

Effective energy planning requires the estimation of clean electricity in NTB

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ABSTRACT

Nusa Tenggara Barat (NTB) is an Indonesian province with a Regional Energy General Plan (RUED) and the Mandalika Special Economic Zone (KEK), both of which have contributed to rising electricity demand across households, businesses, industries, and public services. Despite its vast renewable energy potential, NTB's electricity supply remains largely dependent on fossil fuels. This study employs the Low Emission Analysis Platform (LEAP) to project energy demand and supply under three scenarios: Business as Usual (BAU), RUED, and Renewable Energy (RE), with projections extending to 2050. The analysis shows that under BAU, fossil fuel dependence continues, whereas the RUED pathway accelerates renewable energy adoption and reduces emissions substantially. The RE scenario demonstrates the feasibility of eliminating fossil fuel use, achieving near-total decarbonization, and significantly enhancing energy security. These findings underscore the crucial role of renewable energy in facilitating a sustainable and resilient energy transition in NTB.

Keywords: renewable energy; energy transition; energy planning; LEAP

INTRODUCTION

Nusa Tenggara Barat (NTB) is one of Indonesia's provinces with the most significant number of islands, totalling 418, and covering an area of 20,124 km². NTB consists of 10 regencies/cities with a population of 5,320,092 as of 2020, and a population growth rate of 1.63% from 2010 to 2020. The province's climate conditions, presented in Table 1 (Badan Pusat Statistik, 2021)(Global Solar Atlas, 2025) This indicates significant potential for solar energy utilisation.

Table 1. Climate conditions in NTB

Parameter	Value	Unit
Average temperature	26-28	°C
Average humidity	76-83	%
Average wind velocity	3.8-5.3	m/s
Duration of sunshine	73-81.5	%

Electricity consumption in NTB has been increasing annually. In 2020, total electricity consumption reached 2,149.42 GWh, with the household sector accounting for the highest demand at 1,428.13 GWh, followed by the industrial sector at 376.45 GWh, as shown in Figure 1 (PT. PLN, 2016)(PT. PLN, 2017)(PT. PLN, 2018)(PT. PLN, 2019)(PT. PLN,

2020)(PT. PLN, 2021). This rise in electricity consumption has also been accompanied by an increase in the number of electricity customers across sectors, as shown in Figure 2 (PT. PLN, 2016)(PT. PLN, 2017)(PT. PLN, 2018)(PT. PLN, 2019)(PT. PLN, 2020)(PT. PLN, 2021).

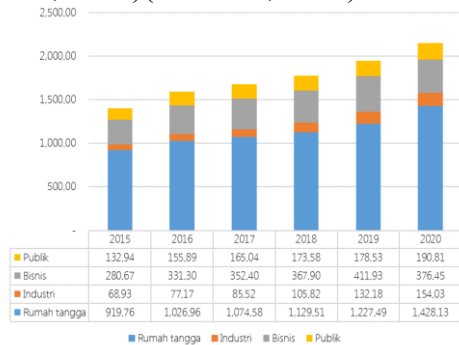


Figure 1. Total electricity consumption (GWh)

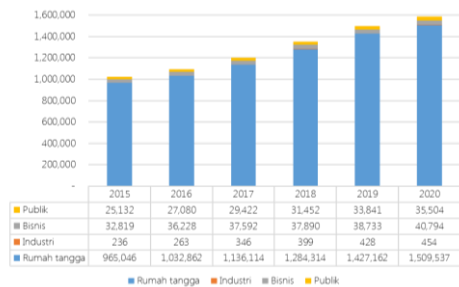


Figure 2. Number of electricity customers (unit)

The current electricity demand in NTB is met by PLN, primarily through power plants that rely on fossil fuels. Natural gas power plants contribute the largest share of electricity production, followed by diesel and coal power plants, as PT. PLN, (2022), shown in Table 2 (*Independent Power Producers (IPPs) and leased generators are excluded from this table, and PLTMG is classified under PLTG for consistency with RUED planning*). However, in alignment with

Indonesia’s energy management policies outlined in the General Planning of National Energy (RUEN), NTB has formulated its Regional Energy General Plan (RUED) (Table 4) to optimise the use of regional energy sources, particularly renewable energy (Pemerintah Provinsi NTB, 2019). Given NTB’s abundant renewable energy potential (Table 3) as (Tim CASINDO, 2011; Ditjen EBTKE, 2016), the development of renewable energy has become a key focus in the region’s energy strategy.

Table 2. Existing electricity power plant in NTB

Years 2020		
Power plant	Capacity (MW)	Energy production (GWh)
Natural gas	2.02	5.28
Diesel	77	387.44
Coal	144.12	204.98
Hydro	233.02	1,041.63
Solar	0.83	0.89

Table 3. Renewable energy potential in NTB

Renewable energy	Potential	Unit
Geothermal	169	MWe
Solar	9,931	MW
Wind	2,605	MW
Bioenergy	394,1	MW
Waste	8,87	MW
Total hydro	212,48	MW

Table 4. Projection of power generation needed by RUED

Power plant	2025	2030	2035	2040	2045	2050
PLTD (MW)	50	40	30	20	10	0
PLTD rent (MW)	25	20	15	10	5	0

PLTU coal (MW)	654	654	654	654	654	654
PLTG (MW)	360	420	450	480	510	540
PLT MH (MW)	4.62	6	7	8	12	16
PLTS (MW)	431	501	521	541	671	801
PLT M (MW)	50	55	55	55	57.5	60
PLTP (MW)	20	100	134.5	169	169	169
PLTA (MW)	30	50	55	60	60	60
PLTB (MW)	25	25	37.5	50	50	50
PLTB m (MW)	10	15	20	25	25	25
PLTS a (MW)	4	6	7	8	9	10
Total (GW)	1.66	1.892	1.986	2.08	2.232	2.385

The growing demand for electricity and the commitment to transitioning towards clean, locally sourced renewable energy necessitate comprehensive and precise energy planning. Effective energy planning should estimate future energy demand and identify appropriate supply technologies that ensure safety, economic viability, cleanliness, and reliability (Reddy et al., 1995). Several energy planning methodologies exist, including multicriteria decision techniques, Delphi surveys, and participatory approaches, which evaluate multiple factors such as energy efficiency, clean energy integration, emissions reduction, sustainability, and investment costs (Rabe et al., 2020).

One widely used tool for energy planning is the Low Emissions Analysis Platform (LEAP). LEAP is a software developed by the Stockholm Environment Institute, widely utilised in over 190 countries for energy demand forecasting, policy analysis, and climate change mitigation assessments (*LEAP: Low Emissions Analysis Platform*, 2021). The LEAP framework integrates various energy planning models, including trend analysis, econometric modelling, and end-use approaches, making it a versatile tool for assessing long-term energy strategies (Rajagukguk et al., 2015).

METHODOLOGY

The Low Emission Analysis Platform (LEAP) system is used to model NTB's electricity sector up to 2050, matching electricity demand with supply-side technologies while calculating electricity generation, total production, and GHG emissions. (Windarta et al., 2018). LEAP's four key modules — assumptions, demand, transformation, and resources — are applied using NTB statistical data, PLN statistics, the 2021–2030 RUPTL, and renewable energy potential data.

This study compares three scenarios: Business as Usual (BAU), Regional Energy General Plan (RUED), and Renewable Energy (RE). The BAU scenario follows current fossil fuel-based trends, the RUED scenario integrates NTB's Regional Energy General Plan, and the RE scenario aims for a complete shift to renewable energy by 2050. Each scenario assumes different energy sources: BAU relies on PLTU (coal), PLTD (diesel), and PLTG

(natural gas), RUED follows RUED projections, while RE phases out fossil fuels by 2050, prioritising PLTS (solar), PLTB (wind), PLTBm (biomass), and PLTA (hydropower). LEAP simulations generate electricity sector projections, with results visualised in graphical charts for analysis.

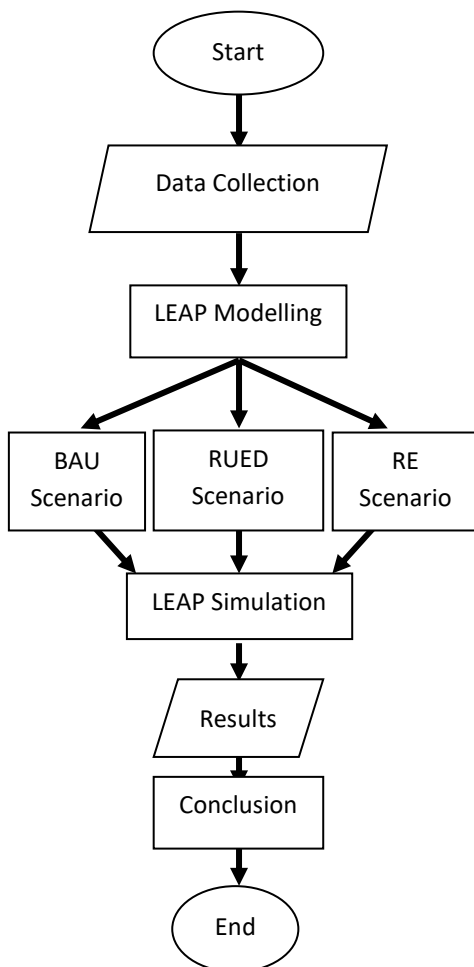


Figure 3. Flowchart

RESULTS AND DISCUSSION

Energy demand in Nusa Tenggara Barat (NTB) continues to grow in line with increases in customer numbers, consumption, and energy intensity. Energy intensity is calculated by dividing total consumption by the number of

customers. Figure 4 illustrates the rising energy demand from 2020 to 2050, with the highest demand in 2050 coming from the industrial sector (25,453 GWh), followed by households (18,946 GWh), businesses (2,212 GWh), and the public sector (1,452 GWh).

The significant rise in energy demand is attributed to the increase in energy intensity resulting from growth in customer numbers across each sector. Specifically, energy intensity and customer growth rates are as follows: industry (339.273 MWh/unit, 14%), households (0.946 MWh/unit, 9%), businesses (9.228 MWh/unit, 4%), and the public sector (5.374 MWh/unit, 7%). This sharp increase in electricity demand is primarily driven by continuous population growth and economic expansion, which in turn lead to increased electricity consumption. This finding aligns with the research conducted by Windarta et al. (2018), which highlights the correlation between population growth and economic growth, as well as the subsequent rise in energy demand.

The consistent growth in population and economic activity necessitates proactive energy planning to prevent potential issues such as power shortages and ensure a reliable electricity supply for future development (Perwez et al., 2015).

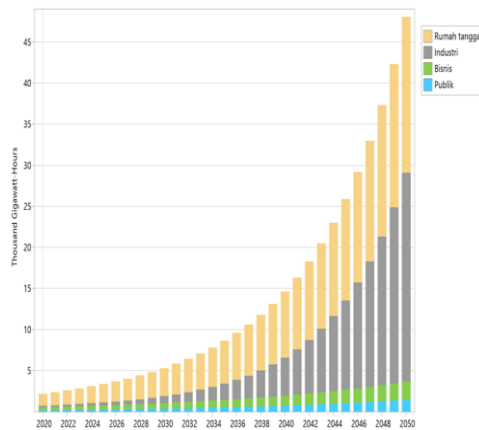


Figure 4. Energy demand in each sector

The composition of the electricity generation mix in the Business as Usual (BAU) scenario remains predominantly reliant on fossil fuels, including coal, natural gas, and diesel oil. In 2025, the electricity supply mix is dominated by coal-fired power plants (PLTU), which contribute 1,486.2 GWh (45%), and natural gas power plants (PLTG), which contribute 1,204.7 GWh (36%). Meanwhile, renewable energy (RE) accounts for only 12.2 GWh (0.4%).

By 2050, the electricity supply composition is projected as follows: coal power plants (PLTU) will generate 14,877.6 GWh (71%), natural gas power plants (PLTG) will contribute 4,588.4 GWh (22%), and renewable energy (RE) will supply only 25 GWh (0.1%) (see Figures 5 and 6). The national renewable energy target for 2025, as outlined in the Electricity Provision Business Plan (RUPTL 2021–2030), is set at 23%. However, the BAU scenario falls significantly below this national target, indicating the need for stronger policy interventions to accelerate the

transition toward clean energy sources.

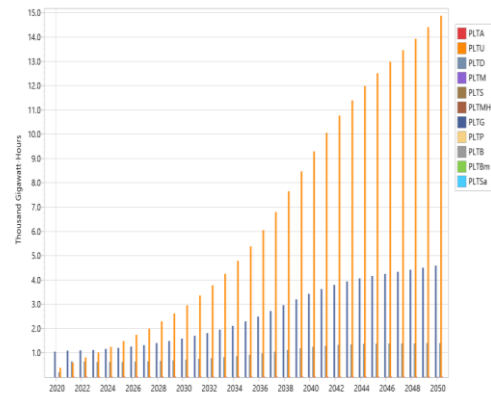


Figure 5. Projection of the BAU scenario electricity generation

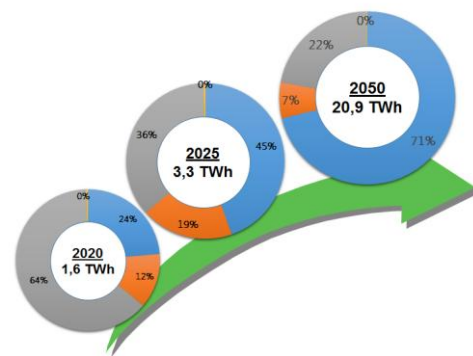


Figure 6. Electric power generation mix (BAU scenario)

In the RUED scenario, there is a notable increase in renewable energy utilisation and a reduction in fossil fuel dependency. As illustrated in Figures 7 and 8, electricity demand in 2025 is projected to be met by coal-fired power plants (PLTU), contributing 1,309.6 GWh (39%); renewable energy, 1,150.7 GWh (35%); and natural gas power plants (PLTG), 720.9 GWh (22%). The renewable energy mix consists of solar power (PLTS) at 863.1 GWh (75%), hydropower (PLTA) at 60.1 GWh (5.2%), and wind power (PLTB) at 50.1 GWh (4.4%).

By 2050, 50% of electricity demand is expected to be supplied by renewable energy, with coal-fired power plants (PLTU) contributing 27% and natural gas power plants (PLTG) 23%. The composition of renewable energy generation includes solar power (PLTS) at 67.3%, geothermal power (PLTP) at 14.2%, and hydropower (PLTA) at approximately 5%. In this scenario, the electricity generation mix in 2025, with 35% renewable energy, successfully meets the RUPTL target.

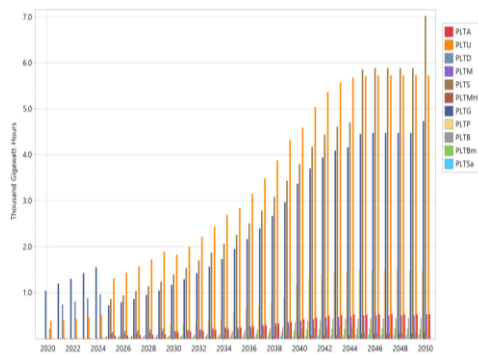


Figure 7. Projection of the RUED scenario electricity generation

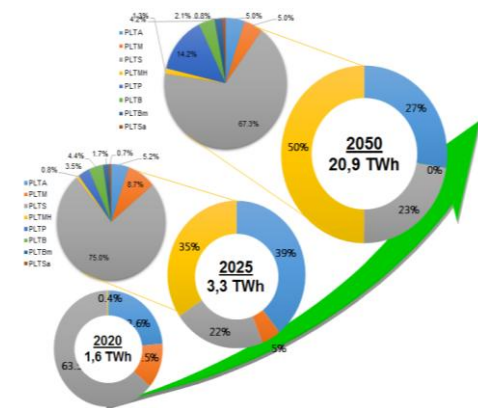


Figure 8. Electric power generation mix (RUED scenario)

In the Renewable Energy (RE) scenario, fossil fuel use is assumed to be completely phased out by 2050, based on the optimisation of the

RUED scenario. The projections indicate that by 2025, the share of renewable energy will reach 51%, while coal-fired power plants (PLTU) will contribute 25%. By 2050, the share of renewable energy is expected to reach 100%.

In this scenario, the renewable energy composition consists of 58.6% solar power (PLTS) and 17.1% wind power (PLTB) (see Figures 8 and 9). This scenario successfully aligns with the renewable energy targets outlined in the RUPTL.

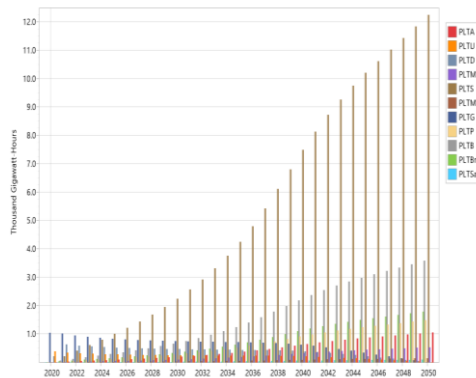


Figure 9. Projection of the RE scenario electricity generation

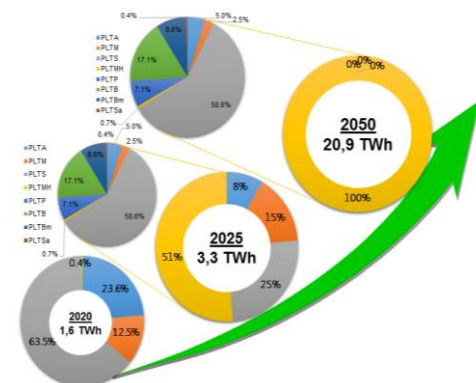


Figure 10. Electric power generation mix (RE scenario)

Figure 11 illustrates the progress toward achieving 100% clean electricity, which refers to electricity generation that produces no carbon

emissions, such as solar, wind, geothermal, and hydroelectric power. (Lew et al., 2021).

In the BAU scenario, the share of clean electricity is projected to reach only 0.4% in 2025 and decline to 0.1% by 2050. In contrast, the RUED scenario is expected to achieve 35% clean electricity by 2025 and 50% by 2050. Meanwhile, the RE scenario is projected to reach 51% clean electricity in 2025 and attain 100% by 2050.

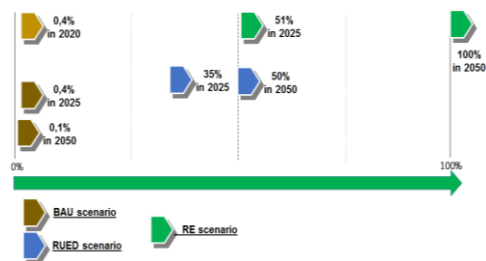


Figure 11. Progress to 100% clean electricity for all scenarios

Figure 12 presents data on primary energy demand across different scenarios. In the BAU scenario, demand for coal and natural gas is projected to increase continuously until 2050, reaching 23,027.6 MBOE for coal and 6,312.8 MBOE for natural gas. In the RUED scenario, demand for coal and natural gas also rises but at a lower rate compared to the BAU scenario, due to the greater adoption of renewable energy, with 8,867.4 MBOE for coal and 6,508.2 MBOE for natural gas.

In the RE scenario, demand for coal and natural gas is projected to drop to zero by 2050 due to a significant shift toward renewable energy sources. This highlights the energy needs and supply conditions in the NTB Province, which does not produce coal or natural gas, making it

highly dependent on fossil fuel imports from other regions and thus vulnerable to energy security risks. Conversely, in the RE scenario, the majority of electricity is generated from local renewable energy sources, enhancing energy security in the province.

This finding aligns with Cox et al. (2019), who state that renewable energy enhances energy security by diversifying power generation sources, including geographical distribution, energy types, and fuel supplies (Cox, Beshilas, and Hotchkiss, 2019). Similarly, Hikam (2014) defines energy security as a region's ability to sustainably meet its energy needs by maximising local natural resources (Hikam, 2014).

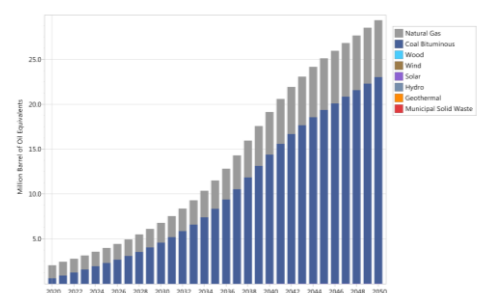


Figure 12. Comparison between the projection of primary resources in all scenarios (a: BAU scenario)

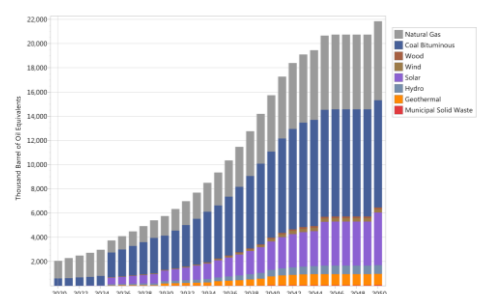


Figure 12. Comparison between the projection of primary resources in all scenarios (b: RUED scenario)

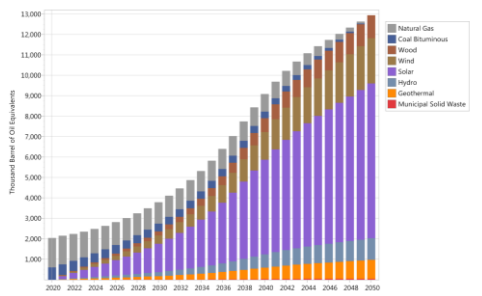


Figure 12. Comparison between the projection of primary resources in all scenarios (c: RE scenario)

Figure 13 presents a comparison of carbon emissions across the three scenarios. By 2050, the BAU scenario is projected to emit 15.7 thousand metric tons of CO₂, the RUED scenario will release 6.9 thousand metric tons of CO₂, and the RE scenario will emit only 0.023 thousand metric tons of CO₂.

The RUED scenario achieves emission reductions of 34% by 2025, 42% by 2030, and 56% by 2050 compared to the BAU scenario, while the RE scenario demonstrates a 55% reduction in 2025 and a 99.85% reduction by 2050. These findings indicate that both the RUED and RE scenarios result in lower emissions than the BAU scenario, with the RE scenario producing the lowest emissions and having the least environmental impact.

The transition to renewable energy and the reduction of fossil fuel dependence play a crucial role in lowering CO₂ emissions, mitigating the greenhouse gas effect, and preventing environmental degradation and climate change-related disasters caused by global temperature increases (Qudrat-Ullah, 2022).

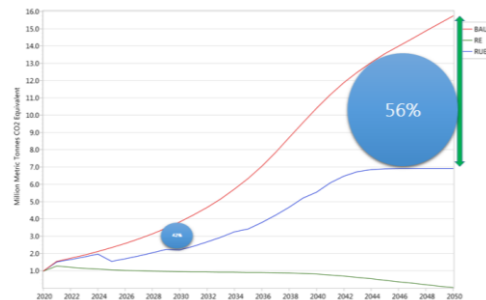


Figure 13. Emission reduction

CONCLUSIONS

The significant growth in electricity demand is mainly driven by the rising number of electricity customers and higher sectoral energy intensity. Addressing this requires effective energy supply strategies and the promotion of efficiency measures, such as adopting energy-efficient appliances and fostering an energy-saving culture.

Scenario analysis suggests that renewable energy (RE) penetration has the potential to surpass national targets, with a transition pathway that can substantially reduce fossil fuel dependency and carbon emissions, while enhancing energy security. However, achieving 100% renewable electricity by 2050 presents significant challenges. Beyond technological readiness, the transition requires overcoming critical financial barriers (high upfront investment and limited funding mechanisms), infrastructural barriers (grid integration, energy storage, and transmission systems), and institutional barriers (regulatory frameworks and governance capacity).

Success will depend on the active roles of key stakeholders, including strong government commitment and policy support, private sector

involvement in innovation and investment, and the active participation of local communities in adopting and supporting renewable solutions. Coordinated action across these actors is essential to accelerate the transition toward a sustainable and resilient energy future.

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