 and requires 4,139 TJ of hydro energy. At the end of the year scenario (2050), the demand for reservoir hydro energy increased drastically to 103,636 TJ. Besides the hydro reservoir, this scenario proposes a hydropower run-off river in the beginning year. The inquiry for hydropower run-off-river will decrease to 2,902 TJ and start rising by 2038. In 2050, the need for hydro run-of-river energy will reach 8,705 TJ.

In 2021, the solar power plant was yet to be interconnected with the electricity system. However, it is expected to be connected in 2023 with a capacity of 100 MW (equal to 1.892 TJ of solar energy). After that, the growth rate of solar energy has increased quite significantly, and by 2050, it is expected to be possible to build a solar energy plant with a capacity of 1,878 MW (35,524 TJ of solar energy).

Biogas power plants were yet to be interconnected in the electricity system in 2021. It will be connected to the electricity system in 2025 with a capacity of 15 MW and the required biogas capacity of 1,014 TJ. In 2050, the demand for biogas energy will decrease to 847 TJ. Moreover, a biomass power plant was installed using 1,014 TJ of biomass energy. Then, starting in 2024, there will be a significant addition of biomass-generating capacity. In 2050, biomass fuel needs 11,847 TJ to meet a biomass power plant totaling 145 MW.

The nuclear power plant was yet to be interconnected to the electricity system in West Kalimantan in 2021. However, it is expected to connect for 100 MW in 2028 (with a need for uranium nuclear material of 8,963 TJ). After that, uranium demand growth will increase significantly to 58,776 TJ in 2050 (to support the 2,000 MW nuclear power plants).

In this case, the policy that no other coal power plant be connected to the electricity system still holds. However, the need for natural gas fuel was quite significant in 2021 (10,372 TJ), with the growth rate of natural gas demand fluctuating. In 2050, natural gas fuel needs will be 7,475 TJ.

The analysis of fuel demand under Scenario-3 in West Kalimantan is depicted in Fig. 8. The cumulative total calculation of fuel demand under this case is 4,140,490 TJ (Fig. 8a), which consists of hydro reservoirs (26.0%), coal (20.5%), nuclear (17.8%), solar (13.2%), biomass (8.9%), natural gas (7.9%), hydro of run-off-river (5.1%), and

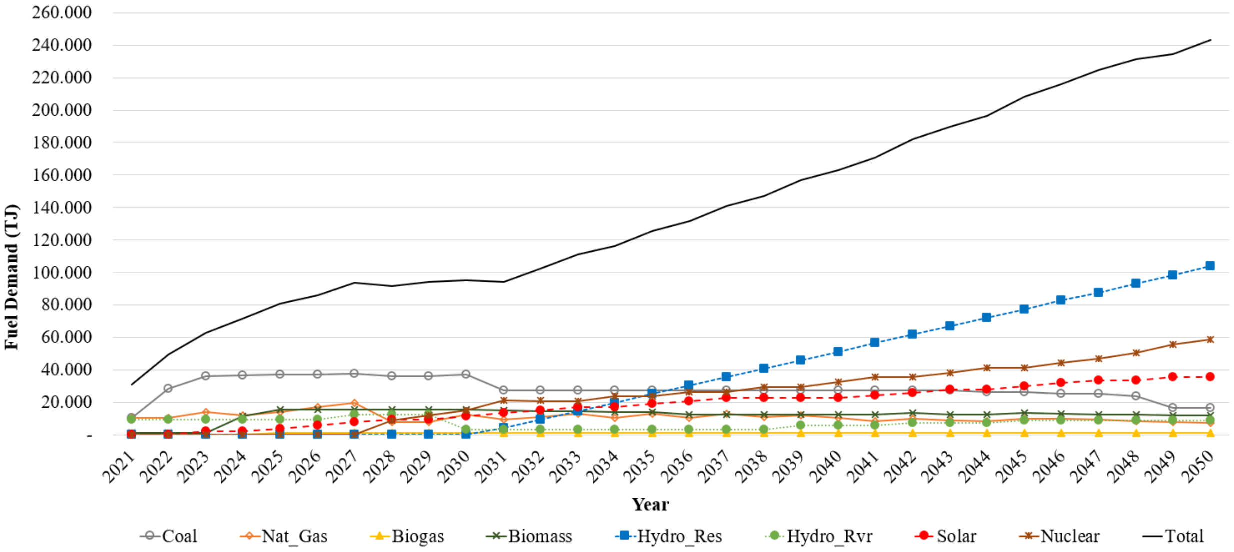
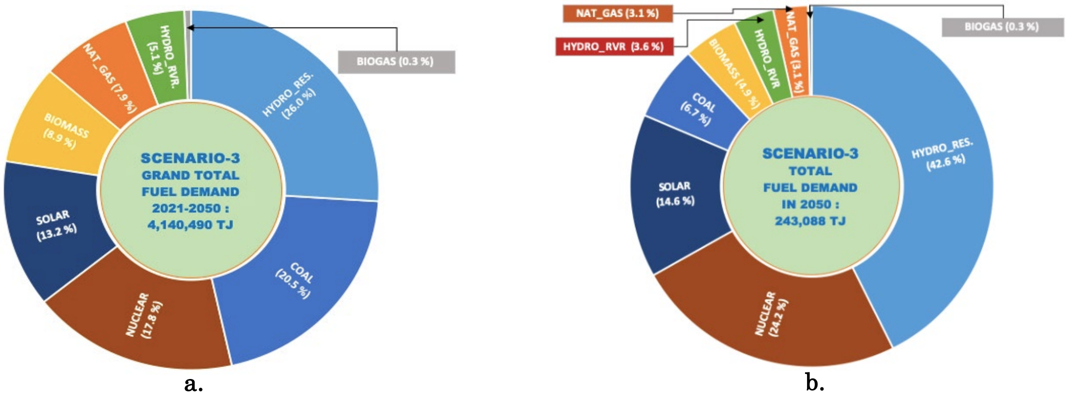


**Fig. 7:** The optimization of generation expansion planning under Scenario-3 (P_X_NC).



a. b.

**Fig. 8:** Cumulative total calculation of fuel demand under Scenario-3 in West Kalimantan,
(a) Total cumulative calculation during 2021-2050, (b) Total calculation in 2050.

biogas (0.3%). Moreover, Fig. 8b shows the total calculation of fuel demand under Scenario-3 in West Kalimantan at the end of the research year (2050), namely 243,088 TJ, which consists of hydro reservoirs (42.6%), nuclear (24.2%), solar (14.6%), coal (6.7%), biomass (4.9%), hydro of run-of-river (3.6%), natural gas (3.1%), and biogas (0.3%).

The comparison simulation of three energy supply-demand scenarios based on the type of fuel during the research period 2021–2050 in West Kalimantan is shown in Fig. 9. It is noted that scenario-3 requires an immense total fuel demand (4,140,490 TJ), followed by Scenario-2 (3,339.517 TJ) and Scenario-1 (2,592,246 TJ). It can be seen that coal and hydropower reservoirs have a dominant contribution. For the cumulative need for coal-type fuel, the three scenarios require almost the same amount of coal because all the scenarios apply the policy that no additional coal power plants are connected to the electricity grid system. However, the value of the fuel requirement is almost exact and constant for all scenarios for the hydro reservoir type since all hydro reservoir potency is used as a baseload in the grid system. Further, the comparison of the total cumulative fuel needs for natural gas, biomass, hydro run-off-river, solar, and nuclear shows a significant difference for the three scenarios. For biogas, the contribution of the three scenarios is minimal, below 1%.

A comparison of the cumulative total fuel demand between NRE and fossil fuels in West Kalimantan during the period 2021–2050 is presented in Fig. 10. Under Scenario-1, the ratio of the cumulative contribution of NRE fuel needs to fossil fuels is already good, which is 67% for NRE against 33% for fossil fuels. Meanwhile, under Scenario-2, the ratio of NRE and fossil fuel needs is 68% for NRE and 32% for fossil fuel. In addition, under Scenario-3, the ratio is 72% for NRE to 28% for fossil fuel. Furthermore, fuel demand in 2050 is shown separately. Under Scenario-1, the contribution of NRE versus fossil fuels is dominated by NRE, namely 88% for NRE and 12% for fossil fuels. Moreover, under Scenario-2, the ratio between NRE and fossil fuel needs is 89% for NRE and 11% for fossil fuel. Further, under Scenario-3, the ratio is 90% for NRE to 10% for fossil fuel With such conditions in 2050, the NZE target is expected to be achieved in 2060.

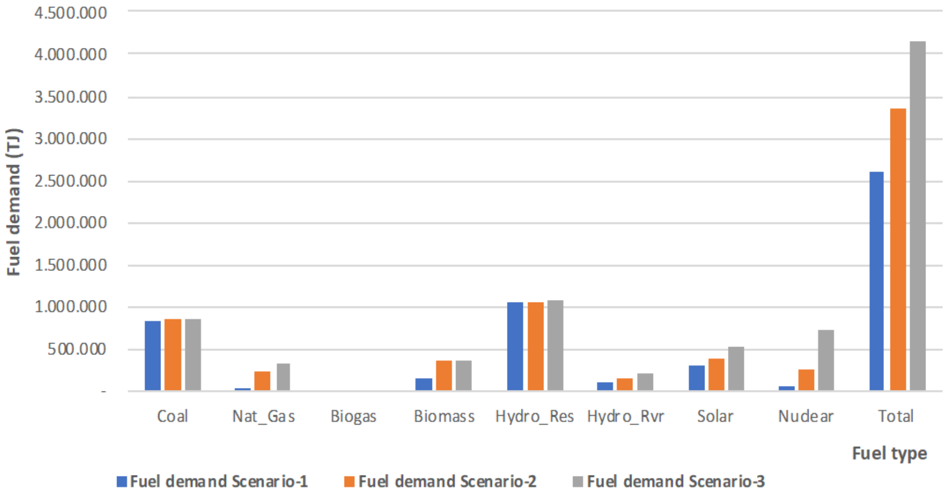


**Fig. 9:** Scenarios result in comparison of cumulative total calculation based on the type of fuel demand during the period 2021-2050 in West Kalimantan.

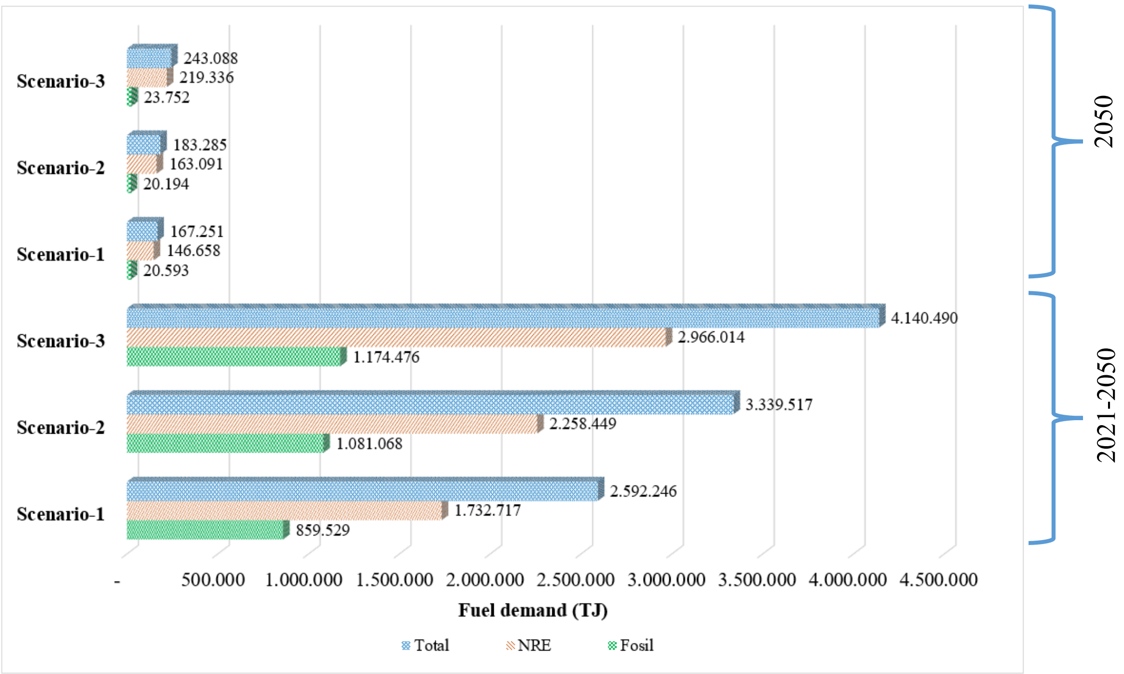


**Fig. 10:** Comparison of cumulative total calculation of fossil and NRE fuel demand in West Kalimantan.

## 6. Conclusion

The fuel demand simulation of the sustainable power generation expansion planning in West Kalimantan has been calculated based on the least cost of the power generation method. It can be concluded that Scenario-3 requires the most significant total fuel demand (i.e., 4,140,490 TJ), followed by Scenario-2 (3,339.517 TJ) and Scenario-1 (2,592,246 TJ), with coal and hydro reservoirs having a dominant contribution effect to simulation constraints. In contrast, the total cumulative fuel needs for natural gas, biomass, hydro run-of-river, solar, and nuclear significantly differ for the three scenarios. Analysis using Scenario-1 shows that the contribution of NRE is dominant at 88%. Meanwhile, under Scenario-2, the percentage of NRE is 89% and 11% for fossil fuels, and under Scenario-3, 90% for NRE and 10% for fossil fuels. With such conditions in 2050, the NZE target is expected to be achieved in 2060.

The above result is derived from the model that operates at an aggregated level and may not capture the distinctive geographic characteristics and finer spatial and temporal dynamics of the West Kalimantan region, resulting in generic conclusions that may fail to reflect the complexities and specific challenges of the region. Further, changes in input assumptions or parameters can lead to different outcomes. While sensitivity analysis can help assess the model's robustness, capturing and quantifying all sources of uncertainty is challenging. The model also needs more stakeholder engagement and participation. The involvement of diverse stakeholders, including local communities, industry representatives, and policymakers, can provide a more comprehensive understanding of the region's needs, aspirations, and constraints. Future work should refine modeling techniques, expand the scope of analysis, incorporate stakeholder perspectives, and conduct sensitivity analyses to upgrade the reliability of the research findings.

However, the research findings can inform the government's and energy planners' policy decisions and long-term energy planning strategies in West Kalimantan. The model can help discover the most efficient mix of power generation technologies to meet the region's energy demand while accounting for some factors such as cost, environmental impact, and energy security. Understanding the future energy landscape in West Kalimantan, evaluating future business opportunities, and assessing the sustainability of various energy projects will benefit energy corporations and investors. Academics and researchers can utilize the research findings to model alternative power generation scenarios, gaining insights into the complex dynamics of energy systems, the interconnections between different technologies, and the implications of various policy and investment decisions.

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## Nomenclature

| | |
|---|---|
| *BATAN* | National Nuclear Energy Agency |
| *BESS* | Battery Energy Storage System |
| $CO_2$ | Carbon dioxide |
| *CVR* | Conservation Voltage Reduction |
| *DH* | District Heating |
| *DJEBTKE* | Directorate General of New, Renewable energy, and Energy Conservation |
| *DJK* | Directorate General of Electricity |
| *SubC-FGD* | Sub-Critical using Flue Gas Desulfurization |
| *GW* | Giga Watt |
| *KEN* | National Energy Policy |
| *KESDM* | Ministry of Energy and Mineral Resources |
| *kWh* | kilo Watt hour |
| *MTOE* | Million Tonne of Oil Equivalent |
| *MW* | Mega Watt |
| *NOX* | Nitrogen oxides |
| *NPP* | Nuclear Power Plant |
| *NRE* | New and Renewable Energy |
| *NZE* | Net Zero Emission |
| *P3TKEBTKE* | Research and Development Center of Electricity, New-Renewable Energy and Energy Conservation Technologies |
| *PLN* | State Electricity Company |
| *PLTA* | Hydro Power Plant |
| *PLTB* | Wind Turbine Power Plant |
| *PLTBg* | Biogas Power Plant |
| *PLTBm* | Biomass Power Plant |
| *PLTG* | Gas Turbine Power Plant |
| *PLTGU* | Combined Cycle Gas Power Plant |
| *PLTM* | Mini Hydro Power Plant |
| *PLTMG* | Gas Engine Power Plants |
| *PLTS* | Solar Photovoltaic Power Plant |
| *PLTU* | Coal Fired Power Plant |
| *PTBGN* | Center for Nuclear Minerals Technology |
| *RUEN* | National Energy General Planning |
| *RUPTL* | Electricity Procurement Plan |
| *Simple-E* | Simple Econometric Simulation System |
| $SO_2$ | Sulfur dioxide |
| *SubC* | Plant Sub-Critical |
| *TJ* | Tera Joule |
| $U_3O_8$ | Triuranium octoxide |

### Coefficients/relationships

| | |
|---|---|
| *a* | Annual capacity. recovery |
| *A* | Annual resource |
| *c* | Extraction coefficient |
| *ce* | Back pressure coefficient |
| *k* | Idle fuel consumption |
| *K* | Capacity |
| *Loss* | Loss factor |
| *Mm* | Minimum unit load |
| *r* | Variable resource |
| *T* | Target |
| *W* | Emission factor |

### Variables (endogenous)

| | |
|---|---|
| *D* | Demand (MW) |
| *Dn* | Shutdown (#) |
| *G* | Generation (MW) |
| *I* | Investment (MW) |
| *L* | Storage level (MWh) |
| *O* | Unit online (#) |
| *S* | Start unit (#) |

| | |
|---|---|
| $X$ | Transmission (MW) |
| $Z$ | System costs (USD) |

*Greek symbols*

| | |
|---|---|
| $\eta$ | Marginal efficiency (–) |
| $\kappa$ | Nominal unit size |

*Subscripts*

| | |
|---|---|
| $a$ | Areas |
| $c$ | Cost |
| $e$ | Electricity |
| $f$ | Fuel |
| $g$ | Technology |
| $h$ | Heat |
| $t$ | Time |
| $w$ | Emission |
| $x$ | Transmission line |

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