

Article

Preliminary LEAP-Based Scenario Analysis of Electricity Demand and Renewable Energy Development in South Sulawesi

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Abstract: South Sulawesi possesses abundant renewable energy potential, particularly from hydro, wind, solar, and biomass resources. However, rapid population growth and increasing energy consumption across sectors create challenges in ensuring sustainable energy supply and planning. This study aims to project the mid-term renewable energy supply and demand in South Sulawesi using the Long-range Energy Alternatives Planning (LEAP) model. By simulating various scenarios—including the business-as-usual (BAU) and renewable policy intervention scenarios—this research analyzes the region's future energy trajectory up to 2035. The findings reveal that South Sulawesi's average population growth of 1.028% (approximately 142,000 people per year) and electricity demand growth of 7.94% annually significantly increase regional energy needs. Without intervention, fossil fuels will continue to dominate the energy mix, but policy-driven scenarios demonstrate that renewable energy contributions could exceed 45% of the total supply. The study provides valuable insights for regional energy planning and supports policy formulation toward achieving a sustainable, low-carbon energy system in South Sulawesi.

Keywords: LEAP, renewable energy, energy forecasting, South Sulawesi, sustainable development.

Citation: Arham., Kolewora, L. M. A., Saiful, M., Setiawan, A. A., Taufiq, M., Wicaksono, V. I. (2026). Preliminary LEAP-Based Scenario Analysis of Electricity Demand and Renewable Energy Development in South Sulawesi. *Recent in Engineering Science and Technology*, 4(4), 209–223. Retrieved from <https://www.mbi-journals.com/index.php/riestech/article/view/165>.

Academic Editor: Yudhi Ariadi

Received: 8 June 2026

Accepted: 16 October 2026

Published: 31 October 2026

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1. Introduction

The increasing population and economic growth in South Sulawesi have led to a continuous rise in energy demand across all sectors. Based on data from the *Badan Pusat Statistik Sulawesi Selatan* (South Sulawesi Statistics Agency), the province's population has grown at an average rate of 1.028% per year, equivalent to approximately 142,000 additional people annually. This demographic growth contributes directly to higher household and industrial energy consumption, accelerating the region's overall energy requirements.

Electricity consumption in South Sulawesi has shown a steady upward trend over the past decade. The household sector remains the largest consumer, followed by business and public sectors, while industrial consumption—although smaller—continues to increase steadily. According to the RUPTL 2025–2034, electricity sales in South Sulawesi grew at an average annual rate of 7.94% between 2015 and 2024, increasing from 4,480 GWh in 2015 to 9,225 GWh in 2024. These figures represent electricity sales across the household, public, business, and industrial sectors, reflecting the region's growing electricity demand [1].

Despite these increases in demand, South Sulawesi holds substantial renewable energy potential that remains underutilized. The province's *Regional Energy General Plan (RUED-P Sulsel 2015–2050)* identifies various renewable sources: hydroelectric power plants (2,946.8 MW), wind power (4,193 MWe), solar PV (7,588 MWp), micro-hydro

(7,622.9 MW), and geothermal resources (800 MW). However, only a small portion of these potentials has been developed to date. The full realization of these resources could play a vital role in achieving regional and national renewable energy targets.

Given this context, developing a long-term and data-driven energy planning model is essential. The *Long-range Energy Alternatives Planning* (LEAP) system provides a comprehensive analytical framework for evaluating future energy scenarios, considering population growth, economic development, technology adoption, and policy measures. By applying the LEAP model, this study aims to project the mid-term supply and demand of renewable energy in South Sulawesi and assess the implications of various policy scenarios [2], [3].

Ultimately, the results are expected to assist policymakers, local governments, and stakeholders in designing effective strategies to accelerate the energy transition, reduce dependence on fossil fuels, and achieve a more sustainable and resilient energy system for the province[4], [5].

1. Materials and Experiment Methods

2.1 Power Sector Structure

The power sector in South Sulawesi plays a strategic role in supporting the island's economic development and industrial growth. It forms part of the interconnected Sulawesi Power System, managed primarily by PT PLN (Persero), Indonesia's state-owned electricity company. The system operates as part of the Sulbagsel (South, Southeast, and West Sulawesi) grid, ensuring electricity transmission and distribution across provinces through high-voltage networks and substations. Electricity generation in South Sulawesi is characterized by a diverse mix of energy sources, with thermal power plants particularly those using coal and diesel still dominating the generation capacity. However, the province has made significant progress in integrating renewable energy sources into its power mix, driven by national energy transition targets and regional initiatives. As of recent data, hydropower (PLTA) and wind power (PLTB) represent the largest contributors among renewables, supported by several operational plants in Sidrap, Jeneponto, and Tana Toraja.

South Sulawesi's electricity system consists of generation, transmission, and distribution subsystems. The generation segment includes both PLN-owned and Independent Power Producer (IPP) facilities, comprising hydropower plants, coal-fired power plants, diesel generators, and renewable installations such as wind and solar farms. The transmission network, operated under PLN's regional units, connects major load centers including Makassar, Parepare, Palopo, and Bone, forming the backbone of electricity delivery across the province. The distribution network serves urban and rural areas, supporting residential, business, and industrial customers with varying reliability and capacity.

According to the RUPTL 2025–2034, the South Sulawesi power system is projected to experience continued demand growth of approximately 7–8% per year, primarily driven by population increase, economic activity, and industrial expansion. The household sector remains the largest electricity consumer, accounting for over 50% of total demand, followed by the business and public sectors. Meanwhile, the industrial sector though smaller in share is expected to grow steadily as the province develops new manufacturing and processing zones.

To address the growing demand and reduce dependence on fossil fuels, the government and PLN are promoting the expansion of renewable energy generation, particularly through the development of additional hydropower, solar photovoltaic

(PLTS), and wind power projects. These initiatives are supported by the provincial Regional Energy General Plan (RUED-P Sulsel), which emphasizes diversification, energy security, and environmental sustainability. In summary, the power sector structure of South Sulawesi reflects a transitional system—moving from fossil fuel dependency toward a more balanced, renewable-based energy mix. Continued investment in grid infrastructure, renewable integration, and energy efficiency will be essential to ensure sustainable and reliable electricity supply for the province's long-term development[6].

2.2 Analysis of Electricity Demand

Electricity demand in South Sulawesi has shown a consistent upward trend over the period 2015–2024. The total number of customers increased from 4.48 million in 2015 to an estimated 9.23 million in 2024, representing an average annual growth rate of approximately 8%. This steady rise reflects both population growth and economic expansion across various consumer sectors.

The household sector remains the largest consumer group, growing from 2.32 million customers in 2015 to 3.61 million in 2024. This growth indicates the continuous electrification of residential areas and an increase in household electricity usage driven by lifestyle changes and appliance adoption[7].

The business sector also shows a positive trend, increasing from 0.93 million customers in 2015 to 1.33 million in 2024, highlighting the expansion of small and medium enterprises in the region. Meanwhile, the public sector experienced moderate growth, from 0.41 million to 0.67 million customers, in line with the development of public facilities and government infrastructure[8], [9].

The most notable increase occurred in the industrial sector, which rose significantly from 0.83 million customers in 2015 to 3.62 million in 2024. This sharp growth, especially between 2020 and 2023, suggests a surge in industrial activity and investment, possibly linked to regional development programs and the establishment of industrial zones in South Sulawesi.

Annual growth in total electricity demand fluctuated between 0.5% and 19.1%, with the highest spike in 2022, reflecting post-pandemic economic recovery and industrial resurgence. Overall, the data indicate robust demand growth across all sectors, reinforcing the need for strategic planning in electricity generation and distribution to sustain economic development in South Sulawesi.

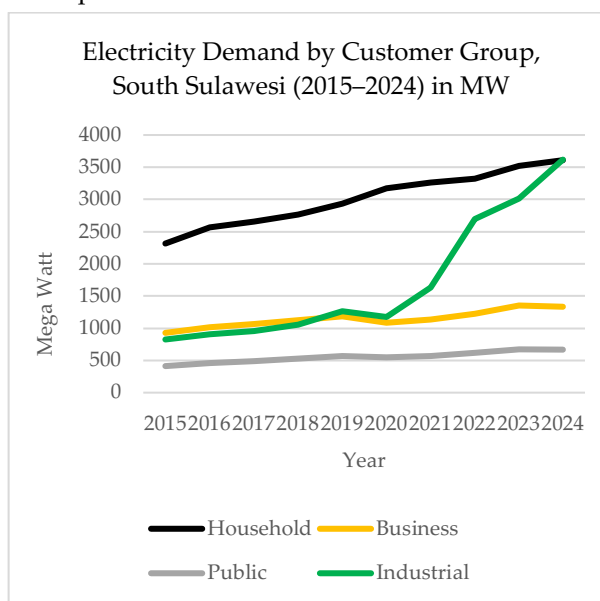


Figure 1. Electricity Demand by Year

2.3 Analysis of Electricity Supply

In 2025, the total electricity production in South Sulawesi is projected to reach 9,798.53 MWh, generated from a mix of fossil fuels and renewable energy sources. The data indicate that coal remains the dominant source of power generation, contributing approximately 5,864.52 MWh, or about 60% of the total production. This heavy reliance on coal reflects the region's continued dependence on conventional energy sources to meet growing electricity demand.

Among renewable sources, hydropower plays a significant role, producing around 1,498.26 MWh (15% of total output). Smaller-scale renewables such as minihydro (370.51 MWh) and microhydro (4.31 MWh) complement the larger hydro facilities, reflecting ongoing efforts to utilize local water resources for power generation[10].

Wind energy contributes 465.39 MWh, showing potential for further development given South Sulawesi's favorable wind conditions, particularly in coastal and highland areas. In contrast, solar power remains minimal, producing only 2.38 MWh, suggesting that solar energy infrastructure is still in its early stages.

On the fossil fuel side, gas and steam plants produce 1,260.39 MWh, while diesel and gas-only generation contribute 250.83 MWh and 81.93 MWh, respectively. The relatively small share of oil-based generation indicates a gradual transition toward cleaner and more efficient technologies.

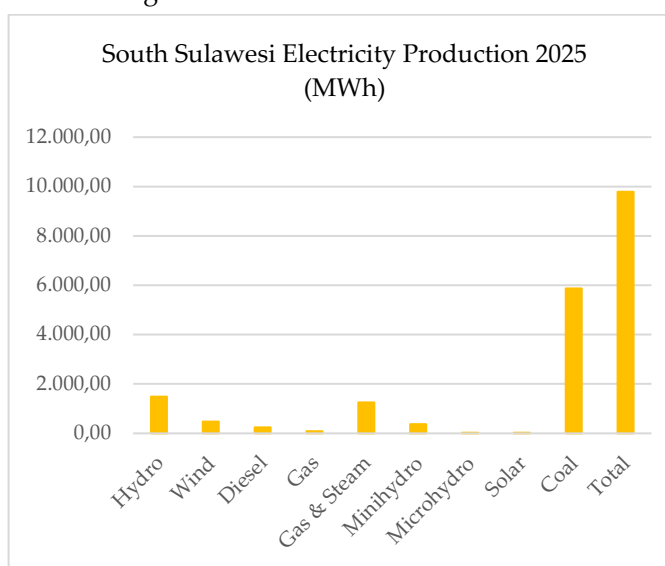


Figure 2. Electricity Production in South Sulawesi

2.4 Methodology

2.4.1 South Sulawesi's LEAP Model Framework

The LEAP (Long-range Energy Alternatives Planning) model framework developed for South Sulawesi provides a systematic approach to analyze and forecast the province's future energy demand, supply, and emissions under different development scenarios. This framework integrates both bottom-up demand modeling and top-down supply analysis, allowing for a comprehensive assessment of the region's energy system over time[11], [12].

The framework begins by structuring the demand side according to key consumer sectors—household, business, public, and industrial—based on historical electricity consumption data from 2015 to 2024. Each sector's growth trend is modeled using socioeconomic indicators such as population growth, regional GDP, and industrial

expansion rates. These factors serve as the primary drivers of electricity demand in the projection period up to 2040 (or as defined in the study).

On the supply side, the LEAP framework incorporates data on electricity generation by energy source, including coal, hydro, wind, diesel, gas, steam, minihydro, microhydro, and solar, as observed in 2025. These inputs form the baseline scenario, representing the existing energy mix and technological structure. The framework then allows for the development of alternative scenarios—such as renewable energy expansion, energy efficiency improvement, or decarbonization pathways—to evaluate their long-term impacts on production, cost, and emissions[13], [14]. The model structure follows LEAP's hierarchical logic:

1. Current Accounts – representing the base year (2025) energy situation of South Sulawesi.
2. Demand Modules – projecting energy use by sector and subsector.
3. Transformation Modules – modeling electricity generation and fuel conversion processes.
4. Resources and Emissions Modules – estimating fuel inputs, resource availability, and environmental outputs (CO₂ and other emissions).

Through this framework, the LEAP model serves as a decision-support tool for policymakers and planners in South Sulawesi, enabling them to explore different energy development strategies and assess their implications for energy security, sustainability, and emission reduction.

Table 1. Economic Growth Development

Year	Quarter	Growth (%)
2021	Q1	-0.21
2021	Q2	7.70
2021	Q3	3.24
2021	Q4	7.89
2022	Q1	4.31
2022	Q2	5.22
2022	Q3	5.69
2022	Q4	5.12
2023	Q1	5.30
2023	Q2	5.00
2023	Q3	4.04
2023	Q4	3.82
2024	Q1	4.82
2024	Q2	4.98
2024	Q3	5.08
2024	Q4	5.18
2025	Q1	5.78

The LEAP (Long-range Energy Alternatives Planning) model for South Sulawesi is developed based on a series of key assumptions that define the structure and behavior of both the energy demand and supply systems over the modeling period. These assumptions are essential for ensuring that the model reflects realistic socioeconomic, technological, and policy conditions within the province[15].

On the demand side, the model assumes that future electricity consumption will be driven by the growth of four major consumer sectors: household, business, public, and industrial. The projection of each sector is influenced by macroeconomic and demographic factors such as population growth, gross regional domestic product

(GRDP), and sectoral economic expansion. Economic growth is assumed to remain stable in the medium term, averaging around 5–6 percent annually, based on recent regional trends. Population growth is projected to continue moderately, leading to increased household electricity demand. Energy intensity (energy use per unit of economic output) is assumed to gradually decline due to efficiency improvements and technological adoption[16].

On the supply side, the baseline scenario assumes that the existing energy mix observed in 2025 dominated by coal and supported by hydro, wind, and other renewables will serve as the reference structure. The capacity of renewable energy sources such as hydro, minihydro, wind, and solar is expected to expand gradually in line with national energy transition policies and regional renewable potential. Meanwhile, fossil fuel-based generation (coal, diesel, and gas) is assumed to maintain a significant share in the short term but gradually decrease under alternative or policy-driven scenarios[17].

Additional assumptions include the use of current technology efficiencies, plant lifetimes, and capacity factors based on available data from PLN and regional planning documents. The model also assumes that no major disruptions—such as extreme policy shifts, large-scale energy crises, or drastic demographic changes—will occur during the simulation period. Carbon emission factors are based on standard IPCC values, and fuel price assumptions follow national energy planning parameters (RUEN or RUPTL data). Overall, these assumptions provide the analytical foundation for simulating different development pathways—such as business-as-usual, renewable energy expansion, or low-carbon scenarios—allowing the LEAP model to assess their impacts on energy demand, supply structure, and emission outcomes in South Sulawesi.

While the LEAP (Long-range Energy Alternatives Planning) model provides a flexible and comprehensive framework for analyzing South Sulawesi's energy system, several limitations should be acknowledged to ensure a balanced interpretation of the results.

First, the model's accuracy is highly dependent on the quality and availability of input data. In the case of South Sulawesi, historical energy consumption and production data may contain inconsistencies or incomplete records, particularly for smaller renewable energy systems such as microhydro and solar. Limited access to up-to-date regional statistics can introduce uncertainty into demand projections and energy balance estimations.

Second, LEAP operates primarily as a deterministic model, meaning that it does not automatically account for uncertainties in future socioeconomic or technological developments. Variables such as economic growth, population change, fuel prices, and technology costs are treated as fixed assumptions within each scenario. Consequently, sudden economic shocks, policy changes, or external factors (for example, global energy price fluctuations) cannot be dynamically captured without manual scenario adjustments.

Third, the spatial dimension of energy planning is not explicitly represented in LEAP. The model focuses on aggregate regional data and does not simulate geographic variations in energy supply or distribution infrastructure within South Sulawesi. As a result, it cannot fully evaluate localized grid constraints, transmission losses, or site-specific renewable resource availability.

Fourth, LEAP's environmental module, while useful for estimating greenhouse gas emissions, relies on default emission factors that may not perfectly reflect local fuel characteristics or technology performance. This can lead to small discrepancies between modeled and actual emission outcomes.

Finally, the model does not perform economic optimization or cost-benefit analysis automatically. It estimates energy requirements and emissions based on user-defined pathways rather than identifying the least-cost or most efficient solutions. This limits its capability to determine the optimal investment portfolio without integration with other analytical tools, such as MARKAL or TIMES[18], [19].

In summary, while LEAP offers valuable insights for scenario analysis and long-term energy planning, its results should be interpreted with caution. The model's outputs are most effective when used as guidelines for policy discussion and comparative scenario evaluation, rather than as precise forecasts or investment recommendations.

1.4.1 Scenario Development

In this study, two main scenarios were developed within the LEAP model to evaluate the future electricity outlook in South Sulawesi: the RUPTL Scenario and the National Target (RUEN) Scenario. The RUPTL Scenario (Rencana Usaha Penyediaan Tenaga Listrik) reflects the official electricity supply plan of PLN, emphasizing a realistic projection based on current infrastructure, investment plans, and committed generation projects. It assumes gradual growth in electricity demand consistent with regional economic development, with the energy mix still dominated by coal and hydropower, while renewable penetration increases moderately following PLN's 2021–2030 planning targets[20], [21].

The National Target (RUEN) Scenario (Rencana Umum Energi Nasional) represents a more ambitious pathway aligned with Indonesia's national energy policy, which aims to achieve 23% renewable energy share by 2025 and 31% by 2050. This scenario emphasizes stronger integration of renewables such as solar, wind, and hydro, along with energy efficiency improvements and gradual reduction of fossil fuel dependency[22].

2. Results and Discussion

3.1. Demand Projection

The projected final energy demand in South Sulawesi shows a consistent upward trend from 2024 to 2034. Total electricity consumption increases from approximately 9 TWh in 2024 to around 12.5 TWh by 2034, reflecting steady economic growth and rising energy needs across all sectors.

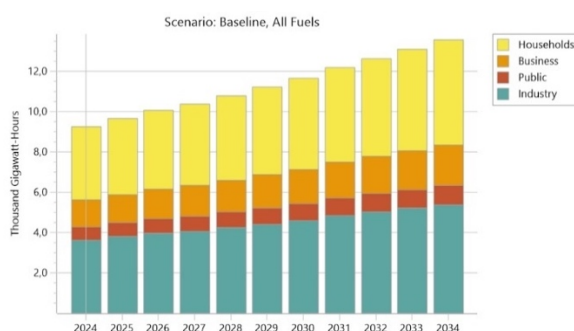


Figure 3. Demand Projections in South Sulawesi

Among the four main sectors households, business, public, and industry the industrial sector remains the largest energy consumer throughout the projection period. Industrial electricity demand grows significantly, indicating continued expansion in manufacturing and processing activities within the province[23], [24]. The household sector also contributes a substantial share of total demand, rising steadily as electrification rates improve and living standards increase. The business sector shows moderate growth,

corresponding to the development of commercial areas and small enterprises. Meanwhile, the public sector which includes government buildings and public services—maintains a smaller but gradually increasing share[25], [26]. Overall, the projection suggests that total electricity demand will continue to grow at an average annual rate of around 3–4%, aligning with South Sulawesi’s expected economic development and population growth. This rising demand underscores the importance of expanding generation capacity, promoting energy efficiency, and accelerating renewable energy integration to ensure a reliable and sustainable energy supply in the coming decade.

3.2 Electricity Generations Projections

3.2.1 Comparison Based on Installed Capacity

The comparison between the RUPTL Scenario and the RUEN Target Scenario highlights different pathways for electricity generation capacity development in South Sulawesi from 2024 to 2034. Under the RUPTL Scenario, total installed capacity shows steady growth from around 3.3 GW in 2024 to approximately 5.1 GW in 2034. The generation mix remains dominated by coal-fired power plants (PLTU) and large hydropower (PLTA), while renewable sources such as mini-hydro (PLTM), solar (PLTS), and wind (PLTB) increase only moderately. This scenario reflects a more conservative expansion approach, focusing on reliability and gradual integration of renewables in alignment with current PLN planning documents.

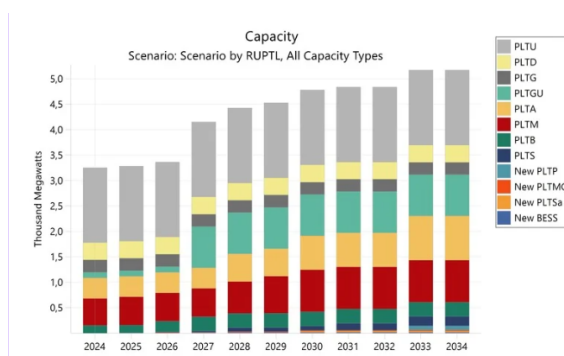


Figure 4. RUPTL Scenario

In contrast, the RUEN Target Scenario (National Energy Policy Plan) projects a stronger commitment to renewable energy integration. Although total installed capacity reaches a similar level of around 5 GW, the composition differs significantly. The share of renewable energy plants including solar (PLTS), geothermal (PLTP), and mini-hydro (PLTM) expands considerably, while dependence on coal (PLTU) gradually decreases. This reflects national efforts to achieve the renewable energy mix target of 23% by 2025 and beyond, in line with Indonesia’s clean energy transition goals[27].

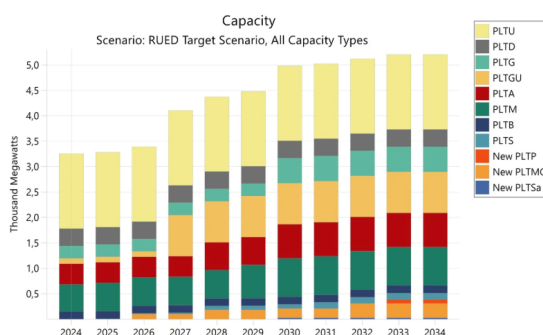


Figure 5. RUED Target Scenario

3.2.2 Comparison Based on Output

Under the RUPTL scenario, the generation mix remains dominated by coal-fired power plants (PLTU), as represented by the large grey portion of each bar in the chart. Despite moderate growth in renewable energy sources such as hydropower (PLTA), mini-hydro (PLTM), biomass (PLTSa), and solar power (PLTS), coal continues to contribute the largest share of electricity generation throughout the projection period[28], [29].

Diesel (PLTD) and gas turbine (PLTG) plants also maintain a noticeable presence, indicating limited diversification of the generation portfolio. This scenario represents a business-as-usual pathway, where energy security and capacity expansion are prioritized over the rapid integration of renewables. Consequently, the RUPTL pathway implies continued reliance on fossil fuels, leading to higher carbon emissions and slower progress toward Indonesia's clean energy targets[30], [31].

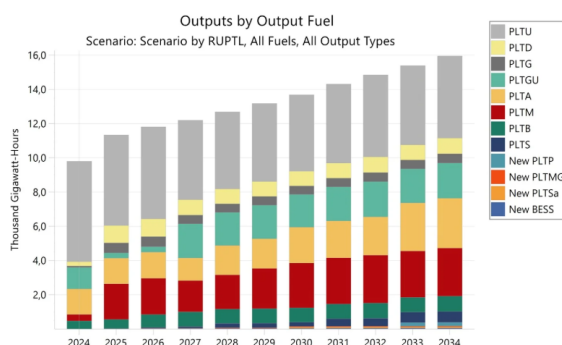


Figure 6. RUPTL Scenario Based on Output

In contrast, the RUED target scenario envisions a significant transformation of the energy mix toward renewable sources. While the total electricity generation output follows a similar upward trend, the contribution of PLTU (coal), shown in yellow, gradually declines relative to other technologies[32], [33].

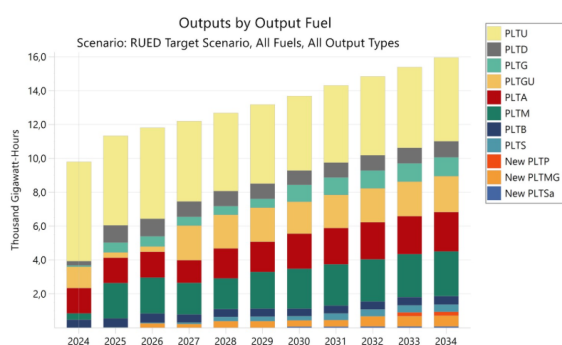


Figure 7. RUED Scenario Based on Output

Renewable energy sources such as PLTA, PLTM, PLTB, and PLTS experience substantial growth, complemented by the introduction of new plants including New PLTP (geothermal) and New PLTS (solar). This indicates a strategic shift toward low-carbon and sustainable energy systems, in line with Indonesia's national commitment to increase the share of renewable energy in its primary energy mix and reduce greenhouse gas emissions[34], [35].

3.3 Renewable Energy Projections

Projected capacity of renewable energy power plants from 2024 to 2034, measured in megawatts (MW). The capacity includes several renewable technologies, namely hydropower (PLTA), mini-hydro (PLTM), biomass (PLTSa), solar power (PLTS), geothermal power (New PLTP), and new solar installations (New PLTSa).

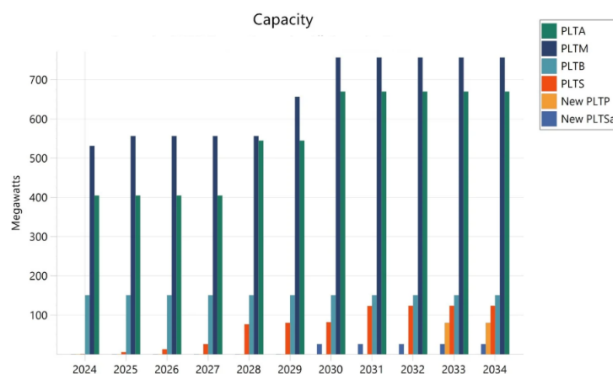


Figure 8. Renewable Energy Projection

Throughout the projection period, the total installed renewable capacity exhibits a steady upward trend. The most dominant contributors to renewable generation capacity are PLTM and PLTA. PLTM maintains the largest share from the beginning of the period, starting at around 530 MW in 2024 and increasing to approximately 750 MW by 2034. PLTA also shows significant growth, rising from about 400 MW in 2024 to more than 600 MW by 2034.

Biomass (PLTSa) and solar (PLTS) capacities gradually expand over time, indicating continuous development and diversification of renewable sources. PLTS capacity grows noticeably starting in 2026 and continues to rise steadily through 2034. In addition, the appearance of new geothermal (New PLTP) and solar (New PLTSa) projects from around 2027 onwards marks an important milestone in the renewable expansion plan[2]. Overall, the figure reflects a strong commitment to renewable energy development. The increasing capacity across multiple renewable technologies suggests that future energy policies prioritize sustainability, diversification, and carbon emission reduction. The integration of new geothermal and solar power plants also indicates an effort to enhance system reliability while supporting Indonesia's national renewable energy targets for 2030 and beyond[36], [37].

3.4 Supply and Demand Balance

The balance of energy supply and demand across various energy sources indicates that the total primary energy supply reaches 36,207 MWh, mainly sourced from imports of solid fuels (13,348 MWh) and natural gas (9,118 MWh), along with domestic generation from hydropower (6,503 MWh) and other renewables (5,132 MWh). During the transformation phase, these primary energy sources are converted into secondary energy, predominantly electricity. Negative values in the transformation section for solid fuels, natural gas, hydropower, and renewables indicate their use in electricity generation, which produces 15,953 MWh of electricity. After accounting for transformation and distribution losses, the total transformed energy is -22,649 MWh. [38].

	Solid Fuels	Natural Gas	Hydropower	Renewables	Electricity	Oil Products	Total
Production	-	-	6,503	5,132	-	-	11,635
Imports	13,348	9,118	-	-	0,000	2,108	24,574
Exports	-	-	-	-	-0,003	-	-0,003
Total Primary Supply	13,348	9,118	6,503	5,132	-0,003	2,108	36,207
Electrical Generation	-13,348	-9,118	-6,503	-5,132	15,953	-2,108	-20,257
Transformation and Distribution	-	-	-	-	-2,392	-	-2,392
Total Transformation	-13,348	-9,118	-6,503	-5,132	13,560	-2,108	-22,649
Households	-	-	-	-	5,215	-	5,215
Business	-	-	-	-	2,001	-	2,001
Public	-	-	-	-	0,958	-	0,958
Industry	-	-	-	-	5,383	-	5,383
Total Final Energy Demand	-	-	-	-	13,557	-	13,557
Unmet Requirements	-	-	-	-	-	-	-

Figure 9. Supply and Demand Balance

Final energy demand totals 13,557 MWh, distributed among households (5,215 MWh), industry (5,383 MWh), business (2,001 MWh), and the public sector (0.958 MWh). These figures represent final energy consumption across different sectors[39], [40]. Overall, the energy system demonstrates equilibrium between total supply and final demand, with no unmet requirements observed, indicating that the available energy resources and conversion capacity are sufficient to satisfy the projected consumption needs.

3.5 Renewable Cost Data

The data compares key technical and economic parameters of various power plant types, including fossil-based and renewable technologies, for the years 2018 and 2040. Parameters include capital cost, operation and maintenance (O&M) cost, efficiency, lifetime, fuel cost, and maximum capacity factor.

Power plant type	Capital costs (USD/kW) in 2018/2040	Fixed O&M costs (USD/kW/year) in 2018/2040	Variable O&M costs (USD/MWh) in 2018/2040	Efficiency	Lifetime (years)	Fuel costs (USD/GJ)	Maximum capacity factor
Coal	1400/1340 ^{A,B}	41.2/39.3 ^{A,B}	0.12/0.12 ^{A,B}	37% ^{A,B}	30 ^A	2.4 ^C	80% ^{A,B}
Open cycle gas turbine (OCGT)	770/700 ^{A,B}	23/22.5 ^{A,B}	0 ^{A,B}	33% ^{A,B}	25 ^A	6.2 ^E	95% ^{A,B}
Closed cycle gas turbine (CCGT)	750/680 ^{A,B}	23/22.5 ^{A,B}	0.13/0.13 ^{A,B}	56% ^{A,B}	25 ^A	6.2 ^E	95% ^{A,B}
Large hydro	2000/2000 ^{A,B,C,D}	38/34.7 ^{A,B}	0.65/0.6 ^{A,B}	-	50 ^A	-	36% ^H
Small hydro	2600/2600 ^A	53/48.8 ^A	0.5/0.46 ^A	-	50 ^A	-	50% ^C
Geothermal	3700/3050 ^{A,B,C,D}	18/15.9 ^{A,B}	0.25/0.22 ^{A,B}	-	30 ^A	-	80% ^{A,B}
Biomass	1700/1500 ^{A,B,C,D}	48/40.8 ^{A,B}	3/2.59 ^{A,B}	31% ^A	25 ^A	1.3 ^F	80% ^{A,B}
Solar PV	1190/BAS: 610 RE:340 ^{E,D}	11.9/BAS: 6.1 RE: 3.4 ^D	0 ^{A,B}	-	25 ^A	-	17% ^E
Wind	1500/BAS: 1210 RE: 1020 ^{A,B,C,D}	30/26.5 ^{A,B}	0 ^{A,B}	-	27 ^A	-	25% ^{I,J}
Diesel	800/800 ^{A,B}	8/8 ^{A,B}	6.4/6.4 ^{A,B}	45% ^A	25 ^A	15.9 ^C	80% ^{A,B}
Pumped hydro storage	860/860 ^A	8/8 ^A	1.3/1.3 ^A	80% ^A	35 ^A	-	100% ^K
Battery storage	1570/730 ^D	39.3/18.2 ^D	0 ^D	85% ^D	15 ^D	-	100% ^K

Figure 10. Cost Analysis

Coal power plants have a capital cost of 1,400 USD/kW in 2018, projected to decline slightly to 1,340 USD/kW by 2040. They maintain relatively low O&M costs but exhibit moderate efficiency at 37% and a high fuel cost of 2.4 USD/GJ, with an operational lifetime of 30 years. Gas-based plants, including open-cycle (OCGT) and closed-cycle (CCGT) turbines, show lower capital costs (700–770 USD/kW) but have higher fuel costs at 6.2 USD/GJ. CCGT systems achieve higher efficiency (56%) compared to OCGT (33%).

Hydropower systems, both large and small, demonstrate long operational lifetimes (up to 50 years) and low variable O&M costs, though their capacity factors vary between 36% and 50%. Geothermal and biomass plants have relatively high capital costs (3,700 and 1,700 USD/kW, respectively) but offer stable output and moderate fuel costs.

Solar PV and wind technologies show substantial cost reductions by 2040, with solar capital costs decreasing from 1,190 to around 610 USD/kW and wind from 1,500 to approximately 1,020 USD/kW. However, both technologies exhibit lower capacity factors—17% for solar and 25% for wind—due to their intermittent nature. Diesel generation remains relatively costly in terms of fuel (15.9 USD/GJ) and less efficient (45%), making it less favorable for large-scale or long-term applications. In contrast, energy

storage systems, such as pumped hydro and battery storage, present increasingly competitive options for supporting grid reliability. Pumped hydro storage maintains a long lifespan (35 years) and full availability (100% capacity factor), while battery storage achieves high efficiency (85%) and continues to experience rapid cost declines, from 1,570 USD/kW in 2018 to 730 USD/kW by 2040.

3. Conclusion

This study provides a mid-term projection of South Sulawesi's renewable energy supply and demand using the Long-range Energy Alternatives Planning (LEAP) model. The simulation results reveal a steady increase in electricity demand, rising from approximately 9 TWh in 2024 to 12.5 TWh by 2034, driven by population growth, industrial expansion, and economic development. The industrial and household sectors remain the primary contributors to the overall energy demand throughout the projection period.

The comparison between the RUPTL and RUEN scenarios highlights two distinct development pathways. The RUPTL scenario reflects a business-as-usual approach, maintaining high dependence on coal-fired power plants, while renewable energy integration progresses gradually. In contrast, the RUEN scenario demonstrates a more ambitious trajectory toward renewable energy expansion, particularly in hydropower, mini-hydro, solar, biomass, and geothermal generation. Under this policy-driven scenario, the renewable energy share could exceed 45% of total electricity production by 2034.

The renewable energy capacity projection indicates continuous growth across multiple technologies. Hydropower and mini-hydro remain the dominant contributors, followed by the gradual development of solar and geothermal plants. This diversification reflects a growing policy commitment to sustainability, energy security, and carbon emission reduction. The supply-demand balance analysis confirms that South Sulawesi's projected energy system is capable of meeting future electricity needs without major deficits, provided that planned capacity expansions are implemented.

From an economic perspective, renewable technologies show significant cost reduction potential by 2040, especially for solar PV, wind, and battery storage, making them increasingly competitive with fossil-based power plants. These findings underscore the importance of accelerating renewable energy investment, enhancing grid infrastructure, and integrating storage technologies to support a reliable and low-carbon energy transition.

In conclusion, the results emphasize the necessity of aligning regional energy planning with national policy targets to ensure sustainable development in South Sulawesi. Strengthening institutional coordination, promoting technological innovation, and expanding renewable deployment will be essential strategies to achieve a balanced, resilient, and environmentally sustainable power system by 2035.

Acknowledgment: The authors would like to express their gratitude to the Department of Systems Engineering, Faculty of Engineering, Universitas Gadjah Mada, for providing academic guidance and research support throughout this study. All authors are final-year master's students in the Systems Engineering Program, specializing in Renewable Energy Systems. This research was conducted as part of the academic requirements for completing the Master of Engineering degree and reflects the authors' shared commitment to advancing sustainable energy development in Indonesia.

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

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