DINAS ENERGI DAN SUMBER DAYA MINERAL

Danish Energy Agency

Ea Energy Analyses

EMBASSY OF DENMARK
Jakarta

NTB Energy Masterplan

Propelling West Nusa Tenggara to Lead Indonesia's Energy Transition

December 2023

Copyright:

Disclaimer:

The present report was developed in collaboration with local authorities, energy experts and the University of Mataram. However, the results, modelling setup and views expressed in the report do not represent any official statement or position of the aforementioned institutions and it is to be ascribed solely to the main authors, i.e. Danish Energy Agency, Ea Energy Analyses and Dinas ESDM Provinsi NTB.

Acknowledgements:

'NTB Energy Masterplan' is a publication prepared by the Danish Energy Agency (DEA), Ea Energy Analyses and Dinas ESDM Provinsi NTB, in close collaboration with the Embassy of Denmark in Indonesia, PLN UIW NTB, Bappeda Provinsi NTB and Universitas Mataram. The writers of this report would like to warmly thank everyone involved in the process and express their gratitude for all inputs and discussions shared during the ideation, implementation and execution workshops. Also, they would like to extend their appreciation to Oetomo Tri Winarno for his contribution in various data collection, processing and modelling activities.

Danish Energy Agency

Ea Energy Analyses

EMBASSY OF DENMARK
Jakarta

Contacts:

Niken Arumdati, Dinas ESDM Provinsi NTB, Email: arumdati@gmail.com
Konstantinos Athanasiou, Danish Energy Agency, Email: ksath@ens.dk
Anant Atul Visaria, Ea Energy Analyses, Email: aav@eaea.dk

Foreword

The present report is conceptualised and executed in the context of the Indonesia-Denmark Energy Partnership Programme (INDODEPP), a government-to-government programme which is driven by the Indonesian national and regional efforts to improve the energy system while decarbonizing energy consumption.

The long-lasting collaboration with Dinas ESDM Provinsi NTB has already, among others, produced two reports, namely Lombok Prefeasibility studies on RE solutions and Lombok Energy Outlook 2030. The latter has been officially adopted by the local government and constitutes the stepping stone for a non-binding climate pledge, announced by the Vice Governor of Nusa Tenggara Barat at COP26, which was the first of its kind in an Indonesian context, with ambitions well ahead of the national climate commitments. Local resources and ambitions enable the NTB province to act as an innovation hub for other provinces to follow, showcasing an example of how local energy planning, with the support of national government, could contribute to the country's climate and energy targets.

NTB Energy Masterplan offers a comprehensive analysis on a potential development of the provincial energy sector, that encompasses the aforementioned local government ambitions, providing a pathway to net-zero CO2 emissions by 2050 across the whole energy system. The Masterplan considers existing barriers and lays the foundation for a sustainable and just energy transition, adopting an "act now" approach.

Provincial government of Nusa Tenggara Barat

Embassy of Denmark to Indonesia

Executive summary

Introduction

In a global context, achieving net-zero emissions is crucial from social, environmental, and economic perspectives, marking a pivotal milestone in the pursuit of sustainable development. On a local level, achieving net-zero emissions directly address the health impacts of air pollution, safeguarding communities from respiratory diseases and fostering a healthier living environment. The reduction of carbon emissions mitigates climate change, which is crucial in averting the catastrophic consequences of rising temperatures, extreme weather events, and sea-level rise both on global and local levels. From an economic standpoint, transitioning to a low-carbon future promotes innovation, job creation, and global competitiveness in renewable energy industries. Furthermore, it reduces dependence on finite fossil fuel resources, enhancing energy security and resilience. Striving for net-zero emissions allows societies to simultaneously improve public health and stimulate sustainable economic growth, securing a more resilient and equitable future for generations to come. While the journey ahead requires a sustained global effort, it's essential to acknowledge that, like any journey, the first steps must be small and local. Undertaking this challenge demands an ambitious vision and a long-term strategy. This report seeks to contribute to the initial roadmap for this marathon, positioning Nusa Tenggara Barat on the right path for development. Though it represents a modest stride in the grand scheme of things, it reflects an incredible effort in the local, national, and global context.

The purpose of this report is to outline a pathway to achieving the ambitious net-zero-emissions target in the NTB energy sector. The analysis in this report finds average power generation costs being at the same level when realising net-zero-emissions compared to a baseline scenario. Achieving a net-zero emissions scenario requires larger initial investments, but these will pay back over time from saved fuel and operation costs. To secure this pathway, substantial energy efficiency is needed with a large focus on electrification. Both scenarios show large shares of variable renewable energy generation from wind and solar, which requires operational changes. Thermal dispatchable technologies play an important role in providing flexibility and balancing the power system. Likewise, storages and interconnections also play an important role in providing flexibility and balancing the power system, especially on days with higher intermittency of Variable Renewable Energy (VRE).

Background

West Nusa Tenggara (NTB) comprises many islands, with Lombok and Sumbawa being the largest. Dominated by agriculture, forestry, and fisheries, NTB's Gross Regional Domestic Product sees significant contributions from these sectors, while tourism, mining, energy, and electrical sectors attract substantial investments. The region heavily depends on fossil fuels for electricity and transportation, posing a vulnerability to energy security. The high fossil fuel dependency, and emissive activities from various sectors emphasises the need for sustainable practices based on a comprehensive energy plan for a sustainable transition of the NTB energy system.

During COP26 an ambitious target for NTB to reach net-zero emission by 2050 was announced. The NTB masterplan is motivated by this target and aims to conduct a comprehensive energy plan, illustrating an optimal pathway, looking forward from present day to 2050. The modelling setup includes using LEAP for demand side projections, and a detailed power sector analysis using the Balmorel model. The electricity demand from LEAP is incorporated into the Balmorel model and two scenarios are considered for the analysis. One is a baseline scenario representing the system development maintaining current conditions and active policies, as well as following national and provincial trends. The second scenario looks at an ambitious provincial level net zero emissions target for NTB by 2050. Furthermore, based on the modelling results, a financial analysis is conducted looking at the power system cost in the two scenarios along with a basic financial feasibility of solar and wind plants in NTB to shed some light on the financial viability of such investments.

Current conditions

The energy landscape of West Nusa Tenggara (NTB) is multifaceted, encompassing various grid systems, energy sources, and consumption patterns. Currently, fossil fuels dominate electricity generation, but there's a gradual shift towards renewable sources. Electricity sales data from 2011-2020 indicates steady growth across residential, business, public, and industrial sectors. The development of the electric power system infrastructure aligns with economic growth projections, with plans to incorporate diverse renewable energy sources.

In the residential sector, Liquified Petroleum Gas (LPG) is the primary fuel for cooking with gas stoves. Kerosene usage is declining, and the local transmission service operator, PLN, promotes electric stoves. The commercial sector plays a pivotal role in NTB's economic development, marked by increased tourist visits and hotel occupancy rates. The industrial sector, focused on food and beverages, experiences growth, supported by policies favouring local products. The transportation sector, heavily reliant on government-subsidised fuels, sees efforts to promote electric vehicles, including charging stations.

Lastly, the mining, agriculture, and construction sectors contribute significantly to NTB's economy. The agricultural sector, vital for food crops and plantation crops, aligns with the region's economic goals. In mining, PT. Amman Mineral Nusa Tenggara dominates gold and copper extraction, influencing export trends. The government's downstream policies aim to increase the value of raw materials and boost economic growth, with the completion of a copper smelter in 2024 anticipated to generate employment and enhance state revenues.

National and provincial energy policies

Indonesia’s energy policy framework encompasses key legislation emphasising energy independence, sustainability, and a diverse energy mix, while promoting private sector involvement in the sector. The National Electricity Plan (RUKN) sets ambitious targets and guides electricity generation. West Nusa Tenggara has a specific energy policy, of which the Regional Regulation No. 3/2019 outlines energy mix goals, mirroring national directives. Local regulations address energy management, business procedures, and regional electricity plans. Recent instructions from the governor encourage electric vehicle use and solar installations on public buildings.

Furthermore, Local Content Requirements (LCRs) play a key role and have been impacting power projects since 2012, aiming to boost domestic renewable manufacturing and employment. However, this raises production costs and hinders scalability. Changes are being proposed, including competitive tenders and feed-in tariffs, aiming to create a more competitive market while fostering domestic manufacturing.

Implementation strategies for West Nusa Tenggara's energy policy involve infrastructure development, collaboration, renewable energy prioritisation, and stakeholder involvement. Regulations focus on business and engineering aspects, emphasising consumer protection, entrepreneurship, and environmental responsibility. The Regional Development Plan (RPD) 2024-2026 envisions an inclusive, sustainable transformation of West Nusa Tenggara's economy. Economic diversification, reduced reliance on mining, and increased contributions from industry, tourism, and agriculture are key goals. The plan targets over 50% GDP share from the latter.

Overall, Indonesia's energy policies, particularly in West Nusa Tenggara, are comprehensive, emphasising sustainability, diversity, and regional goals. The challenge lies in balancing domestic industry promotion with cost-effectiveness and scalability in the renewable sector. The RPD reflects a broader economic vision beyond energy, aligning with national objectives.

Projections of energy demand

The energy demand analysis for West Nusa Tenggara (NTB) is based on data up to 2021, and projections focus on the Baseline and Net Zero Emissions (NZE) scenarios, with the latter aiming for carbon-neutrality by 2050. NTB's economic activity encompasses the commercial sector, transportation, industry, mining, agriculture, and construction. Lombok, with higher economic activity, dominates the region, while Sumbawa relies heavily on mining. Fuel consumption in NTB includes oil products, coal, LPG, and electricity. Gasoline and diesel are widely used, while coal is primarily for power generation. LPG is prominent in residential settings.

Assumptions for future projections involve GDP growth, population changes, and sector-specific targets for electrification and efficiency improvements. The residential sector is expected to see increased electricity use, with LPG substitution and enhanced energy efficiency. By 2050, all households are assumed to have access to clean cooking and fully electrified appliances. The commercial sector, driven by GDP growth, undergoes changes in subsector contributions that follow BPS trends, e.g., the relative growth of the hospitality sector due to higher touristic attraction. In the industrial sector, policies promote diesel-to-electricity conversion, coal-to-biomass switching, high penetration of biofuels and improved process and material efficiency. Transportation experiences a shift towards mainly BEVs, while drop-in biofuels and FCEVs are considered for heavy-duty road transport, shipping, and aviation. Overall, key assumptions include GDP-driven sectoral growth, electrification wherever feasible and economically viable, substitution of conventional fuels with bio-based options and energy efficiency measures via installations of state-of-the-art appliances and machineries, technological improvements and best practises on energy optimisation and management.

Overall, the demand projections provide a comprehensive overview of NTB's current energy landscape, future scenarios, and the intricate interplay of economic, demographic, and technological factors shaping the region's energy trajectory towards 2050.

Development of energy end-use

The province of West Nusa Tenggara is targeting high annual growth in the short and long term across all aspects of the economy. The energy sector is an integral part of every economy, and its sustainable development is fundamental to avoid depleting resources and stressing the environment, and to improve the livelihoods of local population. De-linking growth from increases in final energy intensity is therefore a crucial but challenging task.

As illustrated in Figure 1, the NZE scenario anticipates lower total energy consumption already by 2030, primarily due to BEVs, shifting away from fossil-based cooking, and energy efficiency measures that relate to more efficient appliances. The difference in final fuel consumption of the two scenarios grows to approximately 7.7 TWh by 2050. Both scenarios rely heavily on electricity. Indicatively, in 2050, the relative shares of Baseline and NZE correspond to 68% and 40% of total energy consumption, with the rest being fossil and bioenergy in the first case and biofuels and hydrogen in the latter. Bioenergy is also pivotal in transforming the energy system of NTB. By 2050, bioenergy consumption in NTB, including biomass direct use, biogas, bio gasoline, biodiesel and bio jet-fuel, accounts for roughly 19% in NZE scenario, while Baseline levels lie at 13%, with biodiesel being the most frequently consumed.

Transportation is the most energy intensive sector throughout 2050 for both scenarios, followed by the residential sector. Industrial activity is relatively low in West Nusa Tenggara but showcases a share increase of 5% between 2025 and 2050. The commercial sector rises almost fivefold in 2050 compared to the 2025 level. In 2050, Baseline attributes roughly 40% of its total final consumption to transportation, 27% to households, 12% is linked to industrial processes and the remaining 16% to commercial and others, while in the NZE scenario the transportation sector lies at 32%, which is only marginally higher than the residential sector and the remaining 40% is following the same distribution as in Baseline.

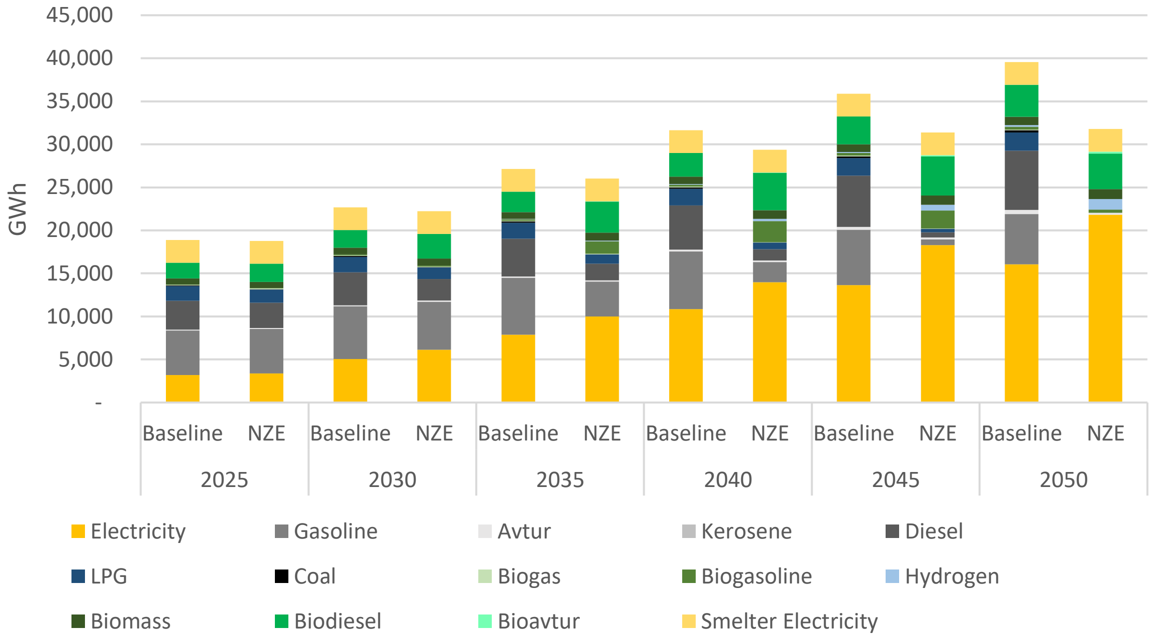


Figure 1: Total end-use fuel consumption in NTB.

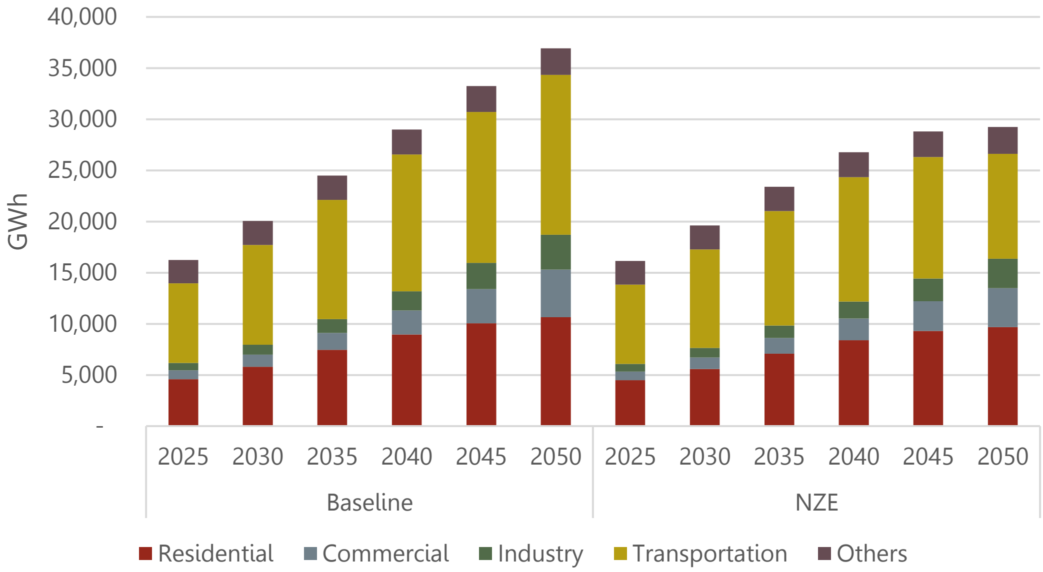


Figure 2: Total end-use energy demand by sector in NTB.

Electricity consumption increases rapidly for all end-use sectors in both scenarios and is the main driver of a more sustainable and responsible development of the demand-side. The residential sector presents the highest electricity demand, while transportation sees the largest growth. PLN's RUPTL21 demand projection has been used to calibrate the consumption of the different sectors up until 2030 for the Baseline scenario. The NZE scenario exceeds the RUPTL21 projections already by 2026, mostly due to BEV sales (private cars and motorcycles) and reaches 21.8 TWh in 2050, roughly a 5.8 TWh difference to Baseline levels.

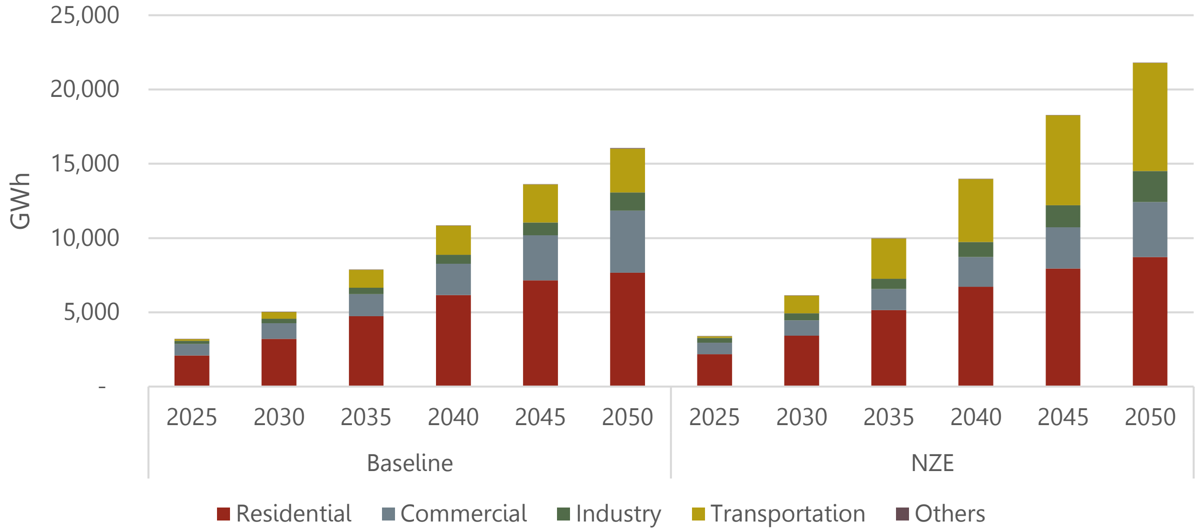


Figure 3: Total end-use electricity consumption by sector in NTB.

When comparing the two scenarios in terms of end-use CO_2 emissions, transportation emerges as the primary emitter for both scenarios throughout, followed by the residential sector. Baseline indicates a rise of roughly 35% between 2025 and 2050. Diesel is the fuel with the highest emission contribution and its impact peaks in 2050 at 1.86 Mt. In the NZE scenario, CO_2 emissions peak in 2025, however, 2030 levels are only marginally lower, with less than 50 kilotons difference. By 2030, NZE achieves a 20% reduction compared to Baseline, mainly driven by decreases in transportation-related emissions. This number is more than tripled by 2040. In 2050, the Baseline scenario reaches 4 Mt, while NZE's very few remaining emissions, roughly 60 kt, come from aviation and represent 1.5% of Baseline's footprint. That could be offset by negative emissions through BECCS or substitution with synthetic jet fuel, however, such technologies have not been considered in the analysis due to cost considerations and/or low readiness levels. In the calculation of total carbon emissions, biofuel combustion is considered carbon-neutral on the assumption that feedstock is procured sustainably, and the consumption does not exceed production levels nor competes with food production.

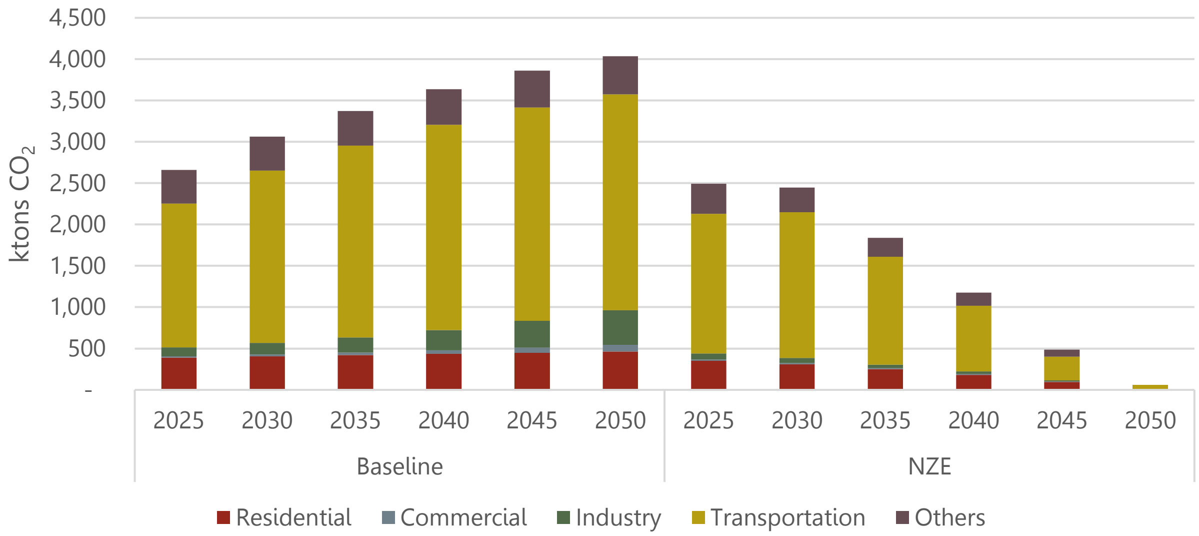


Figure 4: Total end-use CO_2 emissions by sector in NTB (excluding power sector).

Development of the power sector

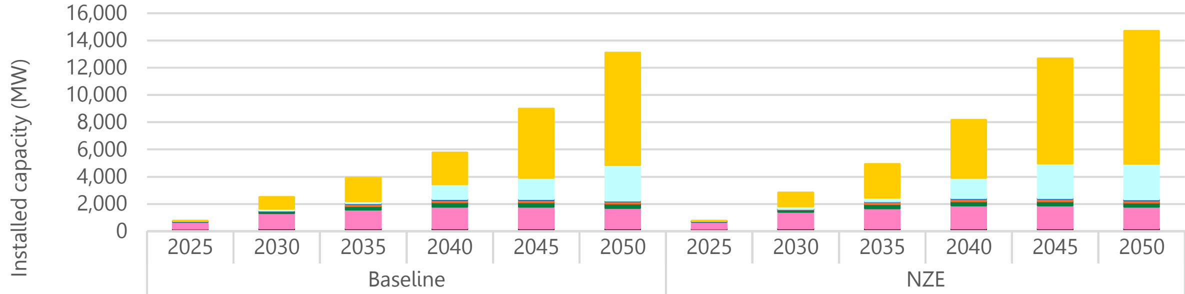
For the power sector modelling fuel prices, based on domestic market obligation and technology investment costs based on the Indonesian technology catalogue, are taken as key inputs. Existing and planned capacity expansion, dominated by fossil fuels with some biomass co-firing, is considered based on information from local partners. Resource potential for NTB, provided by MEMR sources, are indicated in Table 16. This shows high capacity for solar PV and wind, particularly in Sumbawa.

Table 1: Capacity potential by source in Nusa Tenggara province.

Capacity Potential by technology (MW)		
Source	Lombok	Sumbawa
Bioenergy*	297	19
Geothermal	100	75
Hydro	26	26
Municipal waste	32	0
Wind onshore	938	1,667
Solar PV	1000	9,628

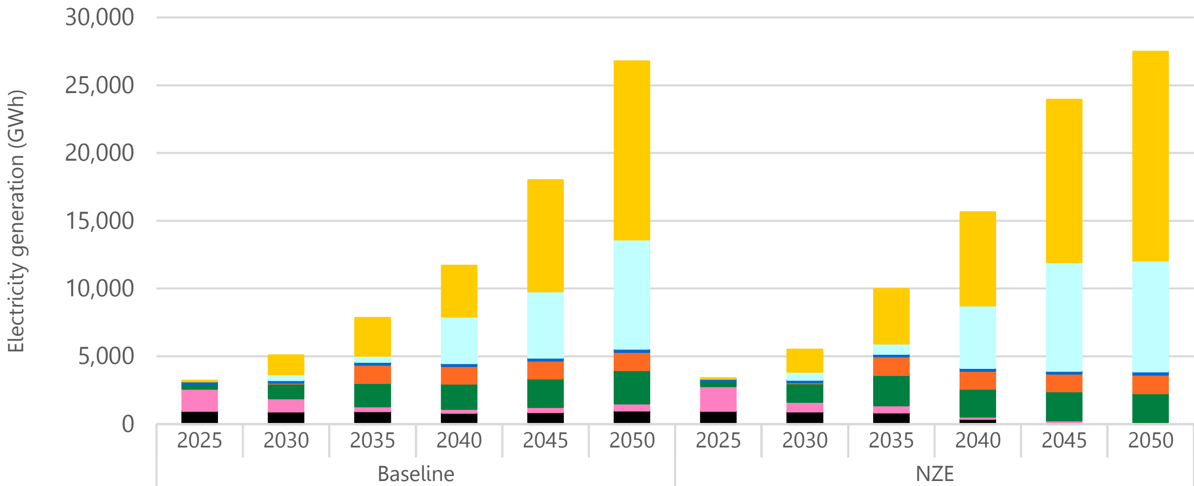
**Bioenergy predominantly refers to potential of biomass, but also includes small amounts for municipal waste, and biogas.*

Analysis of power sector development in Nusa Tenggara Barat towards achieving net-zero emissions by 2050 indicates a significant shift in the energy mix towards solar, wind and biomass. Figure 5 and Figure 6 illustrate the installed capacity and electricity generation, emphasising a shift to renewables towards 2050. In both scenarios, renewable energy dominates power generation, particularly in Sumbawa, where an exponential growth in solar based production is seen, with 9.7 GW solar capacity by 2050 in the NZE scenario. The NZE scenario in Lombok shows a radical shift away from fossil fuels, with increased reliance on imports from Sumbawa to meet demand. Overall, the transition to a less CO_2-intensive system involves significant renewable energy expansion, with 13 GW in the NZE scenario. These are results of least cost optimisation, considering perfect markets and risk of underestimating need for storages. Actual investments will be subject to further limitations such as capital availability, land costs, and changed development in technology costs.



	Baseline 2025	Baseline 2030	Baseline 2035	Baseline 2040	Baseline 2045	Baseline 2050	NZE 2025	NZE 2030	NZE 2035	NZE 2040	NZE 2045	NZE 2050
Solar PV	31	841	1,718	2,318	5,063	8,231	31	1,008	2,467	4,253	7,690	9,758
Wind		143	143	1,098	1,568	2,605		188	241	1,480	2,547	2,605
Hydro	39	39	41	52	52	52	39	39	41	52	52	52
Geothermal		10	175	175	175	175		10	175	175	175	175
Bioenergy	10	122	241	316	316	316	10	174	316	316	316	316
Natural Gas	515	1,138	1,398	1,608	1,608	1,508	515	1,217	1,477	1,687	1,687	1,587
Coal	186	206	206	206	206	206	186	206	206	206	206	206

Figure 5: Installed power production capacity (MW) in the two scenarios.



	Baseline 2025	Baseline 2030	Baseline 2035	Baseline 2040	Baseline 2045	Baseline 2050	NZE 2025	NZE 2030	NZE 2035	NZE 2040	NZE 2045	NZE 2050
Solar PV	47	1,384	2,784	3,755	8,200	13,152	47	1,641	4,025	6,867	11,985	15,406
Wind		438	447	3,429	4,897	8,068		591	756	4,609	8,005	8,188
Hydro	194	188	200	217	217	220	194	192	198	217	217	221
Geothermal		73	1,348	1,280	1,323	1,345		78	1,350	1,322	1,312	1,369
Bioenergy	357	1,089	1,741	1,876	2,098	2,455	357	1,352	2,247	2,045	2,134	2,290
Natural Gas	1,621	960	336	289	374	536	1,818	728	538	180	196	
Coal	982	934	967	837	893	999	982	924	853	388	87	

Figure 6: Electricity generation (GWh) for NTB in the two main scenarios.

In the pursuit of zero CO_2 emissions by 2050, the NZE scenario in Nusa Tenggara Barat sets a cap on annual emissions. The power sector, a significant contributor, undergoes extensive short-term capacity expansion of solar from 2026, resulting in a noticeable reduction in emissions by 2030, as shown in Figure 7. The CO_2 target becomes binding around 2035, with a sharp decline in emissions intensity, reaching zero by 2050. Solar and wind investments contribute to lower emission levels per unit of electricity, ensuring a net-zero outcome in the power sector by 2048. The trend shows a substantial decrease in CO_2 intensity, particularly in the NZE scenario, as shown in Figure 8.

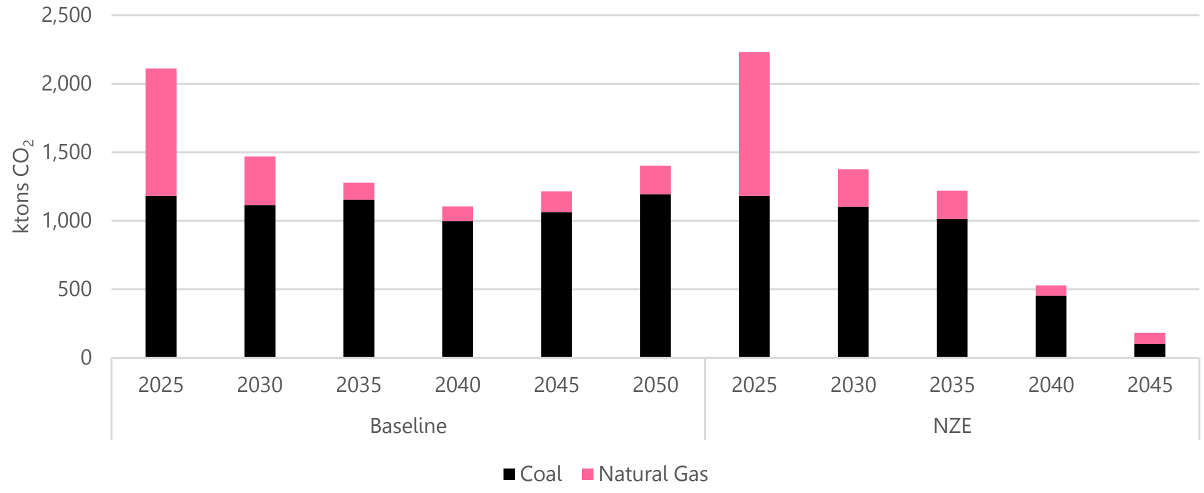


Figure 7: CO_2 emissions by fuel in the two scenarios.

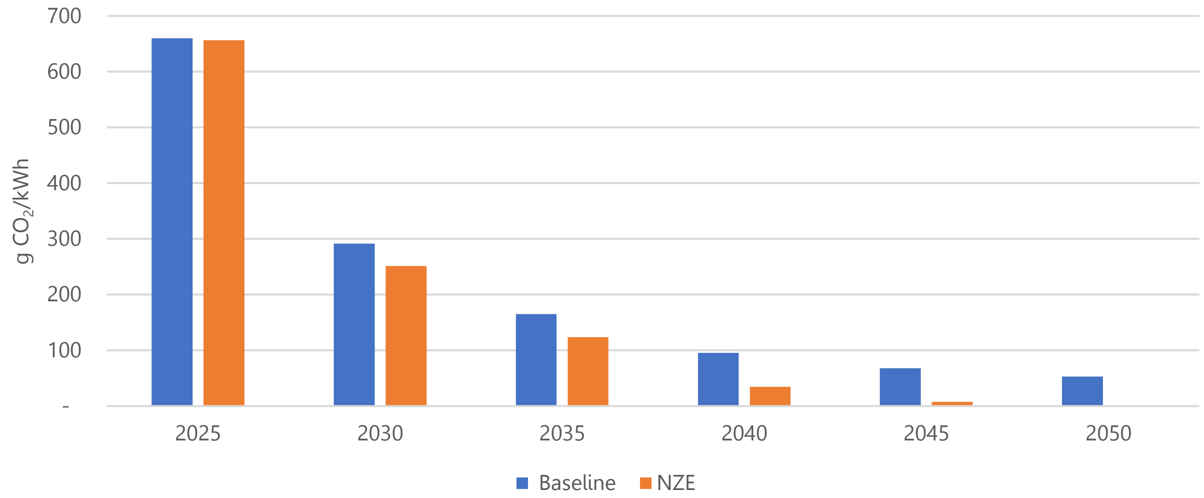


Figure 8: CO_2 intensity of produced power in the two scenarios.

In addition to the generation capacity expansion, there is increased investment in battery capacity, particularly in Sumbawa, to complement the growth of solar power. The synergy between solar capacity and storage, coupled with declining storage costs, enhances flexibility. The NZE scenario, responding to higher demand, accelerates transmission capacity optimisation. Transmission infrastructure expansion becomes vital for interconnecting Bali, Lombok, and Sumbawa such that low emission generation from Sumbawa caters Lombok and flows towards the Java system via Bali which is the largest load centre in Indonesia. Notably, power flows indicate a shift towards sustainability, emphasising the role of interconnected islands in achieving a decarbonised energy system.

The operational behaviour of Nusa Tenggara Barat's power sector, analysed for the years 2023, 2035, and 2050, also reflects the significant transition driven by increased variable renewable energy (VRE) and storage utilisation. As shown in Figure 9, in 2023, dispatch mainly relies on coal, gas, and biomass. By 2035, solar, geothermal, and biomass rise, with storage playing a pivotal role, displacing coal and gas. In 2050, the NZE scenario displays predominant solar and wind dispatch, contrasting with the baseline's continued coal and gas usage.

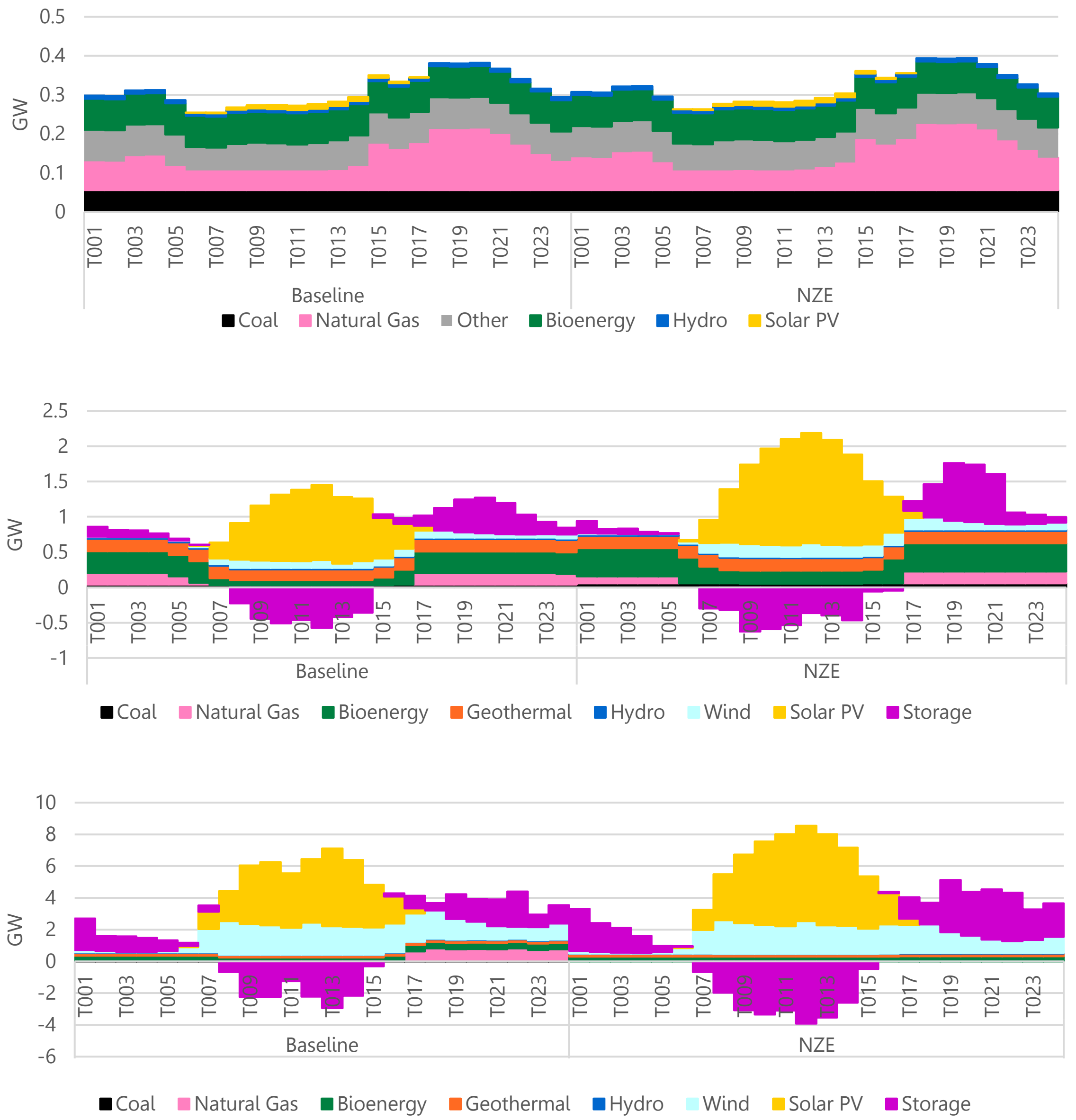


Figure 9: Dispatch in Nusa Tenggara Barat for the years 2023, 2035 and 2050.

Thermal dispatch patterns analysed highlight the role of flexibility in integrating VRE. In 2050, NZE exhibits lower and flatter thermal dispatch due to increased storage, compensating for VRE fluctuations. Importantly, flexibility ensures supply security amid increased dependence on solar generation, which can be prone to intermittent and forecasting errors. Lombok and Sumbawa's operational differences in 2050 showcase VRE's impact. Sumbawa, with abundant solar and wind, exports excess power to Lombok and Bali, balancing the system. In NZE, Lombok's storage compensates for lower VRE, especially by charging in solar peak hours and discharging in the evening where the daily peak demand is observed, emphasising flexibility's role in maintaining balance. Overall, VRE integration, coupled with dispatchable technologies and storage, transforms Nusa Tenggara Barat into a less emissive and surplus energy province. Interconnections between islands play a vital role in achieving a balanced and secure national energy system.

Lastly, the analysis also investigates electric vehicle (EV) charging behaviour, where the possibility of smart charging is considered. EV charging enhances system flexibility by moving charging demand to peak solar hours where possible, thus reducing system costs and stress. Flexible EV charging increases over time, promoting optimal energy utilisation, seen more in NZE due to higher demand.

Financial needs

Extensive investments in the power sector are required for Nusa Tenggara (NTB) to achieve the ambitious target of net-zero emissions across the energy sectors by 2050. The resulting BPP, or average generation cost, are very similar in both scenarios, as shown in Figure 10. When analysing the annual total costs, the Net Zero Emission (NZE) scenario results in higher expenses. This is mainly due to the increased capital investments required for new units, and these elevated costs persist throughout the entire study period. Additionally, fixed operation and maintenance (FO&M) expenses are notably higher in the NZE scenario. However, this needs to be taken in context of the comparatively higher demand in the NZE scenario.

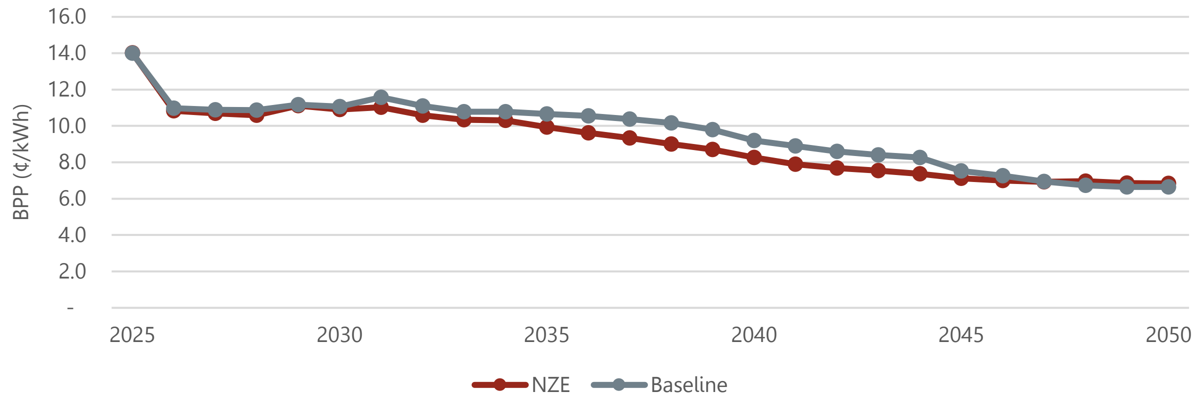


Figure 10: Costs in US cents per kWh (BPP) for the two scenarios.

It is important to note that the increased costs in the NZE scenario are partially balanced by reduced fuel expenses and potentially avoided CO_2 costs. Implementing a CO_2 cost would make the NZE scenario more economically viable; this is illustrated in Figure 11. When looking at the overall period and comparing costs between the two scenarios, the difference between the scenarios will likely expand beyond 2050, although this is beyond the scope of the current analysis.

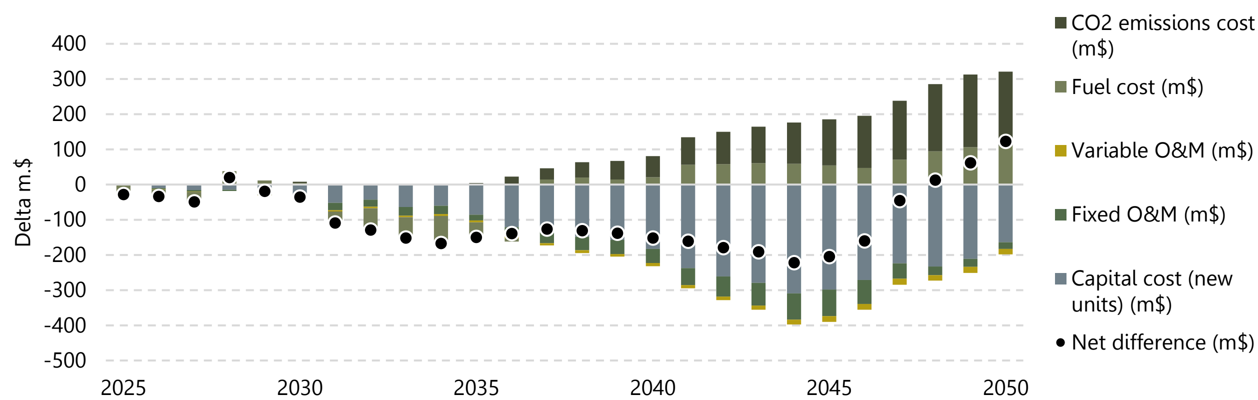


Figure 11: Overview of difference in system costs between NZE and Baseline including CO_2 costs for fossil fuels. Positive values mean lower system costs in NZE.

The analysis also provides financial feasibility for investments in wind and solar PV. The cases presented yield notably positive NPVs, underscoring their feasibility and attractiveness. However, it is essential to acknowledge that the economic analysis may be influenced by uncertainties related to the cost of capital, especially regarding local content requirements, which would require additional analysis.

Conclusions

The report provides a comprehensive analysis of the energy sector in West Nusa Tenggara (NTB) and offers policy recommendations for a sustainable and low-carbon transition of the whole energy system, through a comparative analysis of two scenarios that share a temporal resolution of up until 2050: a Baseline scenario that follows current policies and trends and an NZE scenario that adopts a pathway towards carbon neutrality across all energy sectors.

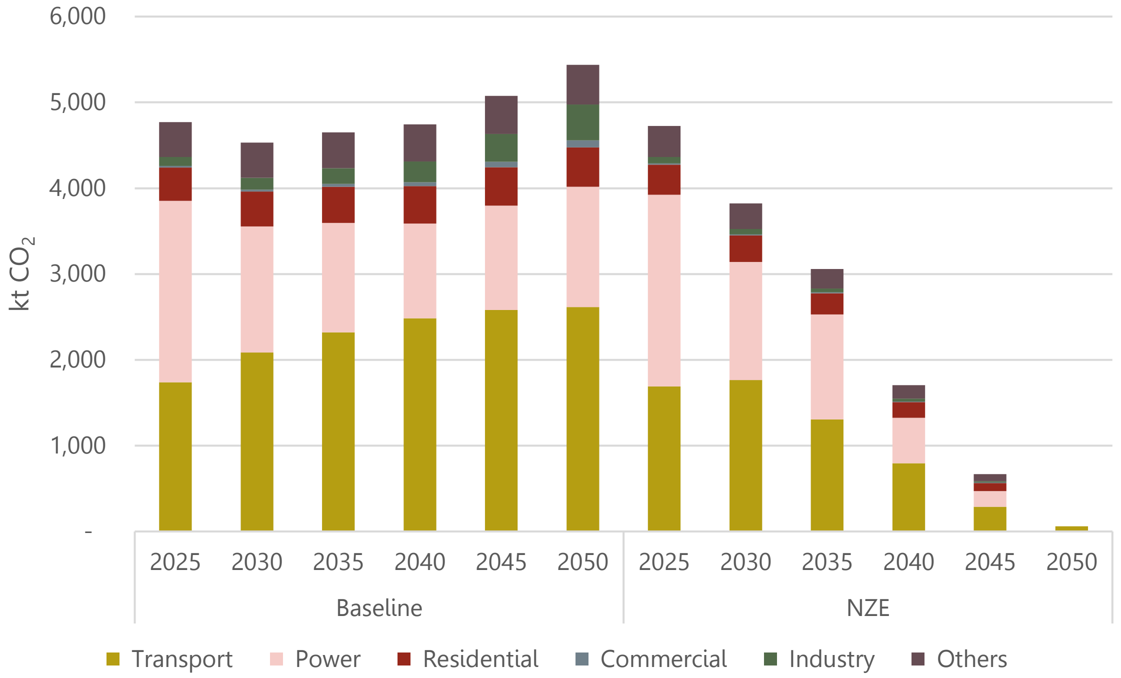


Figure 12: Overview of CO_2 emissions in the NTB energy sector in the Baseline and net-zero emissions (NZE) scenarios.

The above figure shows how total CO2 emissions from the NTB energy system develop over the years for both the scenarios. Evidently, the NZE scenario shows that it is possible to achieve the target by 2050. The key findings regarding achieving this ambitious target include:

- Electrification plays a crucial role: Electricity is the main driver of the energy transition and finds several applications across the majority of end-use types, activities, and processes. Unlocking its full potential requires the implementation of various electrification strategies in residential, commercial, industrial, and transportation sectors. This is especially relevant for the transport sector that is projected to be the highest contributor to emissions. Here EVs play a big role in decarbonisation.

- Efficiency as first fuel: Energy efficiency is equally vital in achieving a prosperous low-carbon economic development. Decoupling energy intensity and economic growth is pivotal to avoid burdening the local energy and material resources. All sectors demonstrate a great potential for reduced energy consumption with the right policies, equipment, and behavioural patterns in place.

- Alternative fuels: Fuel-switching also possesses a central role in West Nusa Tenggara's energy transformation. Indonesia is generally a country with great biomass resources and has already started shifting towards modern utilisation practices. However, due to the growing interest of different sectors towards bioenergy consumption, careful considerations are required on factors such as feedstock sourcing, land-use, and other sustainability matters.

- Going the extra mile: A combination of all aforementioned measures leads to significant decrease in CO_2 emissions. However, reaching carbon-neutrality across the whole energy system would require negative emissions and synthetic fossil-free fuels to fully decarbonise some of the hard-to-abate sectors, such as transport and industry.

- Investments and Emissions: The NZE scenario requires more investments in renewable energy sources, particularly solar and wind, to meet higher demand and CO_2 reduction targets. It achieves a complete phase-out of fossil fuels and CO_2 emissions by 2050, while the Baseline scenario still relies on some natural gas and coal generation.

- Electricity Mix Transformation: Both scenarios see a rapid shift from fossil fuels to renewables in the NTB power system. The NZE scenario achieves a 100% renewable electricity mix by 2050, while the Baseline scenario still has some fossil fuel generation.

- Importance of Storage and Transmission: Storages and electricity transmission are crucial for supporting the integration of variable renewable energy sources, especially solar and wind. The NZE scenario requires more investments in battery storage and interconnection capacity than the Baseline scenario. Additionally, the storage from BEVs also serves as demand response solution providing increased flexibility when considering smarter charging that allows operators to shift the charging load from evening peak to high solar hours in the day.

- Operational Changes: The operational aspects of the power sector change significantly in both scenarios due to the increased integration of variable renewable energy sources. Thermal dispatchable technologies, along with storage, and interconnection play an important role in providing flexibility and balancing the power system, especially on days with higher intermittency of Variable Renewable Energy (VRE).

- Similar generation costs: Despite higher system costs in the NZE scenario, the average generation costs are similar to the baseline scenario due to reduced reliance on fossil fuels, i.e., increased capital cost is partly outweighed by reduced fuel costs. The financial feasibility of the transition is assessed through Net Present Value (NPV) calculations for solar and wind projects, highlighting the positive economic viability of the NZE scenario in the context of long-term sustainable development.

- Accounting for cost of emissions: When he socio-economic cost of the effect of CO_2 emission on the society are factored in, the attractiveness of achieving of an earlier NZE target increase. Similarly, if instead of the artificially controlled DMO prices for coal and natural gas that the current system enjoys, fuel prices are set to market level, it will lead to an accelerated transition away from fossil fuels immediately in the short term.

The report concludes that achieving the NZE scenario is a feasible but challenging task. Technological advancements and significant investments in state-of-the-art equipment and machineries, as well as renewable energy, storage, and grid infrastructure are required. It also necessitates behavioural and operational changes and a shift in daily operations of the power sector.

Content

List of figures

List of tables

Nomenclature

Abbreviations

Bappeda	Regional development planning agency
Bappenas	National development planning agency
BECCS	Bioenergy carbon capture and storage
BEV	Battery electric vehicle
BLS	Baseline scenario
BPS	Central statistics bureau
BUMD	Regional owned enterprises
BUMN	State owned enterprises
CCUS	Carbon capture, utilisation, and storage
Dinas ESDM	Energy and mineral resources provincial office
Ditjen EBTKE	Directorate General of new renewable energy and energy conservation
DJK	Directorate General of Electricity
DMO	Domestic Market Obligation[1]
Kementerian ESDM	Ministry of Energy and mineral resources
LPG	Liquefied Petroleum Gas
LTV/FTV	Loan to value/Financing to value
MW	Megawatts
MWp	Megawatt peak
NTB	Nusa Tenggara Barat
NZE	Net Zero Emissions
Pertamina	State owned oil company
PLN	State owned electricity company
PPnBM	Sales tax on luxury goods
RDP	Regional development plan
RPJMD	Regional medium-term development plan
RPJMN	National medium-term development plan
RUED	Regional energy plan
RUEN	National energy plan
RUKD	Regional electricity plan
RUKN	National electricity plan
RUPTL	PLN's electricity provision plan

[1] In Indonesia, the Domestic Market Obligation (DMO) mandates that a certain percentage of coal and natural gas production must be allocated for domestic consumption before exports. This regulatory measure ensures a stable domestic supply of fuel and aims to support the country's energy security and affordability goals by prioritizing local needs over international markets and setting a price cap on the cost of fuel for domestic use.

Power plant and fuel definitions

PLTU	Coal-fired power plant
PLT(M)G	Gas engine
PLT(M)GU	Combined cycle gas turbine
PLTD	Diesel engine
PLTA	Large hydro power plant (>30 MW)
PLTM	Mini hydro power plant (1-10 MW)
PLTMH	Micro hydro power plant (< 1 MW)
PLTS	Solar photovoltaic
PLTB	Wind turbine
PLTBm	Biomass power plant
PLTP	Geothermal power plant
PLT EBT	RE-based power source
PLT EBT base	RE-based power source used as baseload

1. Introduction

West Nusa Tenggara (Nusa Tenggara Barat – NTB) is one of the 38 provinces in Indonesia. This province is in the western region of the Nusa Tenggara region in Indonesia. Situated in the Lesser Sunda Islands, NTB possesses a strategic location in the southeast part of Indonesian archipelago and covers a land area of approximately 20,150 square kilometres. The province has two municipalities and eight regencies. It consists of several islands, with the two largest ones being Lombok and Sumbawa, the capital is Mataram City. Even though Sumbawa-Bima occupies 78% of total land area, the population density in this area is quite low. The province has 5,389,998 inhabitants with a population density of 255 people per sq.km and 1,499,563 households. The most normal energy sources for cooking are gas/LPG, kerosene, and firewood.

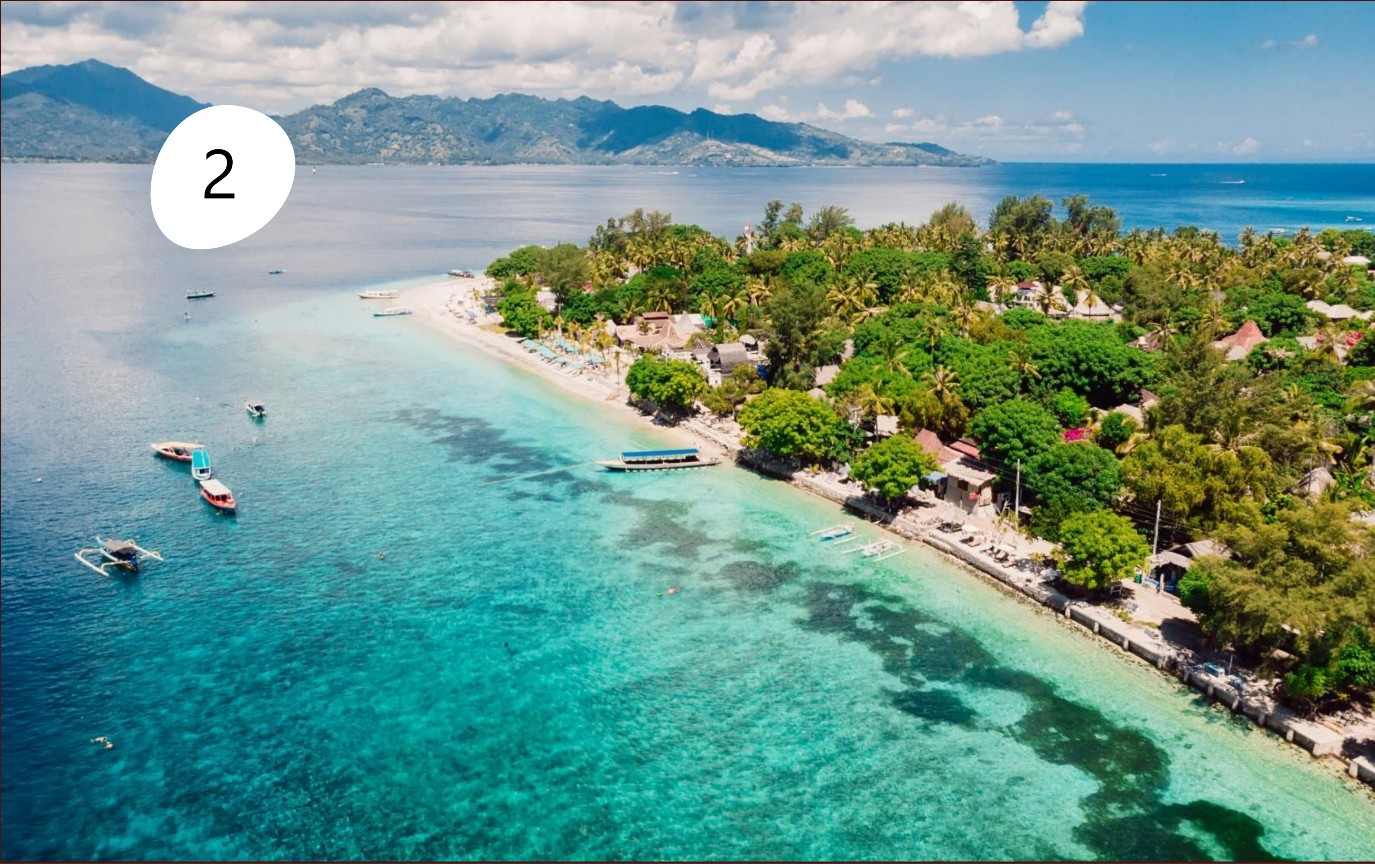
West Nusa Tenggara is in tropical climate and has a mean annual temperature of 27-degree °C. The province has relatively little rainfall compared to the western region of Indonesia. It entails 44 hospitals and 784 Polyclinics and Public Health Centres. West Nusa Tenggara has 4913 schools with 882.353 students enrolled (from primary to high school). Finally, there is one public university and 54 private universities.

Based on BPS statistics of 2022, Gross Regional Domestic Product totalled at IDR 95,437 billion. The agriculture, forestry, and fisheries sectors have the highest contribution to the GDP, while the tourism sector and the mining, energy, and electrical sectors have the highest investment realisation in the region. Lombok has recently become a popular tourist destination of West Nusa Tenggara, known for its stunning beaches, diverse landscapes, and cultural attractions. However, it faces several environmental challenges, particularly the increasing amount of municipal solid waste.

Both the electricity generation and transportation sectors in West Nusa Tenggara are heavily dependent on fossil fuels. Since the region doesn't have any significant resources, it relies on imports to fulfil its provincial fossil fuel demand. Consequently, energy security is vulnerable. The electricity sector is provided by the Lombok grid system and the Sumbawa-Bima grid system, or the so-called Tambora grid system. PT. Perusahaan Listrik Negara (PLN), a state-owned electricity company, has an exclusive right for electricity transmission, distribution, and retailing in the area. However, in electricity generation, private entities have a small proportion of electricity provision in the area. These private entities are known as Independent Power Producers (IPPs).

Despite the high dependency on fossil fuels, greenhouse gas emissions in the region mainly come from the forestry sector, followed by the energy sector, with electricity generation and transportation being the largest sources. The electricity consumption is 2,290 GWh as of 2021 and the electrification rate is 99.98%.

Figure 13 The map of West Nusa Tenggara



2. Current conditions (Energy profiles of West Nusa Tenggara)

2.1 Electricity sector

The electric power system in West Nusa Tenggara province consists of the Lombok 150 kV system and the Tambora (Sumbawa-Bima) 70 kV and 150 kV systems, as well as several small isolated systems. Sumbawa and Bima are used to a separate grid, however since 2021 they were merged into the Tambora grid system. Large electric power systems are supplied with power via different sources, such as PLTU, PLTMG, PLTD and PLTM/PLTMH. Meanwhile, medium-size and small-size systems are mostly supplied by PLTD or Hybrid PV-PLTD, with a small part also using PLTMH to meet their electricity demand.

These grid systems are:

- The 150 kV Lombok system which stretches from Mataram to East Lombok then to Tanjung that supplies Mataram City, West Lombok Regency, Central Lombok Regency, East Lombok Regency and North Lombok Regency.

- The 70 kV and 150 kV systems, consisting of: Tambora system connecting Labuhan (Sumbawa) to Dompu (Bima).
  - The 70 kV Sumbawa system covers West Sumbawa Regency (Taliwang to Alas/Tano) and the 20 kV system supplies Sumbawa Besar City.
  - The 150 kV system that connects the Sumbawa system and Bima system.
  - The 70 kV Bima system covers Bima City, Bima Regency and Dompu Regency.

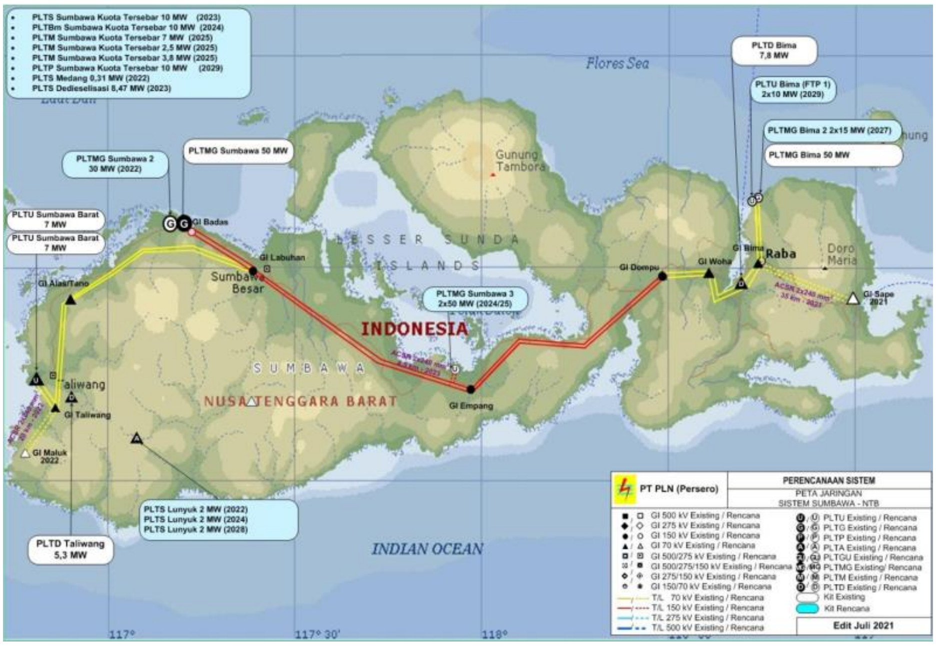


Figure 14 Map of Tambora grid system (Source: RUPTL 2021-2030).

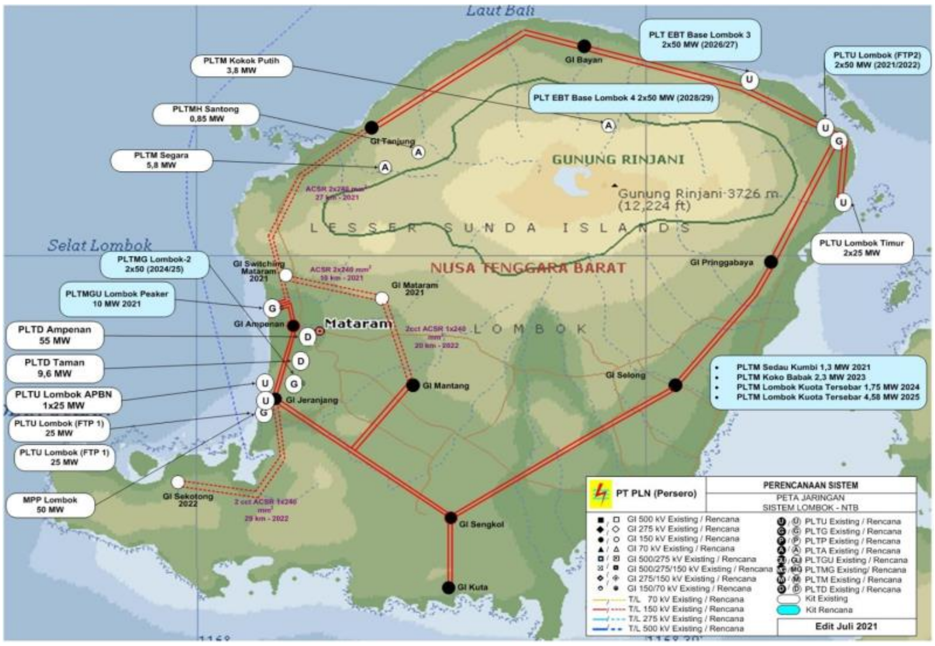


Figure 15 Map of Lombok grid system.

Meanwhile, small isolated systems are found on inhabited small islands scattered throughout the region. These small islands have their own generators and are either connected to the load via a 20 kV grid or directly to the 220 V grid (low voltage). The grid system on the three islands Gili Terawangan, Gili Meno, and Gili Air, is connected to a 20 kV submarine cable to the mainland Lombok system and has been operating since 2012.

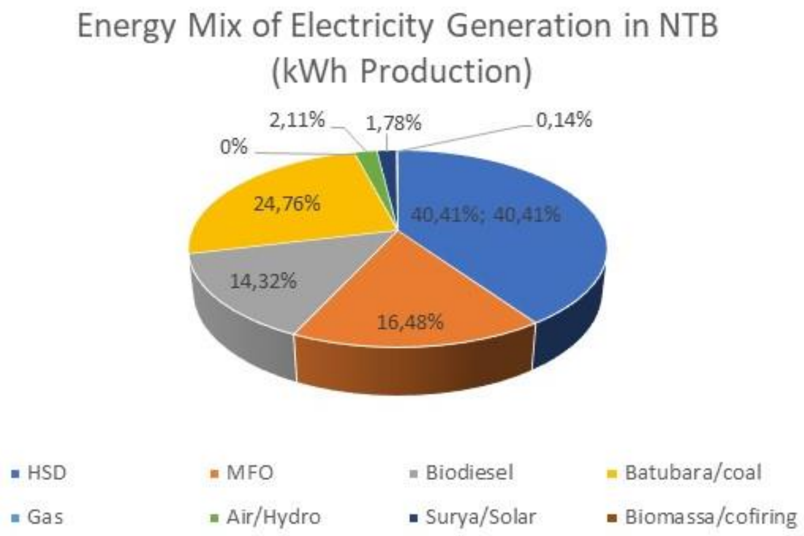


Figure 16 Energy mix for electricity generation in NTB.

Electricity generation is dominated by the use of diesel oil, both HSD and MFO, although this is declining via the use of B35 biodiesel. Likewise, coal is gradually starting to be replaced by biomass through co-firing. Apart from that, small amounts of electricity are also produced from solar energy and hydro power.

2.2 Development of electric power system infrastructure

The economic conditions in West Nusa Tenggara province are quite good in the agricultural sector, mining sector, trade sector, hotels, and restaurants as well as the service sector, which contributes greatly to the GRDP of NTB Province. In accordance with its promising natural potential, the island of Lombok will be developed into an international tourist destination besides Bali. In South Lombok, a Special Economic Zone (SEZ) has been established for tourism, namely the Mandalika KEK. Thus, it is hoped that the NTB economy will grow even better in the future and electricity demand will also grow rapidly.

Based on historical business data, economic growth trends, population growth and an increase in the electrification ratio in the future, the projected electricity demand for 2021-2030 can be seen as follows:

Table 2 Projection of electricity sales (GWh). Source: RUPTL, 2021-2030.

Nr	Customer Type	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1	Household	1,589	1,746	1,913	2,093	2,284	2,487	2,701	2,927	3,165	3,414
2	Business	387	406	437	483	519	559	592	634	685	727
3	Public	196	208	220	233	247	261	275	289	304	318
4	Industry	173	203	211	219	227	238	250	263	274	285
	Total		2,563	2,784	3,028	3,277	3,544	3,818	4,114	4,428	4,745
	Growth %		9.2	8.6	8.8	8.2	8.2	7.7	7.7	7.6	7.2

West Nusa Tenggara has diverse primary energy potential. Geothermal energy is found in three locations, namely Sembalun, East Lombok, Maronge, Sumbawa and Hu'u, Dompu. In addition, there is the potential for hydroelectric power. It is also planned to develop PLTS, PLT Biomass and PLT Hybrid (PLTD+PLTS) to serve isolated areas in the hope of reducing the Basic Cost of Generation (BPP).

There is potential for ocean current energy in the Lombok Strait, Alas Strait and Sape Island, Ocean Thermal Energy Conversion (OTEC) in North Lombok and potential for ocean wave energy in Lombok and Sumbawa, which can be developed with a potential ranging from 10-50 MW but requires further study. Apart from that, along with the development of technological advances in producing electricity, studies will be carried out on the development of alternative technologies such as hydrogen (fuel cells) with energy storage to improve the quality of electricity services, with the hope of reducing BPP, especially in isolated areas.

It is hoped that utilising the potential of new renewable energy can increase the new renewable energy mix. It will be prioritised for entry into the system if it meets the requirements, including the Feasibility Study (FS) document, selling price based on applicable regulations, funding readiness and grid interconnection studies (Grid Study).

To reduce coal-fired power generation, the PLTU, which is still in the planning stage, will be replaced with a PLTMG. In NTB Province there are two PLTUs that will be replaced with PLTMG or PLTGU, namely PLTU Lombok-2 2x50 MW and PLTU Sumbawa-2 2x50 MW. For this PLTMG location, further studies are needed both system wise, on gas supply plans, and infrastructure studies.

Table 3 Electric power system development plan. Source: RUPTL, 2021-2030.

Nr	System	Type	Name of project	Capacity (MW)	COD	Status	Developer
1	Lombok	PLTMGU	Lombok peaker	10	2021	Operational	PLN
2	Lombok	PLTM	Sedau Kumbi	1.3	2021	Operational	IPP
3	Lombok	PLTU	Lombok (FTP-2)	2x50	2021/22	Under con-struction	PLN
4	*Isolated*	PLTS	Lunyuk (Kuota Tersebar)	2	2022	Plan	PLN
5	*Isolated*	PLTS	Medang	0.3	2022	Operational	PLN
6	*Isolated*	PLTS	Dedieselisasi	8.4	2023	Plan	IPP
7	Sumbawa	PLTMG	Sumbawa-2	30	2022	Bidding	PLN
8	Lombok	PLTM	Kokok Babak	2.3	2023	Under con-struction	IPP
9	Sumbawa	PLTS	Sumbawa-Bima (Kuota Tersebar)	10	2023	Plan	IPP
10	Lombok	PLTM	Lombok (Kuota Tersebar)	1.75	2024	Plan	IPP
11	*Isolated*	PLTS	Lunyuk (Kuota Tersebar)	2	2024	Plan	PLN
12	Sumbawa	PLTBm	Sumbawa-Bima (Kuota Tersebar)	10	2024	Plan	IPP
13	Lombok	PLTM	Lombok (Kuota Tersebar)	4.58	2025	Plan	IPP
14	Sumbawa	PLTM	Sumbawa-Bima (Kuota Tersebar)	2.54	2025	Plan	IPP
15	Sumbawa	PLTM	Sumbawa-Bima (Kuota Tersebar)	7	2025	Plan	IPP
16	Sumbawa	PLTM	Sumbawa-Bima (Kuota Tersebar)	3.84	2025	Plan	IPP
17	Sumbawa	PLTMG	Bima-2	2x15	2027	Plan	PLN
18	*Isolated*	PLTS	Lunyuk (Kuota Tersebar)	2	2028	Plan	PLN
19	Sumbawa	PLTU	Bima (FTP-1)	2x10	2029	Under con-struction	PLN
20	Sumbawa	PLTP	Sumbawa-Bima (Kuota Tersebar)	10	2029	Plan	PLN
21	Lombok	PLTMG	Lombok 2	2x50	2024/25	Plan	PLN
22	Sumbawa	PLTMG	Sumbawa 3	2x50	2024/25	Plan	PLN
23	Lombok	PLT EBT *Base*	Lombok 3	2x50	2026/27	Plan	PLN
24	Lombok	PLT EBT *Base*	Lombok 4	2x50	2028/29	Plan	PLN

2.3 Residential sector

For the greater part, fuel consumption for cooking in West Nusa Tenggara is dominated by the use of Liquified Petroleum Gas (LPG). LPG 3 kg is intended for the poor and small households, while LPG in 5.5 kg, 12 kg and 50 kg cylinders are for the upper middle class. Based on data from the Ministry of Energy and Mineral Resources, in 2022, LPG consumption in West Nusa Tenggara reached 129,055 Mt. A small remainder in rural areas, around 3% of the total population, still uses traditional firewood for cooking. In several places, the government, by sharing budgets with a non-government organisation called HIVOS, since 2012, has encouraged the use of household scale biogas digesters, with feedstock coming from manure and organic waste. The number of biogas digesters built are more than 6,000 units.

Kerosene is also still used in small quantities for cooking, but the number of residents who use kerosene keeps decreasing. Since the elimination of subsidised kerosene in 2009 for Lombok Island and in 2020 for Sumbawa Island, the kerosene in sale is non-subsidised at industrial prices. Therefore, people prefer LPG 3 kg since it is cheaper, and the packaging is easy to carry. In order to prevent the misuse of subsidised LPG 3kg, especially by the the upper middle class, starting in October 2023, Pertamina has carried out data collection on purchases of LPG 3kg using personal identity cards. Only poor people have the right to buy these commodities at subsidised prices.

PLN is also promoting the use of electricity for cooking. The use of induction/electric stoves for cooking is expected to absorb PLN's electricity production surplus.

2.4 Commercial sector

The West Nusa Tenggara tourism sector has great potential with its traditions, arts and culture, history and potential folk crafts, and many and diverse destinations, starting from the Mandalika Special Economic Zone (KEK), Saleh Bay area, Moyo and Tambora (Samota) Islands, Mount Rinjani Geopark, and Senggigi Beach.

Tourism development has a significant contribution to economic development, increasing community welfare and regional income. The performance of tourism development is demonstrated by an increase in tourists, both foreign and domestic.

The number of tourist visits in the last three years has increased, with the increase rate in 2022 recorded to rise by 42.76% from 2021. In addition, 2022 will be the first time for West Nusa Tenggara province to hold a world class MotoGP event at Pertamina Mandalika International Street Circuit. The target for tourist visits in 2022 is set at 2,000,000, which is an increase of 100% from the previous target in 2021. It is hoped that this will have a positive impact on tourism development.

Even though the increase in the number of tourist visits during the MotoGP events is seasonal, tourism conditions on the island of Lombok are starting to show a definite, though relatively slow, recovery trend. It can also be seen from the average length of stay of tourists, which was 1.88 days in 2020, 2.23 days in 2021, and 2.31 days in 2022. The increase in the average length of stay of tourists indicates a tendency of tourists enjoying the tourism potential owned by West Nusa Tenggara Province. By the end of 2022, the average hotel occupancy rate in West Nusa Tenggara exceeded 65%.

In the trade sector, the improving trend was influenced by increased household consumption. However, this cannot be separated from the various incentives provided by the government until the third quarter of 2022. Some of the incentives provided include the extension of the provision of PPnBM (sales tax on luxury goods) discounts with a 2% scheme in July-September, as well as the easing of the LTV/FTV (Loan to Value/Financing to Value) policy, which is extended throughout 2022 and is expected to continue to have a positive impact on public consumption, especially vehicles (cars and motorcycles). Meanwhile, for other trade commodities, people are still holding back from buying, because the prices of several commodities have increased or are not yet normal after the pandemic or are influenced by geopolitical conflicts.

2.5. Industrial sector

The West Nusa Tenggara provincial government has made industrialisation a regional priority program. The types of industry that are encouraged are food and beverages, agro industry such as eucalyptus oil refining, the Muslim clothing industry, and processing of livestock products. Apart from that, local workshops are supported as well to produce electric vehicles such as electric bicycles, which are even exported abroad.

The development of West Nusa Tenggara's formal industry from 2018-2022 resulted in a growth of an average of 38.6% per year, while the non-formal industry experienced an average annual growth of 4%. The number of industries decreased from 2018 to 2019, from 9,185 industries to 8,234, a decrease of 951 industries. This was due to the condition of the area, which experienced an earthquake, but in the following years the industry continued to grow because of the policy taken by the government through the social assistance program called “JPS Gemilang” that requires the use of local products.

2.6 Transportation sector

The fuel demand is exclusively provided by PT. Pertamina - state owned oil company that is the official distributor of fuels. There are three types of fuels consumed in the region in the transportation sector, namely RON 88 (Premium Gasoline), RON 90 (Pertalite), and Diesel. RON 88 means that 88% of the contents are octane, while RON 90 means that 90% of the contents are octane. The higher the octane number, the higher the oil ability to fight auto-ignition. The consumption of fuel in the region is dominated by gasoline, particularly RON 90 (Pertalite) which is subsidised by the government. RON 90 (Pertalite) is currently replacing RON 88 (Premium); however, RON 88 (Premium) is still available in limited amounts. Diesel is commonly used for trucks and heavy industry vehicles. The trademark of government-subsidised diesel is biodiesel (B35), where around 35 percent of the content is blended with vegetable oil or palm oil.

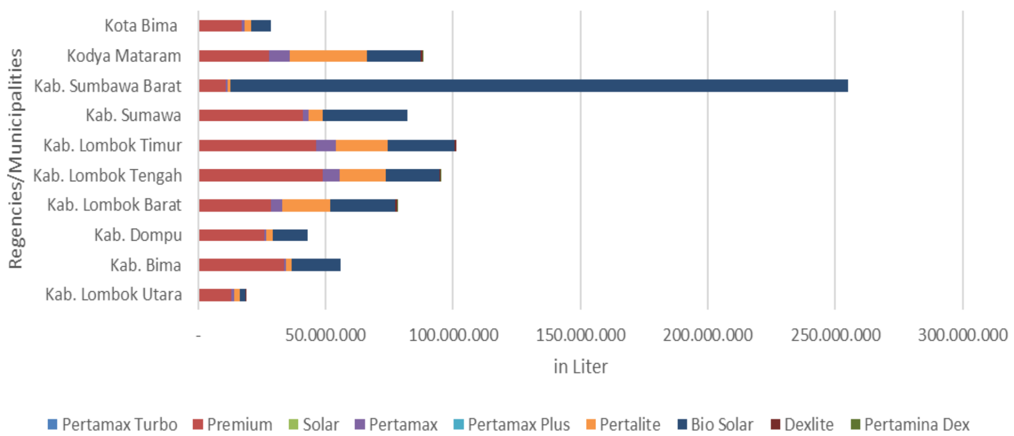


Figure 17 Fuel consumption in West Nusa Tenggara in 2020. Source: Pertamina, 2021.

While the subsidies are meant to financially support low to middle-class citizens, the lack of government regulation means above middle-class citizens can also purchase the subsidised fuel. The government is now trying to limit the use of subsidised fuel, by implementing official registration of vehicle numbers and types through the “My Pertamina” application.

This fuel demand is supplied from three depots, namely the Ampenan Depo in Lombok, the Labuhan Badas Depo in Sumbawa and the Bima Depo in Bima. The next supply chain for the transportation sector is the gas station, which is usually called the SPBU (Stasiun Pengisian Bahan Bakar untuk Umum/public gas station). Remote areas and small inhabited islands also have mini gas stations with limited supply quotas of fuel, yet the price is kept the same.

The government together with PLN are working to raise public interest in switching to electric vehicles. For this reason, the government provides a subsidy of 7 million rupiah for new purchases and conversions of conventional motorbikes with internal combustion engine to electric motorbikes. In West Nusa Tenggara, PLN has also built dozens of electric charging stations for electric vehicles spread throughout this region.

2.7 Others (mining, agriculture and construction)

Looking at the geography of West Nusa Tenggara and most of the local population being farmers, the agricultural sector is a very strategic sector in the economic structure of this region. Along with the development of the economy, which aims towards an era of high industrialisation and tourism expansion, the agricultural sector possesses an important role in materialising the targeted growth.

The agricultural sector consists of three subsectors: food crops, horticultural crops, and plantation crops. Strategic food crop commodities, such as rice, corn, and soybeans, have a main role in meeting domestic food, animal feed, and industrial annual demands, which tend to increase along with population growth and the development of the food and animal feed industry.

For mining, there are three large companies operating in NTB, namely PT. Amman Mineral Nusa Tenggara in West Sumbawa (used to called PT. Newmont Nusa Tenggara), PT. Sumbawa Juta Raya in Sumbawa and PT. Sumbawa Timur Mining in Dompu. All large mining companies are operating in Sumbawa Island. However, of the three companies, only PT. Amman Mineral Nusa Tenggara has entered operational stage, with the types of minerals mined being gold and copper. Meanwhile, the other two companies are still in the exploration stage.

The cumulative total exports of NTB Province in 2015 were 827,652 tonnes, followed by a steep and continuous decline until 2019, when exports reached only 143,668 tonnes, as a result of a decline in exports of non-oil and gas mining/excavated goods by 80.28 percent and other commodities by 97.67 percent. This trend occurred during the transition of management from PT. Newmont Nusa Tenggara to PT. Amman Mineral Nusa Tenggara. Due to mandatory existing regulations, PT. Newmont Nusa Tenggara had to release 51% of its shares to a domestic mining company, resulting in an acquisition by PT. Amman Mineral Nusa Tenggara. However, from 2020 to 2022, total exports of West Nusa Tenggara increased by roughly 155%, totalling 379,610 tons and 966,355 tons in 2020 and 2022, respectively. Mining is by far the most prevailing one, occupying a percentage share above 90% of West Nusa Tenggara exports.

Currently, the government, through the Ministry of Industry, is focused and consistent in continuing the implementation of industrial downstream policies to increase the added value of raw materials. It is hoped that this policy will open up investment opportunities, absorb a large number of local workers, and increase state revenues from exports of value-added materials that are produced domestically. In the end it is expected to boost national economic growth.

The construction of a smelter by PT. Amman Mineral Nusa Tenggara in West Sumbawa is planned to be completed in 2024, with a capacity to process 900,000 tons of copper concentrate that will absorb approximately 1,500 local workers.

2.8 Challenges going forward

The isolated power systems of Lombok and Tambora face several challenges today and in its next future development. These challenges have been identified in a dialogue with both PLN NTB, NGOs such as ICLEI, Penabulu and Energy and Mineral Resources Provincial Office of West Nusa Tenggara, as well as based on a broader stakeholder discussion.

1. Affordable power supply to the islands

In order to provide cheap electricity to the inhabitants of the islands, actions need to be taken to reduce the high average generation cost (BPP). Among the potential measures to achieve a lower cost of electricity, the two most frequently mentioned solutions are:

- Reduction of fuel oil in the mix: the plan is to reduce the supply from diesel, mainly in order to reduce the supply cost, but also to limit pollutants in the mix and to reduce national import dependency. The 150 MW gas peaker is a step in this direction and it is expected to almost entirely offset the generation from diesel in the main grid system.
- Interconnection to Java: the interconnection of Lombok and Tambora systems to Java-Bali through a marine cable to Bali has been a topic of discussion. This would allow lowering the retail price and might support further integration of RE as well as improve grid stability. The project comes however with challenges which include high investment costs and deploying the cable in the deep strait which also has strong currents and occasional earthquakes.

2. Uncertain supply of gas and coal

Based on the projections from RUPTL, the grid system of Lombok and Tambora will rely largely on natural gas and coal. Unlike other locations in Indonesia, West Nusa Tenggara does not have access to natural gas directly from the fields through a gas pipeline. For the new Lombok Peaker power plant, the gas is to be supplied in the form of CNG obtained from the gas supplier in Gresik (East Java). The gas is first compressed in Gresik's facilities, then transported to Lombok using a CNG vessel and finally decompressed in a local facility close to the power plant, located in the Tanjung Karang area, close to Mataram city.

The CNG vessel, transporting the gas to Lombok, is the first-of-its-kind in the world, and will have the capacity to transport as many as 23 mmscf per trip (21.6 BBTU per trip). The total supply available from compression facility of Gresik should be around 40 mmscfd (41 BBTU/day) and only part of this will be supplied to Lombok. The vessel takes 4 days to load, reach Lombok and unload. The daily supply to Lombok is therefore limited to around 5.4 BBTU/d and it is not clear whether it would be possible to expand this in the next future. The maximum daily supply of CNG using the vessel corresponds to roughly 6 hours of operation at full load for the 150 MW power plant.

Four additional power plants are also supposed to be fuelled with natural gas, in this case in the form of LNG: the existing MPP Power plant (50 MW) close to Mataram, the upcoming PLTMG (50 MW) in Sambelia, the existing PLTMG (50 MW) in Sumbawa and another existing PLTMG (50 MW) in Bima, which are currently fuelled with HSD. The original project is expecting mini LNG regassification facilities to be built on site, but no action has been taken so far and the government seems to be evaluating the actual increase in the power demand before investing in new LNG facilities.

As for the coal supply to the islands, it is affected by two sources of uncertainty: price and supply. Through the domestic market obligation (DMO)[2] the Indonesian government forces local coal miners to supply part of their coal production to the domestic market, specifically to coal-fired power plants

[2] In Indonesia, the Domestic Market Obligation (DMO) mandates that a certain percentage of coal and natural gas production must be allocated for domestic consumption before exports. This regulatory measure ensures a stable domestic supply of fuel and aims to support the country's energy security and affordability goals by prioritizing local needs over international markets and setting a price cap on the cost of fuel for domestic use.

as there is a real need for an increase in the nation's power supply. The price of coal for PLN, through the DMO quotas, is capped at 70 $/ton for high grade coal and 43 $/ton for lower grade coal.

Moreover, the amount of coal output from mines is capped nationally to maintain the internal supply stable in the future and West Nusa Tenggara is assigned a certain quota of this total national output. It is uncertain how this cap will evolve in the future and whether West Nusa Tenggara can increase the coal use indefinitely in the future years.

3. Long commissioning process and difficulties with land acquisition

   PLN and Dinas ESDM have stated that long commissioning process for power plant development and buildout is one of the key factors limiting the local capacity expansion. It has for example taken 7 years to receive the final approval of for 50 MW coal power plant on the island.

   Several elements contribute to the slowing down of project development, with the land acquisition process being one of the major barriers. Contributing to the difficulties of the land acquisition is the importance of agriculture which is the major GDP contributor to the island economy, the heritage value of land for farmers, as well as the lack of clarity regarding the ownerships of some lands, due to the lack of clear documentation.

4. Technical challenges for integration of more RE in the system

   As mentioned earlier, the Lombok and Tambora grid systems are non-interconnected systems, with a relatively weak electrical grid, posing challenges to the development of VRE projects. Concerns regarding voltage and frequency stability problems at the distribution grid level as a result of increased solar and wind penetration were the main reasons for limiting the installed capacity of the new solar power plants in Lombok to 5 MW each. This applies as well to the planned solar power plants 2x5 MWp in Sumbawa and Bima which are going to bid soon. Reluctance due to intermittency issues also affects the progress of wind energy development in the southern part of Lombok.

   Another barrier to a larger RE penetration in the grid is the current dispatch mechanism. The power dispatch is organized with a day-ahead scheduling followed by a manual power plant dispatch via radio. In case the power from a certain plant has to increase, the control centre contacts the power plant via radio to request an increase in the power output. This communication channel is very fast to e.g. cover the fluctuation of solar power in the grid.

   Moreover, the dispatch is conducted without deploying any forecasting system. Currently, the solar power plants in the system are scheduled the day-ahead using the full rated capacity and the difference between the scheduled rated capacity (5 MW) and the actual generation (e.g. 3 MW) is to be covered by diesel power plant running as spinning reserve. With this mechanism and the lack of forecasting, the backup needed for RE is 1:1, i.e. for each 1 MW of VRES installed there is a need of 1 MW of reserve.

   Another aspect that constitutes a reason for concern and which could be exacerbated by higher solar generation is the ramping of the load at night.

   Due to these and other reasons, for example the preference for not ramping down baseload generation, the limit to VRES penetration is indicatively set in Lombok to 20% of the hourly power demand, for every hour of the year. This is a major barrier for additional fluctuating RE in the system of Lombok, as well as other regional systems in Indonesia.

5. Post COVID-19 uncertain economic condition

   When the COVID-19 pandemic hit, many hotels, restaurants, and places selling souvenirs closed so that electricity energy sold by PLN decreased.

   After the COVID-19 pandemic, it turns out that the local and global economy will take longer to recover. Even though tourism activities have started to become busy and revived, since the government has been initiated various international events to attract visitors, such as Moto GP, WSBK and MXGP, however they are still seasonal, so not much of PLN's electricity has been absorbed as in post-pandemic conditions.

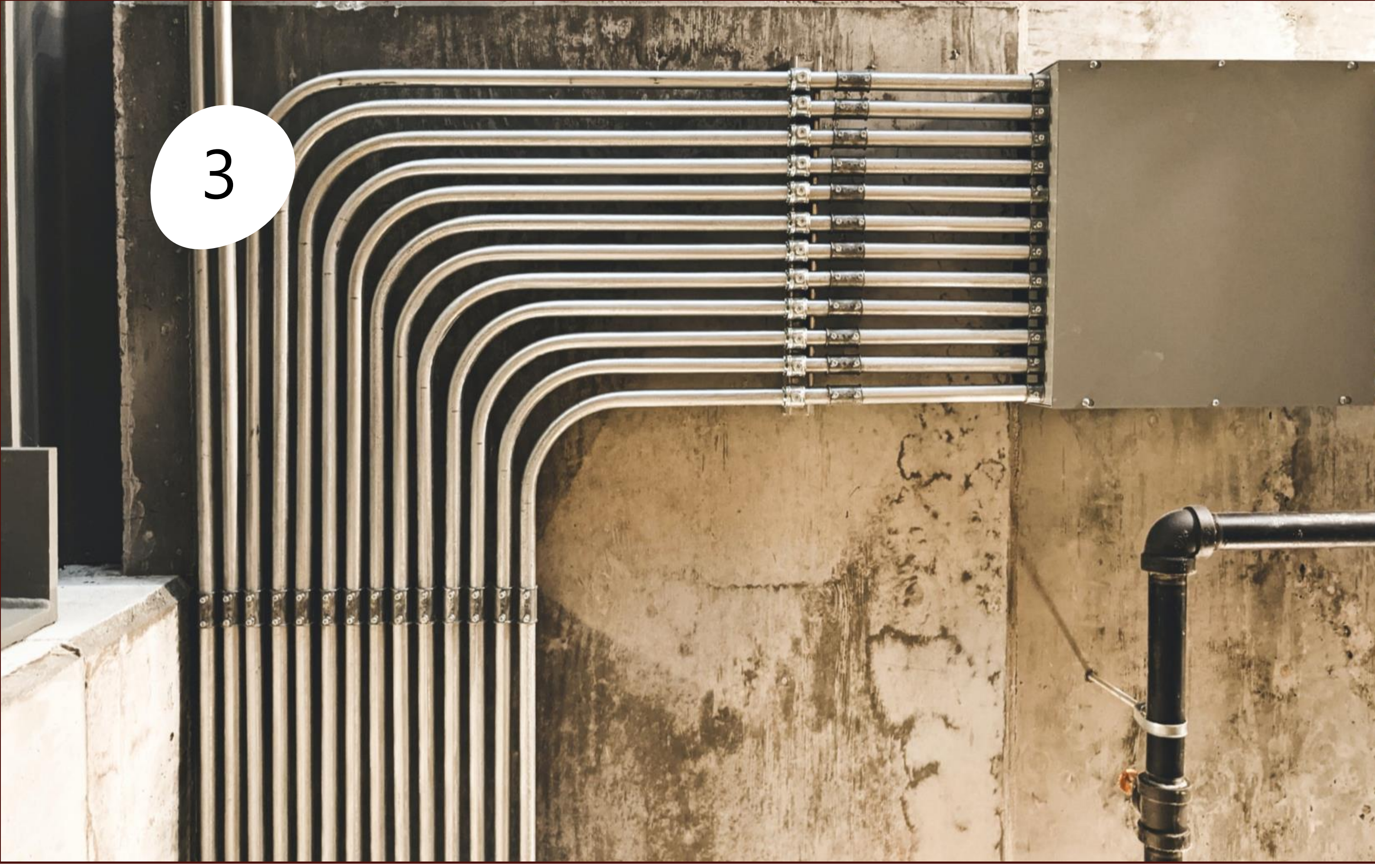
6. Slow progress of cofiring PLTU project

   The PLTU cofiring project requires a stable and large supply of feedstock, because the price is still considered unattractive because the calculation is still based on the DMO coal price multiplied by 80%, so not many local people are interested in becoming suppliers and getting economic benefits from this government program.

   Nowadays, cofiring is being carried out at 2 PLTUs, namely PLTU Jeranjang with installed capacity of 3x25 MW and PLTU Kertasari with installed capacity of 2x7 MW. The percentage of biomass mixture used ranges from 3-5%. Meanwhile, the types of biomass used as feedstock include corncob, rice husk, woodchips and sawdust. The Governor of NTB has officially written to the Ministry of Energy and Mineral Resources to issue a ministerial regulation that regulates the selling price of biomass used in cofiring projects to make it fairer for both PLN and local communities.

7. Just and inclusive energy transition

   With the early retirement plan for coal power plants, it is feared that it will impact the welfare and occupation of local workers. Likewise with local community who depend for their income on the supply chain of gasoline or gas sold at retail. The energy transition must be carried out fairly by mitigating the negative impacts on these vulnerable groups.



3. Energy policy landscape

This chapter presents an overview of the NTB energy policy landscape. First, the national Indonesian energy policies are introduced, whereafter the provincial policies are outlined. This is followed by a description and discussion of the local content requirements, followed by the key implementation strategies and development plans for the energy sector.

3.1 Key policies in Renewable Energy sector

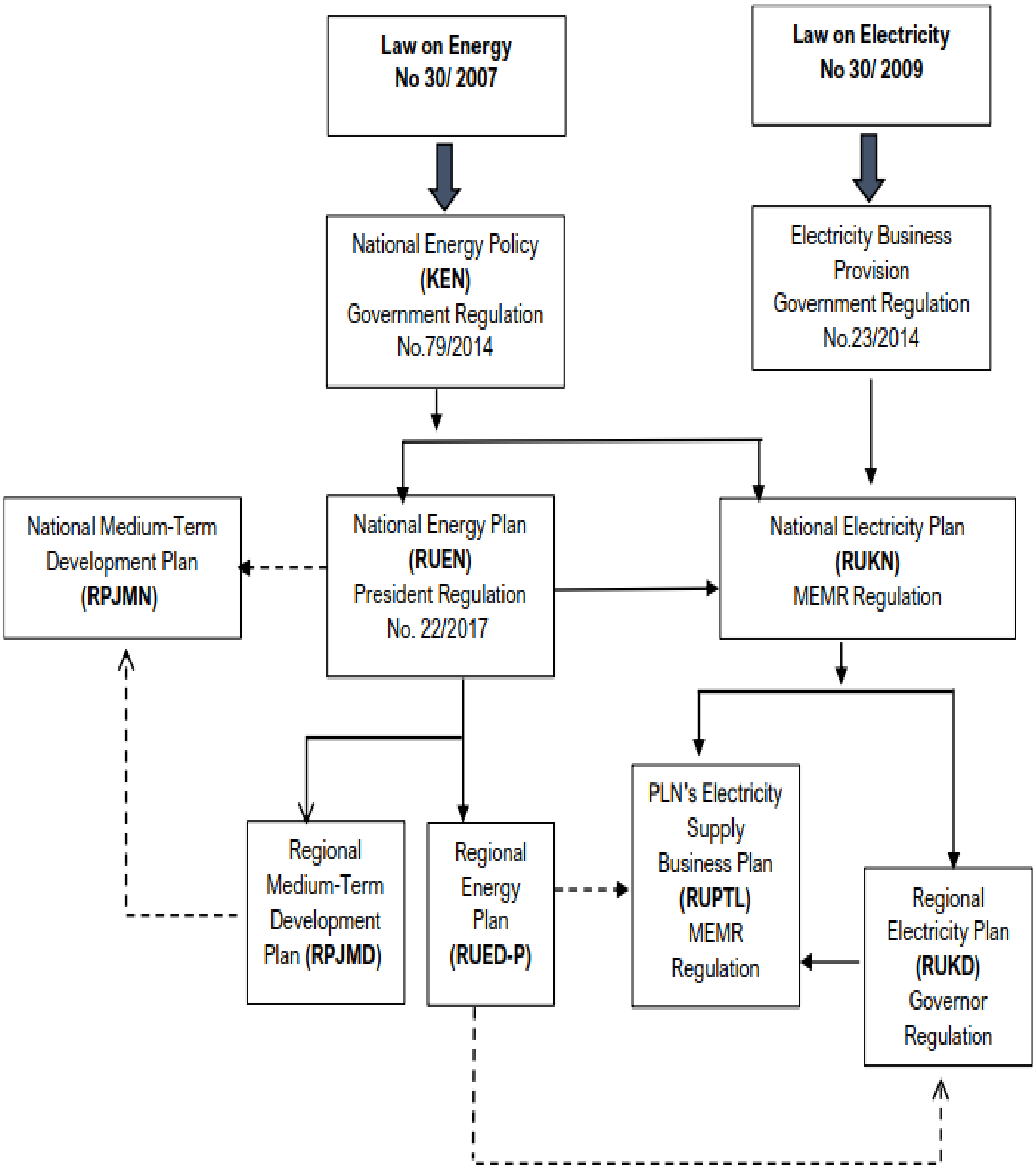


Figure 18 Energy legal framework in Indonesia. Source: ICLEI, 2019.

Table 4 Energy and electricity policies in Indonesia.

Policy	Content
Energy Law No. 30/2007	The law emphasises several priorities in the energy sector including energy independence, national energy availability, sustainable energy management, energy efficiency, and energy accessibility, especially for those residing in isolated islands/areas and having financial difficulties
Government Regulation (PP) No.79/2014 on the National Energy Policy (KEN)	The KEN is an energy roadmap of Indonesia 2010-2050 which provides general energy directions. The KEN shows that Indonesia has an optimal energy mix of (1) Renewable Energy of at least 23%, oil of less than 25%, coal of at least 30% and natural gas of at least 22% by 2025; (2) NRE of at least 31%, oil of less than 20%, coal of at least 25% and natural gas of at least 24% by 2050
PP No. 22/2017 on the National Energy Plan (RUEN)	Issued by the president, to achieve the KEN target. The RUEN is a general energy management direction in Indonesia that depicts the energy vision and status, GHG emission impact reduction, energy availability for national needs, energy development priority, energy utilisation, and energy reservation
Electricity law No. 30/2009	Passed to strengthen the 2007 Energy Law. The law emphasises the role of PLN in the electricity supply business and promotes a greater role for private enterprises, cooperatives, and self-reliant community institutions to participate in the business
PP No. 14/2012 (as amended by No.23/2014) on Electricity Business Provision	Passed to support the 2009 Electricity Law. The law states that the MEMR can determine the National Electricity Plan (RUKN) after consultation with DPR
Presidential Regulation No. 112/2022 on Acceleration of Renewable Energy Development for Electricity Supply (it replaces MEMR Regulation No. 50/2017)	After it is issued, It replaces MEMR Regulation No. 50/2017. No more feed in tariff is applied, instead it regulates price mechanism (price staging), the implementation of procurement through direct selection (auction) and the utilisation of local content requirement (TKDN)
National Electricity Plan (RUKN) 2015-2034	The development of RUKN is based on KEN and RUEN as a reference. The RUKN sets out a projection of electricity demand and supply for 20 years. It acts as a guideline in electricity generation, distribution, and transmission. It also states the electrification rate target, which must reach 100% by 2024, the electricity status per province and consumption growth, the electricity demand, and electricity investment needs
PLN's Electricity Provision Plan (RUPTL)	A 10-year electricity development plant in the operating areas of PLN. RUPTL is an important document for investors in the Indonesian electricity sector because it contains demand and supply forecast, future expansion plans, and procurement's route for IPP
MEMR Regulation No. 50/2017 (as amended by No. 4/2020) on Utilisation of Renewable Energy Sources for Power Supply	This regulation regulates the tariff regimes, project financing, and procurement model for renewable electricity generation

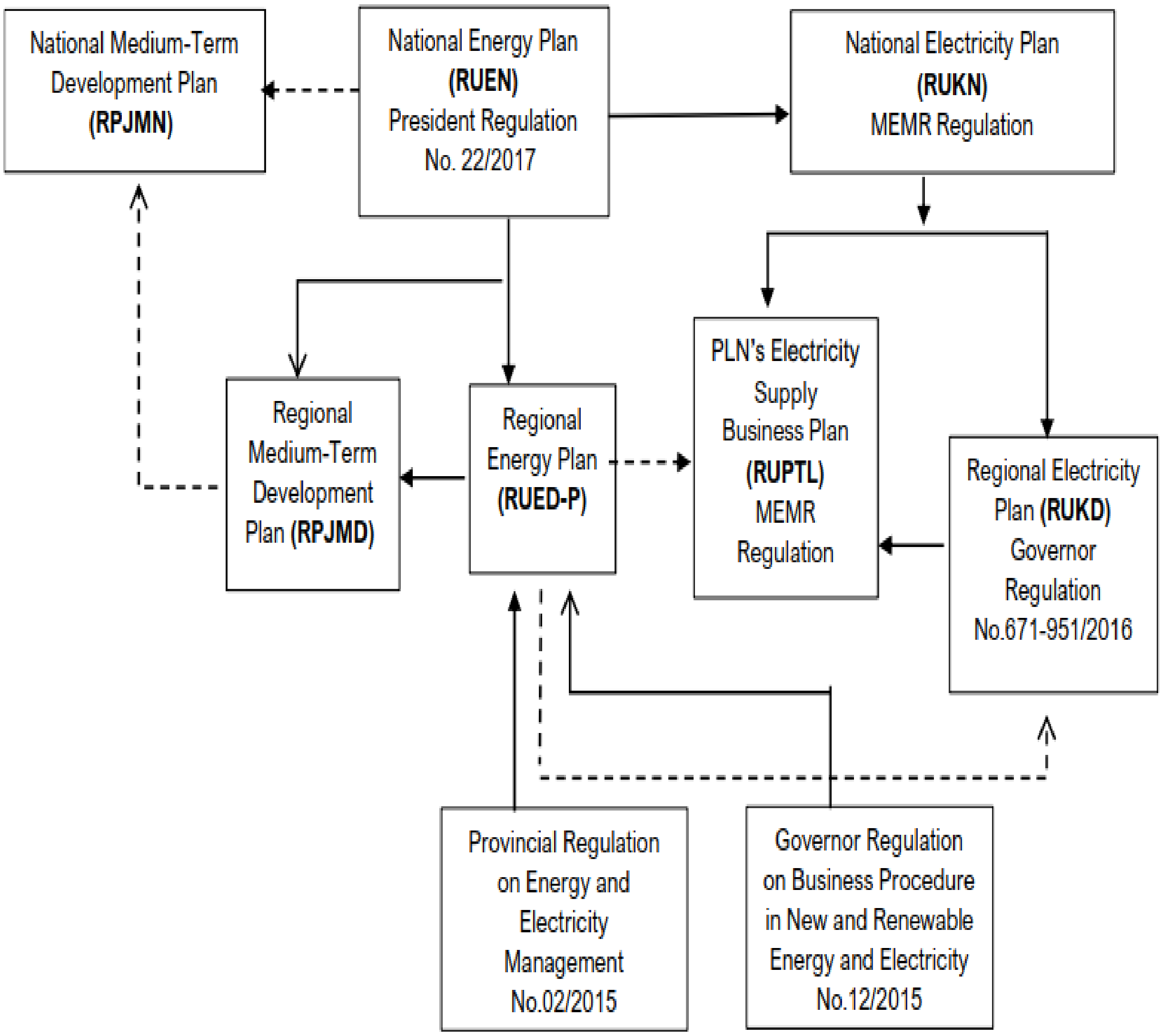


Figure 19 Energy legal framework in West Nusa Tenggara. Source: ICLEI, 2019.

Table 5 Energy and electricity policies in West Nusa Tenggara.

Policy	Content
Regional Regulation No. 3/2019 on RUED of Nusa Tenggara Barat	It sets out the provincial target on energy mix, as well as the general energy management direction in Nusa Tenggara Barat, which shows the region's energy vision and status, energy availability for regional needs, and energy development priority
Regional Regulation No.02/2015 on Energy and Electricity Management	This regulation concerns energy and electricity management in the provincial level including implementation strategies, energy conservation, tariffs and permits in general, as well as legal sanctions
Governor's Regulation No.12/2015 on Business Procedure in New and Renewable Energy and Electricity	It is issued to strengthen the implementation of Regional Regulation No.02/2015. It explains the standard operational procedures for issuing business permits in the energy and electricity sector according to the authorities of the provincial government, which are determined in Law No. 23/2014
Governor's Regulation No: 671-951/2016 on Regional Electricity Plan (RUKD)	It contains the current conditions of the regional electricity sector, supporting regulations, supply and demand projections, electrification rate target, demand growth from 2015 until 2050
Governor's Instruction No: 670/372/DEDM/2023	The governor's instructions to agencies within the Nusa Tenggara Barat Provincial Government encourages them to use electric vehicles and to support local industries related to the manufacturing of electric vehicles.
Governor's Instruction Number: 671/18/KUM/Year 2021	This instruction is calling on owners of government buildings, public facilities, and educational institutions to install rooftop PV min 20% of PLN's installed capacity

3.2 Local content requirements

Power projects in Indonesia have all been subject to local content requirements (LCRs) since 2012. Most of the technologies are obliged to fulfil 40% of local content requirement. As for the solar PV projects, it is more regulated. The requirements for solar projects were updated in 2017 and cover materials, services, and delivery. Different benchmarks are applied to all main components for solar PV projects and are defined in terms of both component value and component weight. Requirements for solar generation projects are shown in Table 6**.**

Table 6 Indonesian local content requirements for solar photovoltaic installations (Hamdi, 2019).

		MEMR Regulation No. 50 of 2017		MEMR Regulation No. 29 of 2018
		Defines the tariff for centralised solar and wind as 85% of the local cost of conventional baseload generation		Allows net metering for rooftop solar with power delivered to the grid compensated at 65% of the PLN tariff
MoI Regulation No. 5 of 2017	Local content requirements			
		Centralised on-grid solar	Centralised off-grid solar*	Stand alone off-grid solar** (including rooftop and home systems)
	% of materials***	34%	38%	40%
	% of services	100%	100%	100%
	% total value	41%	44%	46%
	% of total value was to be ratcheted up to 50% by 2018 and 60% by 2019 Additional detail provided in Ministry of Industry Regulation No 4 of 2017 that defines local content requirements by weight for each component			

The purpose of the local content requirements is to promote the domestic manufacturing industry for renewable energy generation and provide local jobs and economic development. However, these targeted benefits come with a trade-off, which is higher production costs. There is also a higher risk of delays in the supply chain in the short-term while industry is still developing, which may hinder the growth in renewable energy uptake that is needed to support Indonesia's energy transition.

Currently, renewable energy procurement in Indonesia is on small scale and intermittent. The prices paid to renewable energy actors are based on the avoided cost of thermal generation, rather than on the cost of the projects themselves. Under these circumstances, the local content requirements restrain investments since domestic producers cannot benefit from economies of scale and thus become more efficient and less costly. This counteracts the intended purpose of the local content requirement and pushes up total investment costs, making renewable energy projects unprofitable and unattractive to investors in many cases.

A new Presidential Regulation currently being developed seeks to improve the RE procurement scheme. This new approach will involve a mix of large-scale competitive tenders for utility-scale wind and solar PV, and small-scale procurement under feed-in tariffs based on renewable energy project costs for smaller projects and less mature technologies. These changes aim to create a much larger and more competitive market that will, in turn, encourage domestic manufacturing. This should allow renewable energy investors to recover the higher costs imposed by the local content requirements.

3.3. Implementation strategies as mentioned in RUED

To implement the policy above, implementation strategies are needed, namely:

- To encourage the development of primary energy and secondary energy infrastructures in Nusa Tenggara Barat Province.
- Collaborating in infrastructure development with other regions for the security of primary and secondary energy supplies from outside Nusa Tenggara Barat Province.
- Prioritise the use of renewable energy that is available in Nusa Tenggara Barat Province.
- Apply energy saving/energy conservation principles in energy management.

- Implement clean energy technology.
- Increase the role of stakeholders in the utilisation of primary and secondary energy.
- Increase cooperation at national, regional, and international levels, especially in the context of access to information, funding and technology transfer.
- Improving the quality of human resources in the primary energy sector.
- Increase efforts to support primary energy and secondary energy.
- Increase public access to primary and secondary energy.
- Establish and run implementing institutions (energy forum/project implementation team as established for ICLEI project).
- Develop and implement funding schemes to reduce dependency on regional budget (APBD) and national budget (APBN).

To implement the energy policy of West Nusa Tenggara, regulations governing energy management are needed. These regulations concern business and engineering aspects.

The aim of regulating business aspects is to implement energy conservation at affordable prices that support increased use of renewable energy and commercial clean energy technology that is safe and environmentally friendly. The objects regulated in the business aspects are consumers, producers of supporting industrial energy equipment, and developers. Meanwhile, the regulated aspects concern consumer protection, entrepreneurship, supporting businesses and environmental protection. Consumer protection is carried out through standardisation of products and energy installations/systems to provide guarantees for consumers regarding the quality and safety of products, both energy products and energy equipment/system products produced locally, domestically, or abroad, which relate to primary energy and secondary energy. The formulation of these standards is carried out under the coordination of the Directorate General of Electricity. Every business actor is obliged to set "quality and service standards" in accordance with the specified quality and service indicators. Relevant regulations at the provincial level are needed to direct the supply and use of energy to refer to the standards that have been set.

From the business aspect of providing and utilising primary and secondary energy, it is necessary to provide enabling environments in the form of regulations that support the participation of BUMN (State Owned Enterprises), BUMD (Regional Owned Enterprises), Cooperative and Private business entities that have business permits in energy exploitation in the regions. Business implementation must meet the technical requirements set by the Minister of Energy and Mineral Resources and must fulfil administrative requirements. This regulation is intended to create a conducive climate for this business. Technical and administrative requirements are differentiated for companies producing electricity and non-electricity. This convenience includes the ease of obtaining information regarding the need for conducting investment feasibility studies and implementation procedures.

Regulations are also provided for the implementation of supporting business activities related to the supply and utilisation of primary energy and secondary energy, consisting of supporting service businesses, and supporting industries. The support for service businesses includes consulting activities; building and installing installations; testing installations, equipment, and products; operating and maintaining installations; research and development; education and training; and other related businesses. Supporting industries include activities producing energy equipment and utilising energy as a component to build installations. This supporting business arrangement is intended to ensure that the planning, construction, installation, operation, and maintenance of installations and product use are carried out by companies that have capabilities appropriate to the scope of their activities.

What is no less important in regulations, is that every business providing and utilising primary and secondary energy must carry out and prioritise environmental protection. Refreshing renewable energy sources that have been utilised to maintain ecological balance must be included in the business program concerned.

Engineering regulations are aimed at ensuring the supply and utilisation of quality, safe, reliable, environmentally friendly primary and secondary energy, as well as increasing the efficiency of energy utilisation and providing reliable Renewable Energy and clean energy technology as well as information regarding the feasibility of its implementation.

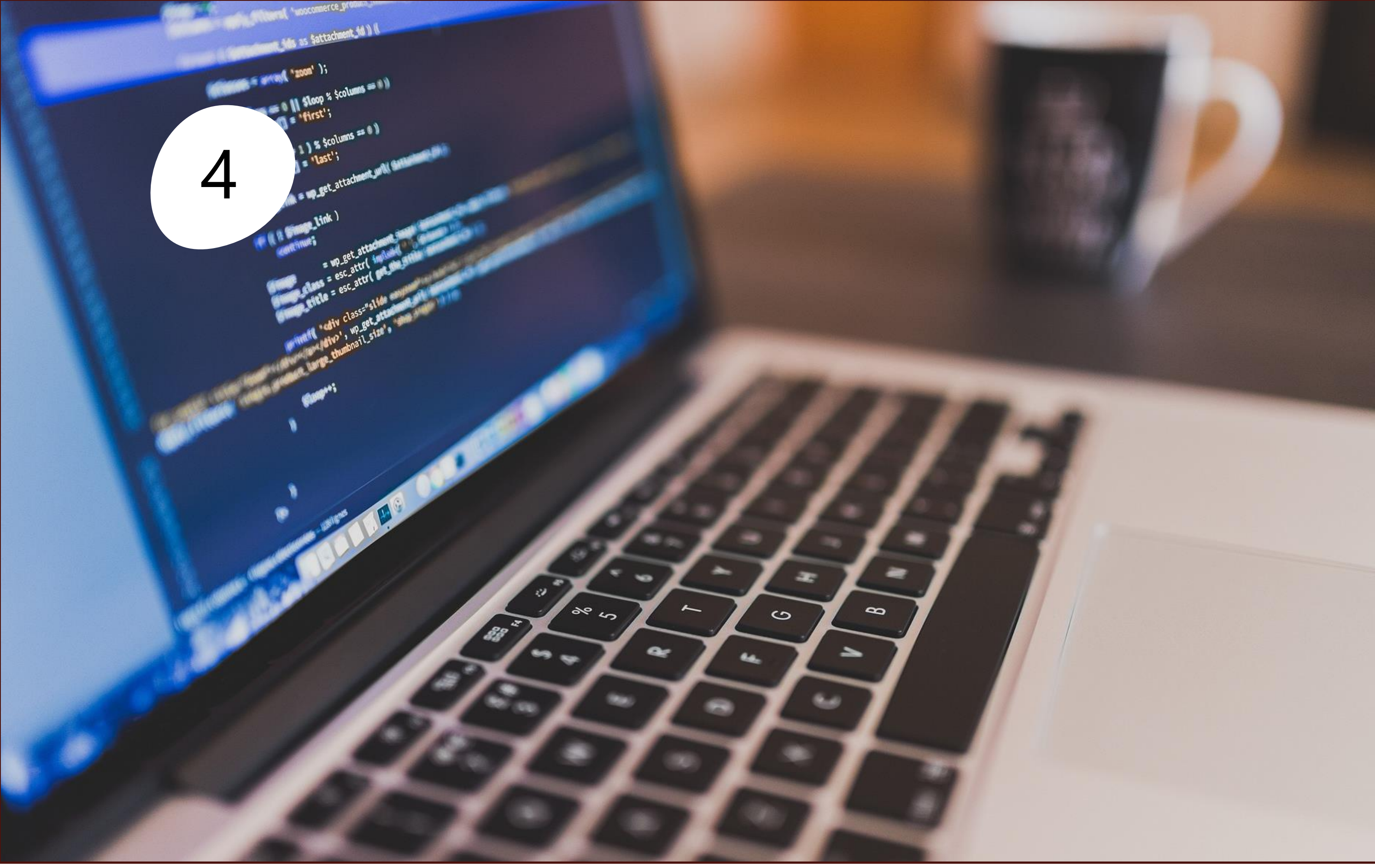
The objects of technical regulation concern producers, consumers, research and development, industry and supporting services and developers. Meanwhile, the regulated aspects are standardisation of products and energy installations/systems, competency of technical personnel, use of technology, efficient use of energy in equipment, supplies and electricity/energy users, operation and maintenance, energy managers (competence is mandatory to have for an energy manager) as well as large energy consumers or consumers with a certain amount of energy use.

Regulations on the use of technology aim to provide opportunities for the development of local technology, so that in time it can compete with imported technology by paying attention to and considering the urgency and national interests, so that national independence in the concept of sustainable development can be achieved. Regulations are carried out through screening imported technology based on the principles of feasibility, reliability, local content, operating period, environmental, economic, and social impacts. Regulations regarding operation and maintenance refer to applicable regulations in the related energy sector.

3.4 RPD (Regional Development Plan) 2024-2026

The RPD is basically an interim regional development plan (RPJMD Transisi) to be used as reference by the interim governor during his tenure in 2024-2026. The ultimate goal to be realised in the 2024 - 2026 RPD is an inclusive and sustainable transformation of the West Nusa Tenggara economy. West Nusa Tenggara 's economic growth is projected to no longer be dominated by the mining sector, but there has been diversification of the economy and business fields, encouraging an increase in the contribution of combined sectors, outside of mining, such as industry and tourism. These are also supported by the agricultural sector in a broad sense, targeting the share value of GDP to reach above 50%.

West Nusa Tenggara 's economic growth in 2022 will reach 6.95%, a significant increase compared to 2021 which had a growth of 2.3%. This growth was strongly supported by the mining sector. Without the mining sector, West Nusa Tenggara's economic growth in 2022 will reach 3.2%, an increase from 2.86% in 2021. The experience of the last five years of economic growth with mining has contracted twice, minus 4.5% to minus 0.62% in 2018 and 2020. Meanwhile, economic growth without considering mining, only experienced one contraction reaching minus 5.17% in 2020 due to the impact of the COVID-19 pandemic. The economic growth data explains that non-mining sectors, especially agriculture, commercial, and industrial sectors, have great potential to uplift the overall economic growth, even though they are currently laying in lower contribution levels, so efforts are made to increase the rate of economic growth in the next three years, for instance encouraging the processing of agricultural and livestock products into products that have added economic value as well as holding national and international events in West Nusa Tenggara to stimulate the tourism and commercial sectors.



4. Energy system modelling

4.1 LEAP model

The mapping of energy consumption across all energy sectors is facilitated by LEAP. LEAP is a modelling tool developed by the Stockholm Environment Institute (SEI) that is designed to assist decision-makers, researchers, and planners in performing integrated energy resource and policy analyses/planning, as well as GHG mitigation and low emission development strategies. LEAP is widely used for energy and environmental planning at regional, national, and sub-national levels across several countries.

Some of the key modelling features are the tracking of energy production, consumption, and resource extraction in all sectors of an economy (both energy and non-energy quantification) and the integration of various energy sectors achieving a comprehensive view of the energy system, as well as the impact assessment of different policies in scenario-based analyses. With its scenario analysis features, LEAP enables its users to evaluate the potential outcomes of diverse policy interventions, technological advancements, and shifts in energy consumption patterns. Spatial and temporal dimensions are also subject to the user, allowing for a more detailed, long-term definition of the system in question.

Data requirements encompass demographic details, macroeconomic elements, activity levels, fuel characteristics, energy intensities of various processes, emission factors, profiles, and shapes and many more, while some of the outputs are energy balances, sector-specific, fuel-specific and activity/process-specific final energy consumptions, as well as GHG emissions.

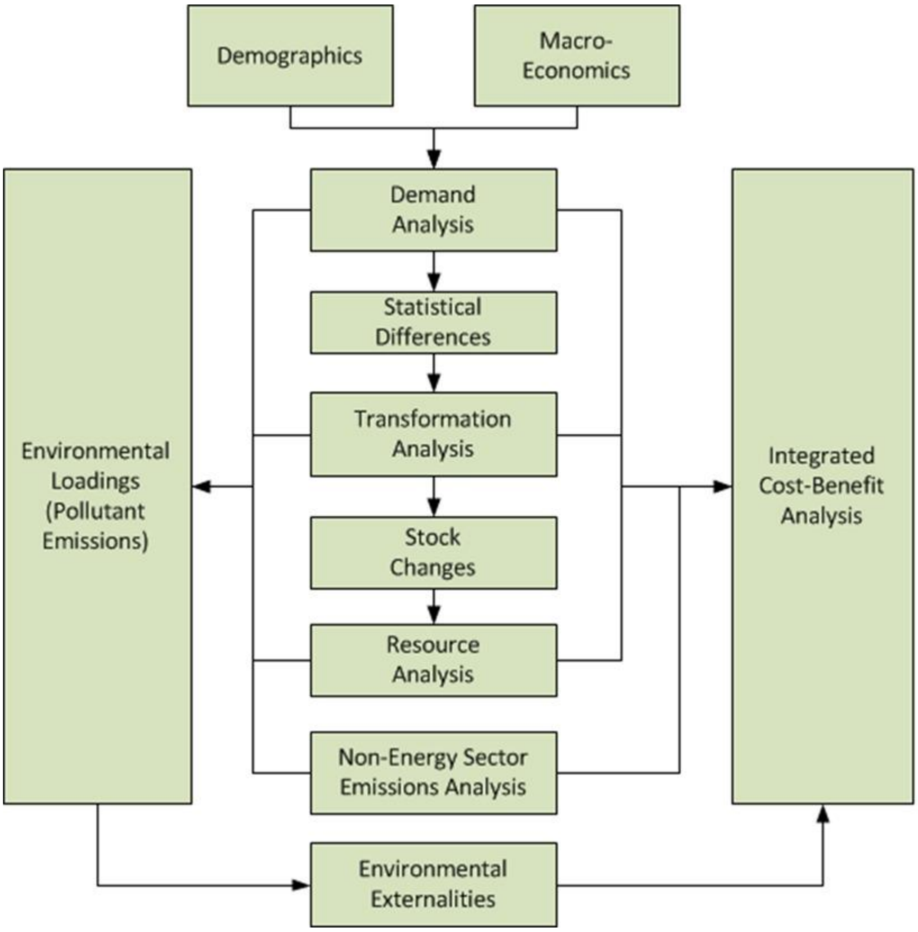


Figure 20: General LEAP calculations' structure (Source: SEI, USA).

LEAP is also used at a national level in Indonesia by different governmental entities, e.g. ESDM or MEMR in English, which is the Ministry of Energy and Mineral Resources and DEN or NEC (National Energy Council) and modelling results are often part of the national development plans that each department is responsible for publishing. The current analysis includes a LEAP model developed and calibrated to match the 2021 levels of economic activity and fuel consumption for both islands of West Nusa Tenggara, namely Lombok and Sumbawa. Assumptions and trends shape the future development of the various modelled sectors, i.e. residential, commercial, industrial, transport, and others that include agriculture, mining and construction.

4.2 Balmorel model

The power sector modelling is quantified through a detailed bottom-up modelling using the Balmorel model. Balmorel is an economic dispatch optimisation, unit commitment, and capacity expansion model, which, subject to a given scenario's boundary conditions, determines the optimal deployment of power generation capacity, power transmission capacity, and storage capacity and determines the optimal operation of this capacity to satisfy load requirements.

Optimal dispatch, unit commitment, and capacity expansion are calculated, subject to the scenarios' specific assumptions. This allows for a comparative analysis, facilitating, for instance, comparison of the total costs, total emissions, or other metrics across scenarios. Furthermore, the modelling serves to illustrate how the system can be run in the future, for instance demonstrating the changing role of different assets in the system, as Indonesia and Nusa Tenggara Barat realise the objectives for reducing CO_2 emissions.

The hour-by-hour simulations provide insight into the challenges and solutions for daily balancing of the system in the future.

The direct outputs of the model include power generation, fuel consumption, transmission flows between grid regions, as well as storage charging and discharging for each simulated unit and for each time step. Additionally, derived results include emissions, investments, fixed and variable operating costs, fuel costs, start-up costs, and possible costs associated with the emission of CO_2. Thereby, the total costs of electricity supply for society, in different scenarios, can be quantified and compared. Additionally, the model yields the marginal values of scarce resources in the system, including the marginal value of the balance between supply and demand for electricity, which can be interpreted as the market value of electricity in each time step in a perfect market. These results can be used to assess the value of marginal system developments in a given scenario, that is the marginal cost of electricity, the marginal value of additional solar or other generation, the scarcity value of constrained fuels, or the marginal cost of reducing CO_2 emissions. The key inputs, outputs, and functionalities of the Balmorel model are illustrated in the figure below.

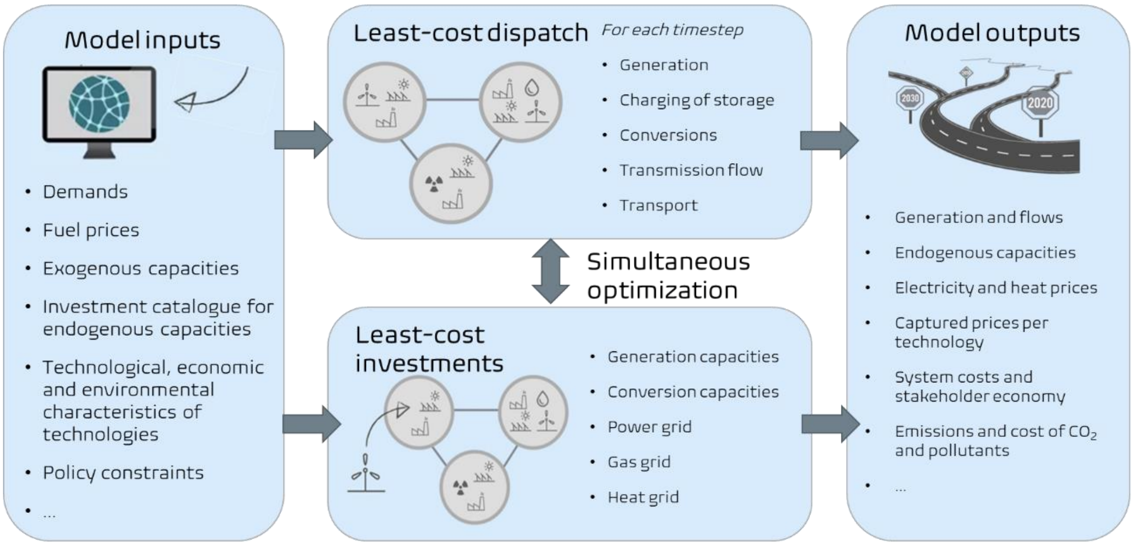


Figure 21: Overview of the Balmorel model's functionality, as well as key inputs and outputs.

The Balmorel model has been benchmarked against the National Electricity Plan modelling results and methodologies. The models are found to have similar fundamental characteristics, implying that similar input data will yield similar results. Balmorel has been used for the development of scenario-based outlooks in several countries, including China (Energy Research Institute of Chinese Academy of Macroeconomic Research, 2021), Vietnam (Electricity and Renewable Energy Authority, Danish Energy Agency, 2021), Indonesia (Danish Energy Agency, EBTKE, 2021), and Mexico as part of government-to-government collaborations.

4.3 Model soft-linking

For the purposes of this analysis, the two models are interlinked, adopting a similar approach as used in the national level by partner government departments. LEAP is run on its simulation mode, in the sense that no optimisation takes place. As aforementioned, all different energy sectors are represented and simulated based on the input data and assumptions given to the model, except for the electricity sector. This is comprehensively mapped and optimised in a least-cost approach in the Balmorel model. The annual total final electricity consumption, as calculated in LEAP across all energy end-uses, is fed to Balmorel which then optimises the required power supply.

Three types of electricity demand are assumed in Balmorel, classic demand that is electricity consumed anywhere besides transportation, EV demand is electricity consumed in BEVs and hydrogen demand which is translated to the equivalent electricity required in the electrolysers to produce e-hydrogen.

4.4 Scenario description

A comparative analysis is undertaken, describing two different development pathways of the current energy system of Nusa Tenggara Barat. In both cases, existing conditions and approved development or expansion plans have been considered to represent and calibrate the base year in the two models. When zooming into end-use sectors, their economic contribution and distribution of value added across the various subsectors are based on statistical data and trends provided by Central Bureau of Statistics. The power system is considering the expansion of the current system as stated in RUPTL21 until 2030 along with recent updates based on information from the national level, while also allowing for investments in generation and transmission earlier, due to quick uptake of electricity consumption in the other sectors. The two adopted scenarios are explained below:

- **Baseline scenario:** This scenario follows existing trends on energy consumption, while considering active national policies, proposals and discussions. Electricity demand, as shaped from the various end-use sectors, follows RUPTL21 projections until 2030, and thereafter is in line with RUKN and the national level data, thereby aiming to achieve net zero emissions by 2060 in whole Indonesia, with no specific provincial target in place. Rest of the fuel consumption is based on projections that follow the current sectoral conditions and patterns. The model-based optimisation of the power sector allows capacity expansion of generation units from 2026 and of transmission line capacities from 2031.

- **NZE scenario:** Net zero emissions scenario explores a pathway where carbon neutrality is achieved across the whole energy system of NTB by 2050. End-use consumption projection is characterised by various actions that lead to a complete transformation of the existing conditions. Power sector optimisation includes least-cost expansion of electricity generation and transmission starting in 2026 and 2028 respectively, while considering a provincial level target for net zero CO_2 emissions by 2050. This NZE (Net Zero Emission) scenario does not allow any emissions from the power sector after 2048 as electrification is a key solution to decarbonisation of other sectors, and therefore the power sector needs to be decarbonised sooner. The relatively higher electricity demand as compared to baseline due to electrification is the reason for allowing capacity expansion sooner in this sooner than in the baseline.

5. Current status and future projections of energy demand

As the ideation phase and data collection of the project were initiated in November 2022, the modelling calibration has stepped on 2021 as the base year of the analysis, due to this being the latest available data at that time. Main source of data for West Nusa Tenggara's different fuel consumptions and sectoral end-use demands is the Indonesian Central Bureau of Statistics or Badan Pusat Statistik (BPS), among other publicly available data of different governmental directorates. Projections made in the Baseline scenario mostly follow current provincial and national sectoral trends, as well as relevant national policies and targets. As described in **4.4 Scenario description**, the NZE scenario sets a pathway for carbon-neutrality by 2050 across the whole energy sector of NTB. Therefore, the projections applied overall include higher electrification rates, higher energy efficiency measures and higher rates of fuel-switching applications than the Baseline scenario.

5.1 Input data – Mapping energy end-use

As mentioned, all input data used to calibrate the base year of the analysis refer to year 2021 and are taken from BPS, General Directorates or consolidated with local experts and stakeholders' feedback.

In terms of macroeconomic elements, Lombok possesses the highest economic activity between the two West Nusa Tenggara regions and more than double the population, with commercial and agriculture sectors contributing largely to the local economy, while Sumbawa is more desolate, depending mainly on mining, both ore and copper, as well as agriculture as main sources of occupation and income.

Table 7 summarises population and its relative growth, regional GDP, as well as GDP per capita, while

Table 8 indicates the structure of GDP within the two regions. Sumbawa's much higher income per capita is attributed to the very high mining activity, hosting the second largest copper mine in Indonesia.

Table 7. NTB Population, GDP and GDP per capita in 2021.

		Lombok	Sumbawa	Total
Population	1,000 people	3,809	1,581	5,390
Population Growth	%	1.34	1.26	1.31
GDP	Billion Rp	53,659	42,639	96,298
GDP per capita	Million Rp/person	14.1	27	17.8

Table 8. NTB GDP structure in 2021.

Sector	Lombok		Sumbawa	
	Billion IDR	%	Billion IDR	%
Industry	3,774	7.1	709	1.7
Commercial	25,753	48.4	12,230	28.7
Transportation	3,203	6	1,456	3.4
Mining	2,581	4.9	14,267	33.5
Agriculture	11,022	20.7	10,899	25.6
Construction	6,756	12.7	3,028	7.1
Other	128	0.2	52	0.1
Total	53,217	100	42,641	100

A sectoral overview of available data

Economic activity in NTB mostly relies on the commercial sector, transportation, industry, mining, agriculture, and construction as shown in **Table 8**. For modelling purposes, mining, agriculture, and construction have been teamed together in a broader group called "Other". The residential sector also contributes to the economy through the construction, and ownership and maintenance phases, however, the residential construction phase is considered part of the overall construction activity of the province and no data is available for the latter phase. As of 2021, Lombok registered 1,100,320 households indicating an average household size of 3.4 people, while in Sumbawa there were roughly 400,000, which corresponds to almost 4 people per household.

The commercial sector is one of the most important sectors economy-wise, representing 48% and 29% of the total GDP for Lombok and Sumbawa, respectively. It is comprised by trade, hotels and restaurants, communications, and different services. The distribution of value added among the different sub-sectors can be found in **Table 9**. Value added measures the additional value created by a particular economic activity and is the difference between the total value of a sector or subsector's output and the value of intermediate goods and services used in the production process, i.e. the net contribution to the overall economy.

Table 9. Commercial sector – Valued added in 2021.

Commercial Sector - Value added (Billion IDR)			
Subsector	Lombok	Sumbawa	Total
Trade	8,073	4,931	13,004
Hotel and Restaurant	847	290	1,137
Communications	2,165	527	2,692
Finance Service	2,680	1,020	3,700
Office Service	2,223	930	3,153
Social Service	7,959	3,760	11,719
Other Service	1,525	556	2,081
Total	25,473	12,013	37,485

Industry has a lower impact of approximately 7% and 1.7% economy-wise for Lombok and Sumbawa, as the overall industrial activity is limited in the province, with the food and beverage subsector playing a key role. That includes various stages of production, from the cultivation of raw agricultural products to the processing and manufacturing of relevant items, and includes the food processing, packaging, beverages productions etc. The values as extracted from BPS for 2021 and the two regions in question are shown in **Table 10**.

Table 10. Industrial sector – Valued added in 2021.

Industrial Sector - Value added (Billion IDR)			
Subsector	Lombok	Sumbawa	Total
Food	2,866	542	3,408
Textile	145	27	172
Wood	259	49	309
Pulp and Paper	56	11	67
Non-Metal	212	40	252
Metal	59	11	70
Other	110	21	131
Total	3,708	701	4,409

Table 11 indicates the available data for the transportation sector. Passenger cars, motorcycles, as well as buses and trucks are listed in numbers of vehicles, while shipping and aviation are expressed in terms of value added. Lombok has more than double the number of residents and therefore, more transportation means. It is also better interconnected to the rest of Indonesia by air and sea in terms of infrastructure, due to the highest economic activity and being closer to Java Island, which is the largest demand centre of the country, but also due to much higher tourism attraction.

Table 11. Transportation sector – Number of vehicles and valued added in 2021.

Transportation Sector - Number of Vehicles and Value added				
Type	Units	Lombok	Sumbawa	Total
Passenger Car	Vehicle	87,927	17,437	105,364
Motorcycle	Vehicle	1,277,066	391,149	1,668,215
Bus	Vehicle	1,272	1,173	2,445
Truck	Vehicle	56,848	20,371	77,219
Sea Transport	Billion IDR	906	388	1,294
Air Transport	Billion IDR	674	75	749

As mentioned before, agriculture, mining and construction have been grouped into one sector, labelled Other, however, they possess a significant role in the local economy. Combined, they represent a total of 38.5% of GDP for Lombok, with agriculture being responsible for more than half of that and approximately two thirds in the case of Sumbawa, while mining is the most crucial activity there.

Table 12. Other sectors – Valued added in 2021.

Other Sectors - Value added (Billion IDR)			
Subsector	Lombok	Sumbawa	Total
Agriculture	10,886	10,775	21,661
Mining	2,483	14,388	16,870
Construction	6,141	2,864	9,005
Total	19,510	28,027	47,537

In terms of fuel consumption, West Nusa Tenggara relies on oil, coal, liquefied petroleum gas (LPG) and of course electricity to meet the energy demand.

Gasoline and diesel are the most commonly used oil products across the energy sector. Gasoline is mostly consumed in light and heavy-duty transport means, while diesel consumption is heavily associated with power generation and land transportation, but also highly used in mining processes, i.e for quarrying in the case of Sumbawa. Other oil products used in the different energy sectors are aviation turbine fuel, also known as avtur, for aviation purposes, kerosene in industry and households, as well as residual or heavy fuel oil that is consumed in power plants for power generation.

Table 13 summarises the different total end-use oil-based consumptions for 2021. Oil consumption data is provided by DG Oil and Gas for whole Nusa Tenggara Barat. Therefore, some assumptions have been drawn in order to split them within the two regions. For aviation fuel, a 90% use in Lombok is considered, while for gasoline and kerosene a 70-30 split is assumed for shipping and residential use, in favour of Lombok and 84-26 split for industrial uses of both fuels. The distribution on diesel assumes that in Lombok 75% of total road transport diesel consumption takes place, along with 70% of total shipping consumption, 84% of NTB industrial use, and 55% of the diesel-based province's power generation. Finally, fuel oil split is considered to be 74% for Lombok and 26% for Sumbawa.

Table 13. Total end-use oil consumption in 2021.

Oil Consumption (Kilo litres)			
Oil Products	Lombok	Sumbawa	Total
Avtur	7,002	778	7,780
Gasoline	282,793	148,099	430,892
- Land transport	279,710	146,938	426,648
- Sea transport	2,408	1,032	3,440
- Industry	675	129	804
Kerosene	5,666	1,688	7,354
- Residential	2,556	1,095	3,651
- Industry	3,110	592	3,702
Diesel (incl. B30*)	363,684	406,256	769,940
- Land transport	127,375	42,458	169,833
- Sea transport	12,128	5,198	17,326
- Industry	36,068	6,870	42,938
- Mining	-	200,000	200,000
- PLN	188,113	151,730	339,843
Fuel Oil	63,855	22,610	86,465
- PLN	63,855	22,610	86,465
Total	723,000	579,431	1,302,431

**Diesel blended with 30% biodiesel*

Coal consumption is vastly associated with power generation in coal-fired power plants for both Lombok and Sumbawa, while also used in smelters as a source of heat to generate the high temperatures required for smelting processes, when looking into Sumbawa. LPG is mostly utilised in the residential sector, especially for cooking gas stoves, while electricity consumption is limited to households and services that lie within the commercial sector, however, its use is expected to grow significantly. In **Table 14** a similar representation is illustrated for coal, LPG and electricity. Coal data for power generation and mining is taken from DG of Mineral and Coal, while industrial consumption is calculated based on BPS Industry Survey. LPG consumption is calculated based on available data of DG Oil and Gas and the reference for electricity is RUPTL21 from PLN.

Table 14. Total end-use coal, LPG, and electricity consumption in 2021.

Coal Consumption (ton)			
Sector	Lombok	Sumbawa	Total
Power Generation	447,184	212,501	659,685
Mining	-	493,889	493,889
Industry	78,630	14,977	93,607
Total	525,814	721,367	1,247,181
LPG Consumption (Ton)			
Sector	Lombok	Sumbawa	Total
Residential	97,355	23,894	121,249
Industry	281	69	351
Commercial	523	129	651
Total	98,159	24,092	122,251
Electricity Consumption (GWh)			
Sector	Lombok	Sumbawa	Total
Residential	1,037	473	1,510
Commercial	476	125	602
Industry	89	89	179
Total	1,603	688	2,290

5.2 Assumptions and future projections on final energy consumption

According to the latest national medium-term development plan, RPJMN 2020-2024, published by the national development planning agency approximately every five years, Indonesia's GDP is expected to steadily grow until 2035, thereafter hitting a plateau until 2040 and decline post 2045. This would be in line with the national ambition of becoming a developed country by 2045. The growth rate adopted in this study is following RPJMN projection specifically for the NTB region, as shown in **Figure 22,** which results in a GDP of 600,000 billion rupiah by 2050. Left axis indicates the development of GDP in monetary terms, while right axis illustrates the annual growth rate. The steep decline appearing between 2022 and 2025 is due to the very high post COVID-19 economic bounce-back achieved in that year.

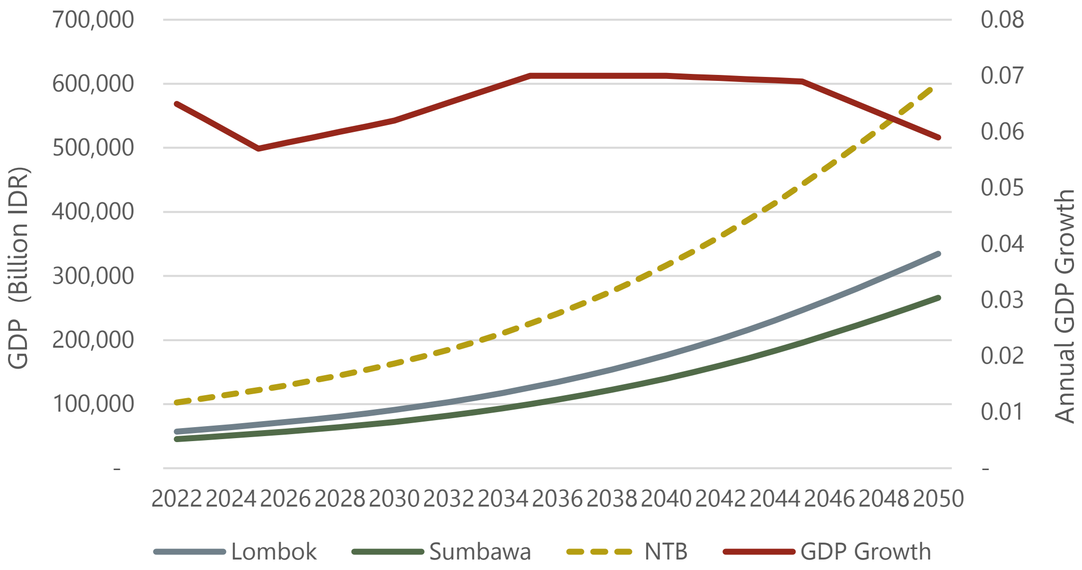


Figure 22: GDP development (left axis) based on annual GDP growth (right axis) (Source: Bappenas, 2020).

As depicted in **Table 7,** both Lombok and Sumbawa presented a much higher average population growth of 1.31% in 2021 compared to rest of Indonesia, indicatively 0.7% (World Bank, 2023). Due to lack of official data on the future provincial population growth but following the national trend of sharp decrease, the population growth for West Nusa Tenggara is assumed to linearly decline throughout 2050 to the existing levels of 0.7%. Thereby, population is expected to reach roughly five million people in Lombok and slightly higher than two million people in Sumbawa in year 2050. **Figure 23** illustrates the population growth in 1,000 residents (left axis) for Lombok, Sumbawa, and the total provincial trend, as well as the assumed annual growth (right axis) for the whole temporal resolution of the analysis.

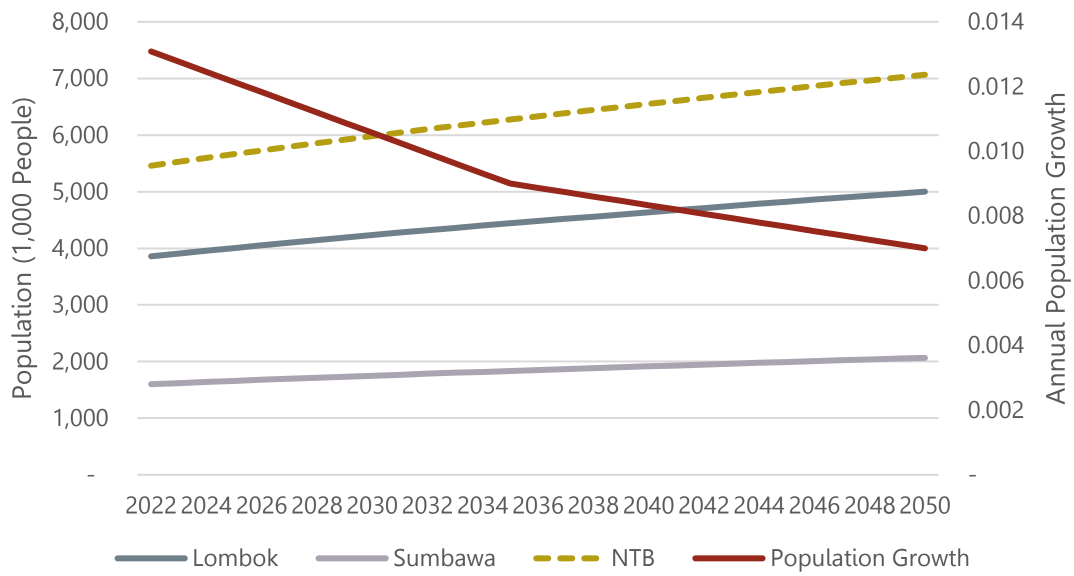


Figure 23. Population evolution (left axis) based on annual population growth (right axis).

Based on the lack of more detailed registered data and in order to simplify the modelling approach in LEAP, the evolution of each sector has been linked to the assumed GDP growth in both scenarios, with elasticity factors and different measures applied to either correct individual trends and avoid a direct 1:1 correlation between GDP and the respective final energy consumption or reach specific activity targets. Naturally, the NZE scenario has more ambitious targets than Baseline, in order to meet the desired goal of reaching net-zero emissions across the whole energy system by 2050.

Fuel switching across all sectors

An overarching substitution of conventional fuels with bio-based fuels is considered as one of the main measures to decarbonise the energy sector. Starting from existing policies, the government's subsidised mandate of 2023 to blend diesel consumption with palm oil-based biodiesel at a 65-35 ratio is applied. This is an improvement to the previous mandate of 30%, and there are already trials for a blend of 60-40. This policy is considered fixed for Baseline, however, the NZE scenario assumes a full substitution of diesel to drop-in biodiesel by 2050. Although less commonly used than lower blends due to compatibility and lower energy content, existing diesel engines could facilitate biodiesel B100 with equipment modifications (AFDC, 2023). Diesel is broadly used in various sectors, such as commercial, industry and others besides transportation, thereby, the assumptions apply to all different diesel uses. Similarly, bio-gasoline and bio-avtur or bio jet-fuel could play an important role towards more sustainable mobility fuel production. Both are compatible with existing internal combustion engines and can be used as drop-in replacements to substitute fossils. They could be derived via well-established processes, such as Fischer-Tropsch (FT) thermal gasification, as main products or by-products. FT is usually used for producing synthetic petroleum products from syngas, and kerosene produced via this process is already approved as a sustainable aviation fuel (SAF) (Kurzawska, 2022). As no existing policies are in place for those fuels, Baseline only assumes a 2% and 5% substitution of conventional gasoline with bio-gasoline in 2030 and 2050 respectively, however, the NZE scenario considers that bio-gasoline consumption will take off post 2030 to reach full substitution in 2050, while bio-avtur is assumed to be half of the total jet-fuel consumption by 2050, starting at zero levels in 2030.

Residential and Commercial sector

A sectoral approach is adopted for other targets implemented in the two scenarios. In the residential sector, household number is expected to grow similarly to the population growth presented in **Figure 23**, without any changes on the household sizes of the two regions. Electricity consumption is expected to rise significantly in both scenarios, substituting the use of LPG and kerosene for cooking and lighting. Baseline indicates a 50% substitution of LPG with electric stoves and full replacement of kerosene with electricity by 2050, while in NZE, LPG consumption is completely eliminated. Biogas is also used as an LPG replacement for heating at a steady 5% ratio from 2025 and onward until it is over-ridden by electricity in both scenarios. This is a result of discussions with local experts that indicated such plans from the local government for Lombok. Also, electric appliances are assumed to become 50% more efficient, as existing appliances and equipment sold in Indonesia today are on average 30 to 50% less efficient than the best available technologies of the domestic market according to IEA (IEA, 2022).

The commercial sector development complies with the GDP growth; however, the distribution of the different subsectors' shares is expected to change for both Lombok and Sumbawa, i.e. the contribution or value added of each subsector as a share of the total commercial sector value added. Applied changes are based on BPS trend projection. Also, for both scenarios substitution of diesel with electricity is assumed. Baseline showcases a 20% conversion of diesel to electricity and NZE a 75% conversion in 2050. Finally, energy efficiency measures are applied on electricity-consuming operational processes, expressed as reduced energy intensity or energy savings, at 10% for Baseline and 25% in NZE at the latest stages. Those could mostly regard buildings and can be achieved via better energy management, energy codes, more efficient equipment, more suitable materials, better ventilation systems etc.

Industry and Transportation

The industrial sector is following the same principles with the commercial sector. Electrification, fuel switching, and energy or material efficiency are key measures to lower both energy and carbon intensity. Industrial evolution adheres to the overall economic growth with increasing value added, although the final energy demand is assumed to increase in a slower pace. Baseline scenario assumes diesel substitution to electricity of 15%, coal switch to biomass of 25% and an LPG shift to electricity of 25%. The respective shares for NZE are 75% for diesel to electricity, and a full switch of coal and LPG to biomass and electricity. All those numbers refer to year 2050 assuming a linear increase from the start year. Energy efficiency measures are expressed as a reduction of 25% of the final energy intensity of value added in the different industrial processes, while only 10% in the case of Baseline. That could be materialised with actions such as heat pump installations, the use of highly efficient electric motors, equipment and overall facility upgrades, etc.

Transportation development is also linked to the economic growth; however, elasticities have been implemented for the different means of transport to showcase a shift towards public transport. Thereby, passenger cars and motorcycles' link to growth of GDP is expressed using a factor that declines throughout the years, while buses use an elasticity of 1, indicating a direct link to GDP growth. Same applies to shipping and aviation. In terms of targets, EVs are the cornerstone of the transition and are anticipated to drive the decarbonisation of mobility. Biofuels and hydrogen fuel cells possess a complementary role. More specifically, NZE assumes that 80% of passenger cars and all motorcycles will be electrified by 2050, while for heavier-duty vehicles such as busses and trucks a 70% electrification rate is used. The remaining 20% and 30% of passenger cars and heavy-duty vehicles are assumed to be powered with hydrogen. Aviation and shipping rely on biofuel switching, namely biodiesel, bio-gasoline and bio-avtur or bio jet-fuel as described earlier in this section.

5.3 Input data and assumptions - Indonesian Balmorel model

In this section, an overview of the key inputs to the model are presented. The following sections describe the input data for parameters identified as being most relevant in understanding the modeling results. The data and assumptions are based firstly on government sources where possible, while in instances without such sources, other public reports or sources have been used. However, it is important to acknowledge the following parameters are assumptions that may significantly vary in reality and thus impact the results. While every effort has been made to validate these assumptions, it must be recognised that no assumption will ever be entirely free from potential error or uncertainty.

Power demand: Rapidly increasing electricity consumption

The electricity demand varies between the two scenarios, as shown in **Figure 24**. Here classic demand represents the electricity consumption by residential, commercial, and industrial sectors combined, the EV demand shows how much electricity is required for charging of electric vehicles, i.e. private cars and motorcycles, buses, as well as trucks and the hydrogen related electricity consumption shows the power used to run electrolysers to produce hydrogen. The demand for EVs is implemented as an increasingly flexible demand, representing that an increasing share of the EV fleet is subject to smart charging.

Both scenarios have an extensive increase of power demand from 2022, with an even higher growth from 2030. It is possible to see from the figure how there is a significantly higher power demand in the NZE scenario, as a higher degree of electrification is required to meet the objective of the scenario. This is reflected in around 2000 GWh higher electricity demand in 2050 compared to the Baseline scenario. This reflects the electrification of various processes in the industrial, residential, commercial and transport sectors.

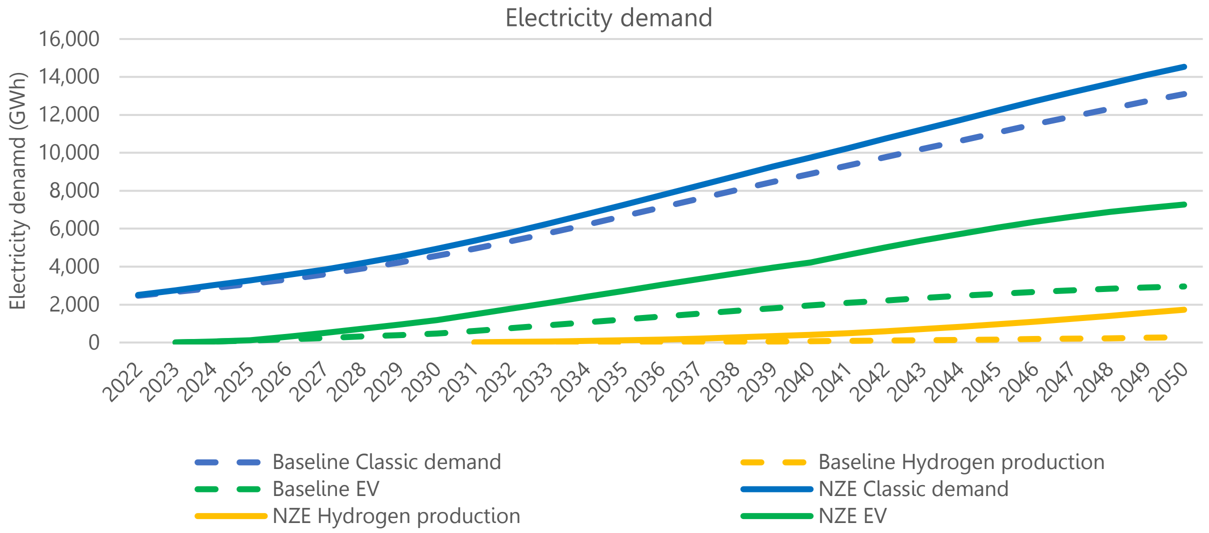


Figure 24 Electricity demand for Nusa Tenggara Barat as a whole in the baseline and NZE scenario.

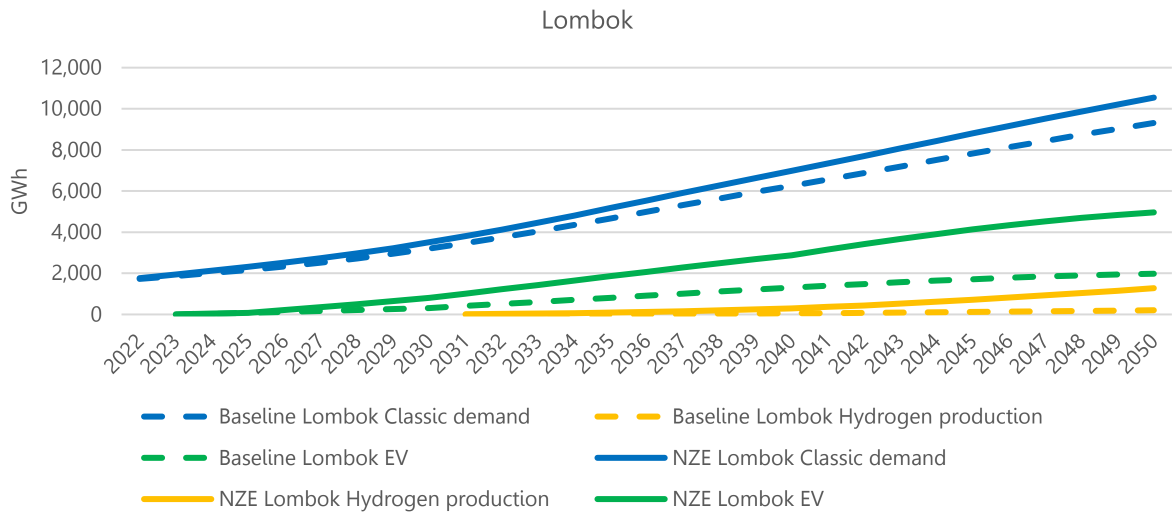


Figure 25 Electricity demand for Lombok in the baseline and NZE scenario.

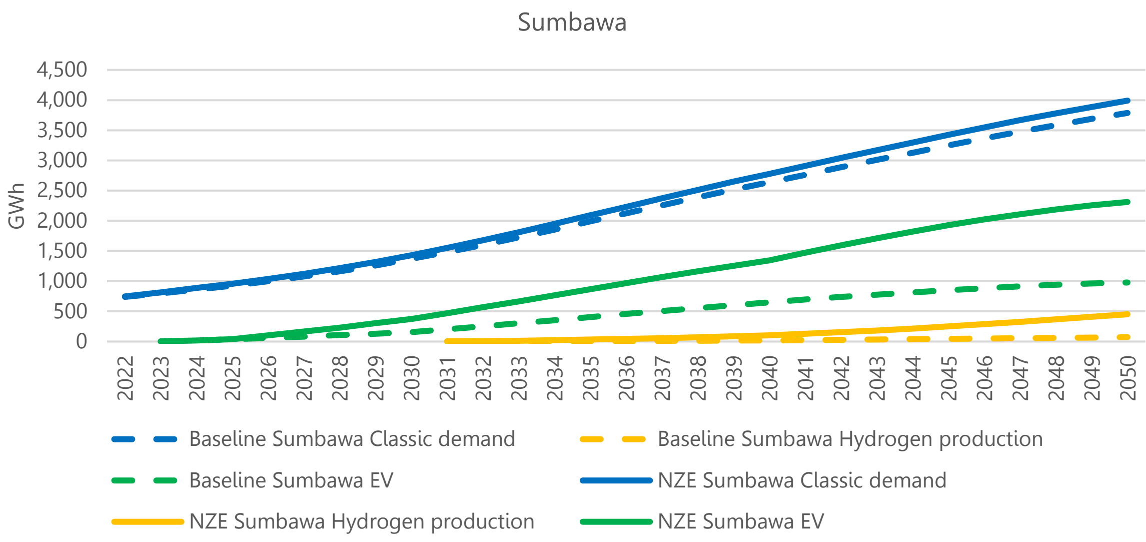


Figure 26 Electricity demand for Sumbawa in the baseline and NZE scenario.

Fuel prices for electricity production and investment costs for capacity expansion

For a more comprehensive understanding of this study, it is essential to consider key factors, including assumptions regarding fuel prices and technology investment costs. **Figure 27** shows the fuel prices used in the modelling. These are calibrated to approximately reflect DMO prices. A sensitivity analysis is included, using market fuel prices, in **Chapter 8**. **Table 15** refers to the capital cost assumed for different fuel options for capacity expansion based on the model optimisation. These costs take the basis from the Indonesian Technology Catalogue (Danish Energy Agency, 2021), with some adjustments. It is important to note that the model does offer the option to invest in other technologies and fuels. The ones mentioned here are most relevant to the Nusa Tenggara Barat province in terms of energy mix and potential. The distinction between locally sourced and imported biomass primarily pertains to fuel costs, while the investment costs for the technologies remain uniform, as both involve the combustion of biomass.

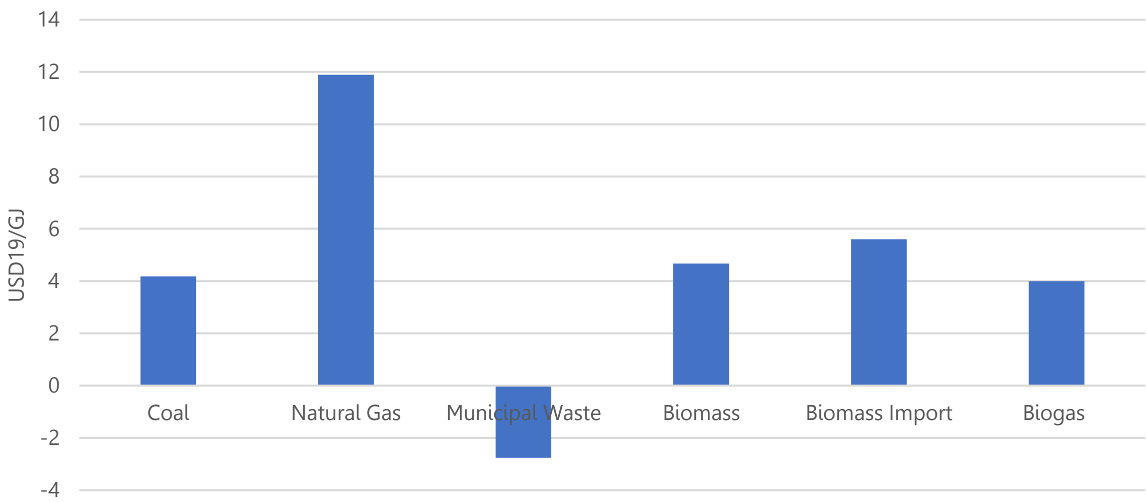


Figure 27 Fuel price assumed for all cases, for the period simulated development towards 2050 in in USD19.

Table 15: Investment costs development towards 2050 in USD19.

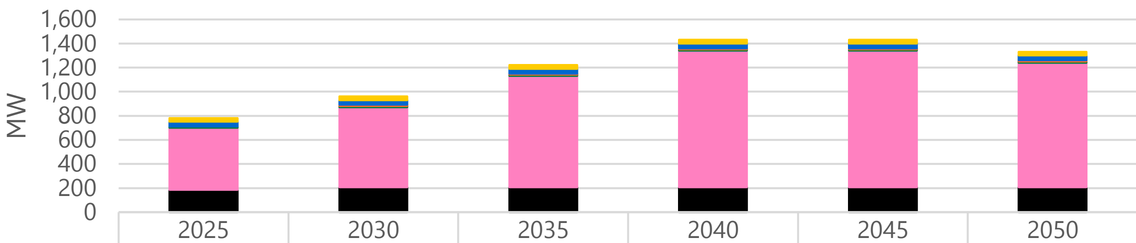
Investment costs (USD19/MW)				
Technology	2020	2030	2040	2050
Solar PV (ground mounted)	0.61	0.43	0.38	0.32
Wind Onshore	1.39	0.73	0.67	0.62
Biomass	1.85	1.69	1.59	1.48
Gas combined cycle	0.94	0.89	0.86	0.82
Gas engine	0.75	0.75	0.75	0.75
Gas Turbine landfill	2.32	2.32	2.32	2.32

Figure 27 and **Table 15**, presented in USD19, are intended to elucidate the price dynamics within the two scenarios, offering insights into the cost trends within the province. They do not represent absolute values of fuel and investment costs but rather provide a valuable perspective on cost developments.

While the fuel costs themselves remain constant throughout the specified period, these graphs serve as a tool to gain insights into the changing costs associated with these fuels. By visualising the price dynamics within the Nusa Tenggara Barat province, these graphs help to provide a more detailed perspective on the study's results, offering a valuable means of better comprehending the model outcomes and the evolving terrain of fuel costs.

Capacity development: Existing and planned investment.

Based on RUPTL21, input from national and local partners, the existing power generation capacity and planned capacity expansion in the Nusa Tenggara province is shown in **Figure 28**. This assumption is the same for the two scenarios. The planned expansion of VRE is limited, and the capacity mix of the province is largely dominated by fossil fuel capacity, predominantly consisting of natural gas and coal. However, some of this coal capacity runs with a mix of biomass co-firing.



	2025	2030	2035	2040	2045	2050
Solar PV	31	31	31	31	31	31
Wind						
Hydro	39	39	39	39	39	39
Geothermal		10	10	10	10	10
Bioenergy	10	10	10	10	10	10
Natural Gas	515	665	925	1,135	1,135	1,035
Coal	186	206	206	206	206	206

Figure 28: Existing and planned capacity expansion in Nusa Tenggara.

Resources Potential: Max capacity expansion allowed for each fuel source

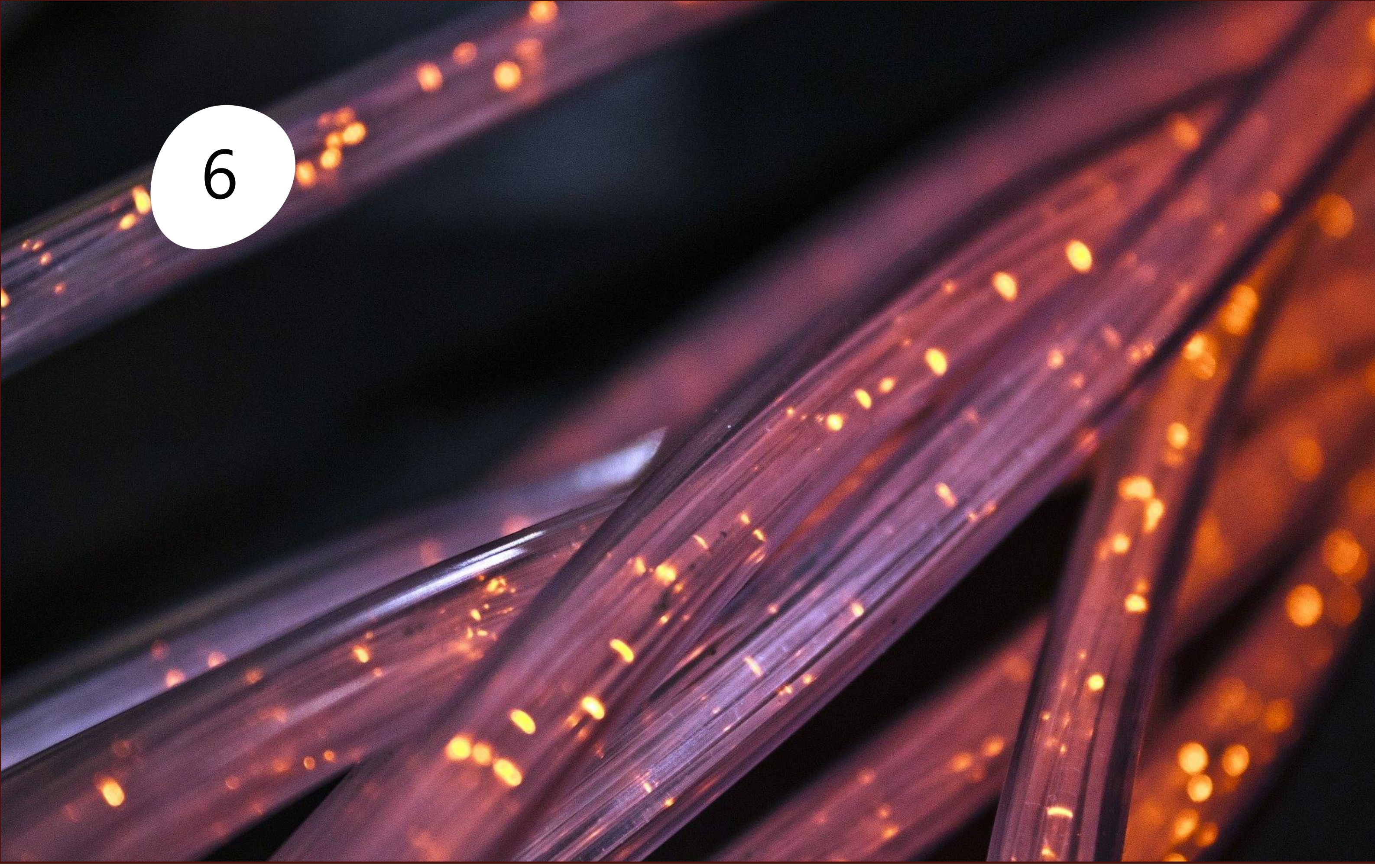
The possible development of the power system of Nusa Tenggara Barat is dependent on the available resources of the territory. This includes understanding which fuels and technologies can best contribute towards power generation to meet the increasing electricity demand, and to what degree. **Table 16** shows capacity potential by fuel following the MEMR (Ministry of Energy and Mineral Resources) estimations.

Table 16: Capacity potential by source in Nusa Tenggara province.

Capacity Potential by technology (MW)		
Source	**Lombok**	**Sumbawa**
Bioenergy*	297	19
Geothermal	100	75
Hydro	26	26
Municipal waste	32	0
Wind onshore	938	1,667
Solar PV	1000	9,628

**Bioenergy predominantly refers to potential of biomass, but also includes small amounts for municipal waste, and biogas.*

As highlighted above, the Nusa Tenggara province is largely characterised by high potential of Solar PV and a significant potential of onshore wind, the largest part of the renewable potential is located in Sumbawa, which makes up the largest part of the province. While both available resources as well as available land is higher in Sumbawa, the main electricity demand comes from the Lombok region. These differences form an important theme in understanding the development of the power sector in the province.



6. Energy end-use development

As described earlier, in both scenarios the overall trajectory of fuel consumption is mainly influenced by the economic growth of NTB, along with various measures applied to shape the assumptions, formulation and objectives of each scenario. Electrification, fuel switching, and energy efficiency are the key components of the energy transition in question.

6.1 Total final consumption overview: A holistic paradigm shift

Figure 29 illustrates the final end-use fuel consumption in selected years for both Baseline and NZE scenario. It is evident that fuel demand is projected to keep increasing throughout 2050, however, NZE presents lower total levels already by 2030 due to energy efficiency measures in various sectors. Indicatively, the two scenarios have a difference of roughly 7,7 TWh by 2050. Electricity is the most important fuel representing approximately 68% of total final consumption in NZE scenario and 40% in Baseline in 2050. The remainder energy demand is met via biofuels, mainly biodiesel and hydrogen. All hydrogen consumption is considered to be electricity-based and its consumption in the transportation sector kicks-off in 2030 for the NZE scenario. Baseline is still heavily relying on fossil fuels to meet its growing demand, with a much lower penetration of sustainable fuels. Smelter electricity is the electricity consumed for powering smelting processes, which is only consumed in Sumbawa, where the ore and copper smelters are located. It is separated than the rest of electricity, as it is assumed to be off-grid and therefore not modelled in Balmorel model.

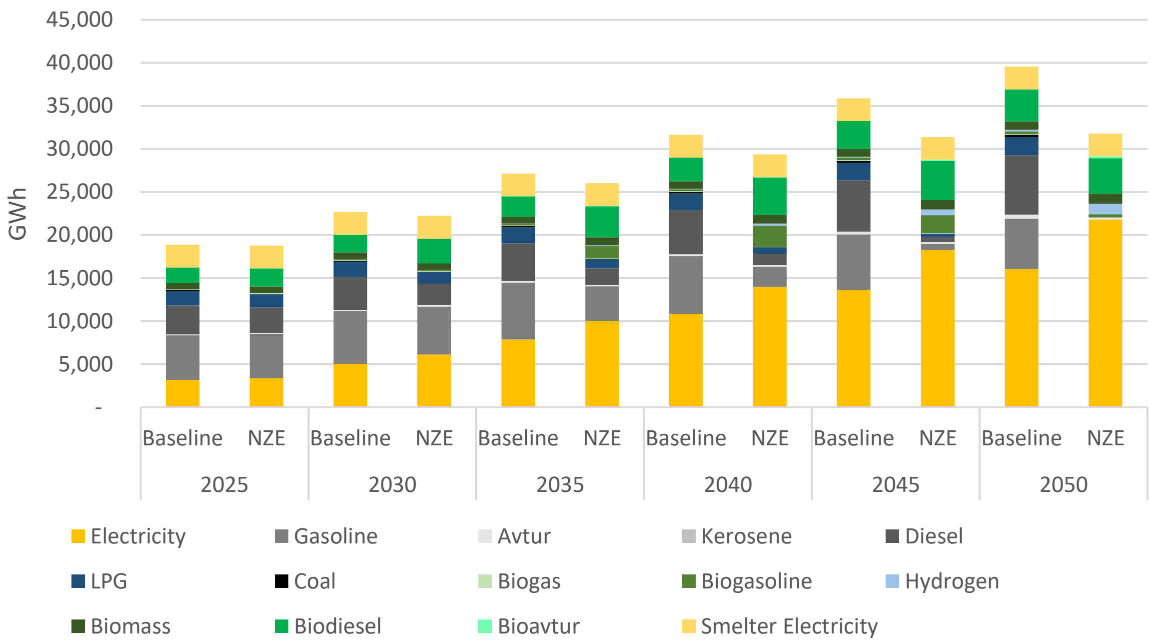


Figure 29. Total end-use fuel consumption in NTB.

A sectoral overview is presented in **Figure 30**. Transportation is the most energy intensive sector throughout 2050 for both scenarios, followed by the residential sector. Industrial activity is relatively low in West Nusa Tenggara but showcases a share increase of 5% between 2025 and 2050, reaching equal levels with others sector, which is rather stable but seeing its share decreasing due to the constant overall demand growth. The commercial sector rises almost fivefold in 2050 compared to the 2025 level. In 2050, Baseline attributes roughly 40% of its total final consumption in transportation, 27% in households, 12% is linked to industrial processes and the rest 16% to commercial and others, while in NZE scenario the transportation sector lies at 32%, which is only marginally higher than the residential sector and the last 40% is following the same distribution as in Baseline.

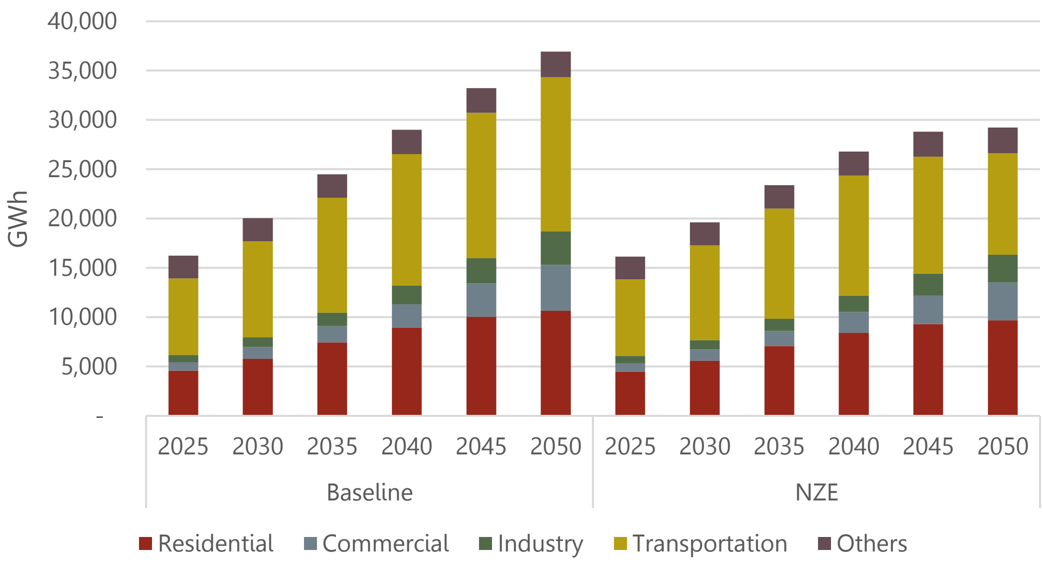


Figure 30. Total end-use energy demand by sector in NTB.

6.2 Total electricity consumption: Driving the transformation

Zooming into electricity consumption, which is the main driver of NTB's energy system transformation, a comparison between the two scenarios and RUPTL21 is illustrated in **Figure 31.** As mentioned in 4.2 Balmorel model, PLN's RUPTL21 demand projection has been used to calibrate the consumption of the different sectors up until 2030 for Baseline scenario. It follows the moderate case until roughly 2026 and ends within the two PLN scenarios. NZE is also following this trend but exceeds the optimistic RUPTL scenario, mostly due to the EV penetration, which is not considered in the PLN document. This figure does not include the separately classified smelter electricity that appears in **Figure 29**.

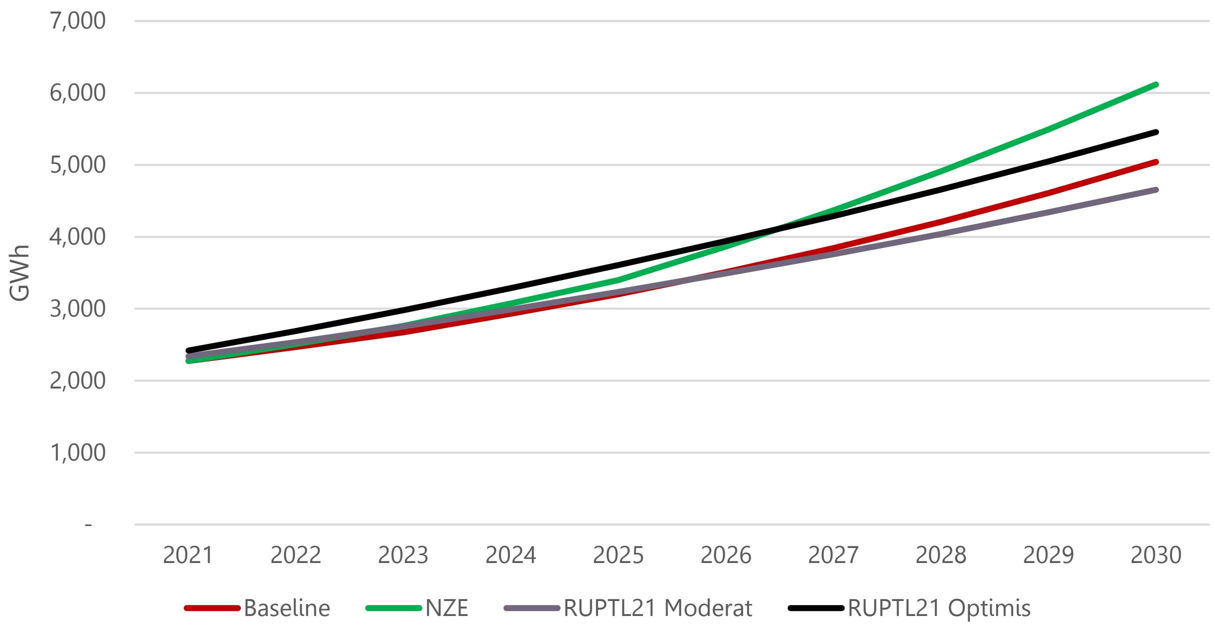


Figure 31. Comparison of electricity consumption between RUPTL21 projection, Baseline and NZE scenarios.

A better grasp of the electricity demand distribution to the various energy sectors is provided in **Figure 32**, which depicts the sectoral consumption for every five years in both scenarios and for whole Nusa Tenggara. All sectors increase their individual electricity demand with transportation enjoying the largest growth, however, residential sector remains the highest-consuming, in both scenarios and for all years. Indicatively in 2050, it is responsible for 48% and 40% of the total share in Baseline and NZE respectively, while transportation reaches 18% and 33%. By 2050, NZE is consuming 21.8 TWh, roughly a 5.8 TWh difference compared to Baseline. The overall growth is subject to electric appliances, machineries and replacing old and inefficient ones, the installation of heat pumps and electric boilers and the high penetration of BEVs in the mobility market.

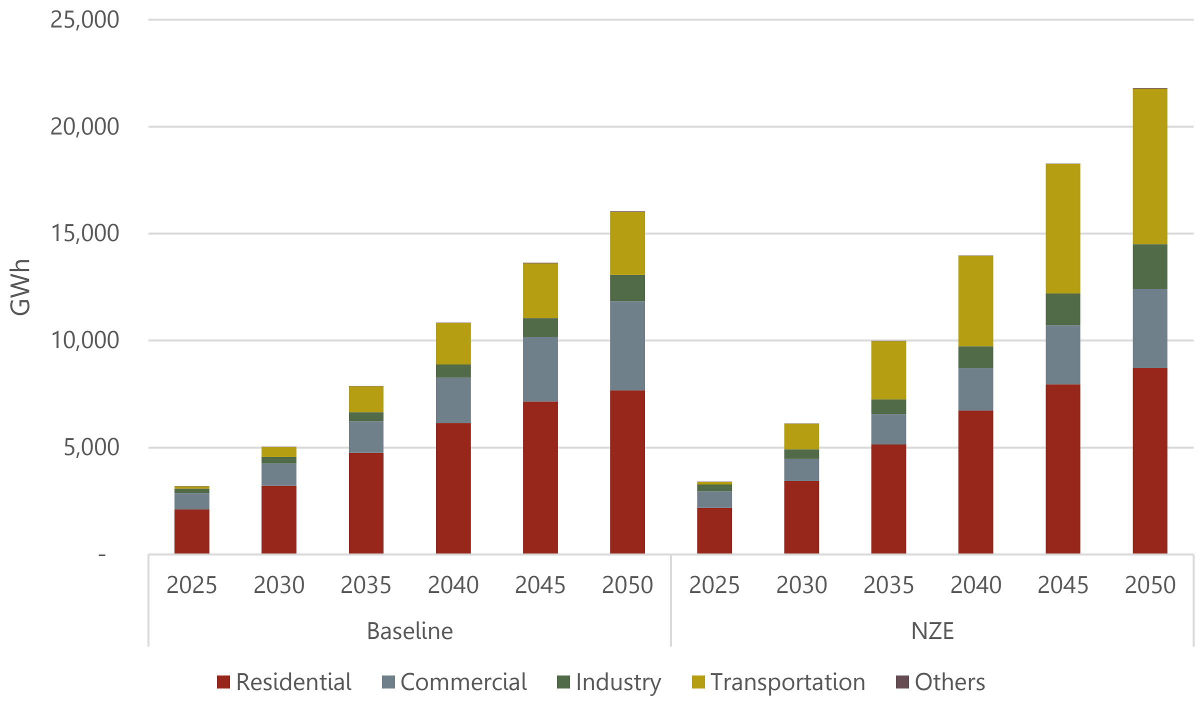


Figure 32. Total end-use electricity demand by sector in NTB.

6.3 Residential sector: Clean cooking and energy efficiency as first fuel

The residential sector is characterised by a great potential of lowering its carbon footprint, with electrification and energy efficiency being focal towards a low-carbon future. By analysing energy use in various household activities such as cooking, lighting, and heating/cooling, better insights can be drawn to design relevant policies and optimise energy use in homes.

The classification of the different activities or appliances considered in the model, along with their total fuel consumption are illustrated in **Figure 33**. Cooking stoves are prevalent in the early years showcasing the highest fuel consumption in both scenarios, while the shares of the different categories are roughly balanced in 2050. All types of stoves have been considered, i.e. gas, electric and wood. Today LPG is most commonly used, followed by woody biomass, while very few homes that are remotely located utilise kerosene. Also, kerosene in similar cases is used for lighting. In NZE, it is assumed that by 2050, all people in West Nusa Tenggara have access to clean cooking and living in general. Also, other cooking and others are considered to only consume electricity. Total energy intensity is higher in Baseline, as NZE considers state-of-the-art electric stoves and generally appliances that are more efficient. No considerations of smart applications have been made.

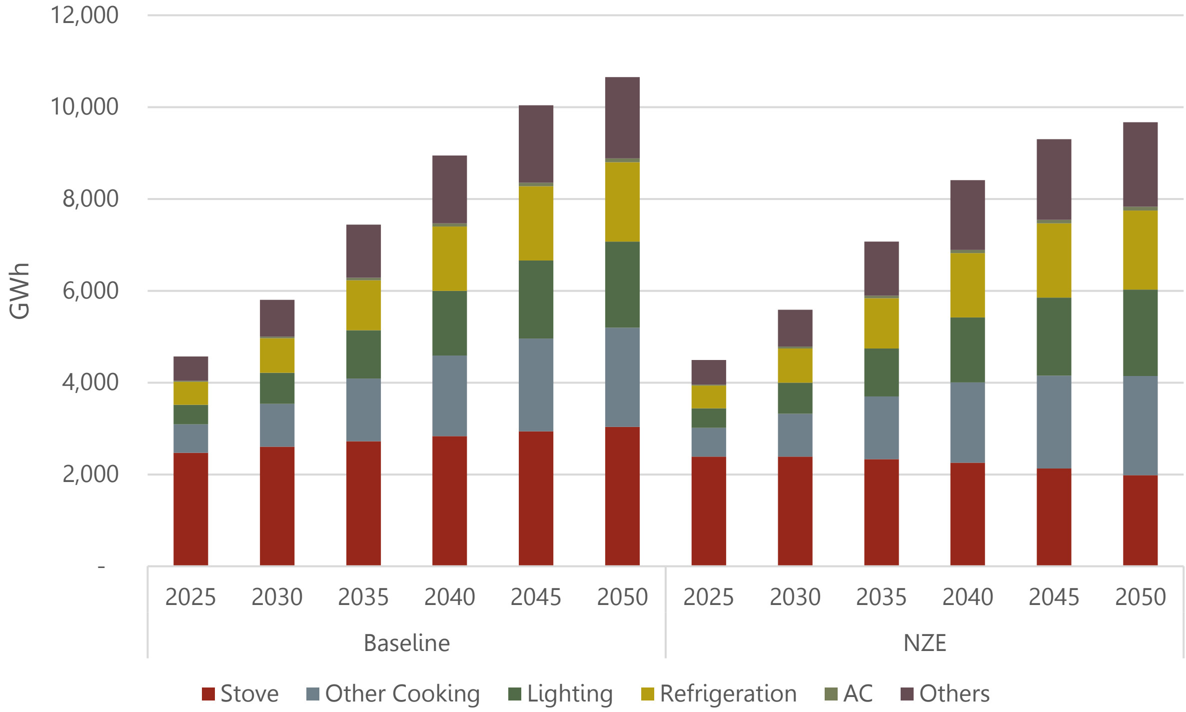


Figure 33. Residential total fuel consumption by application in NTB.

A more intuitive representation of fuel consumption and substitution for Lombok and Sumbawa can be found in **Figure 34** and **Figure 35.** It is evident that electricity is driving the residential demand throughout all modelling years. It is widely used in all residential activities and its share is constantly growing in both scenarios, reaching 6 TWh and roughly 5.2 TWh in Baseline and NZE scenarios for Lombok, while the respective numbers in Sumbawa are 2.6 and 2.4 TWh. Lower numbers of electricity consumption are subject better energy use and more efficient appliances. LPG is highly consumed in the earlier years in gas stoves for cooking processes and remains stable in Baseline for both regions. In NZE, it is gradually substituted mainly with electricity until completely phased down. Biomass is burned in wood stoves and its relatively similar for both scenarios, however, its consumption is steadily increasing, while biogas is used very moderately as an alternative to LPG in cooking. Geothermal energy is also considered for direct use in heating processes in the NZE scenario and only in Lombok, where the resources are located, however, at very low levels of less than 5%. This assumption is based on an ongoing discussion among local energy experts to ensure an affordable source heating for some desolate and mountainous areas of Lombok, however, the heating demand of the region lies on very low levels due to the rather tropical climate. By 2050, all households have achieved a complete phase-down of fossil fuels in NZE scenario in both regions, while Baseline emissions are only linked to LPG consumption, assuming that biomass and biogas are sustainably managed, and their CO_2 emissions are offset via natural carbon sinks, i.e. forestry and agriculture.

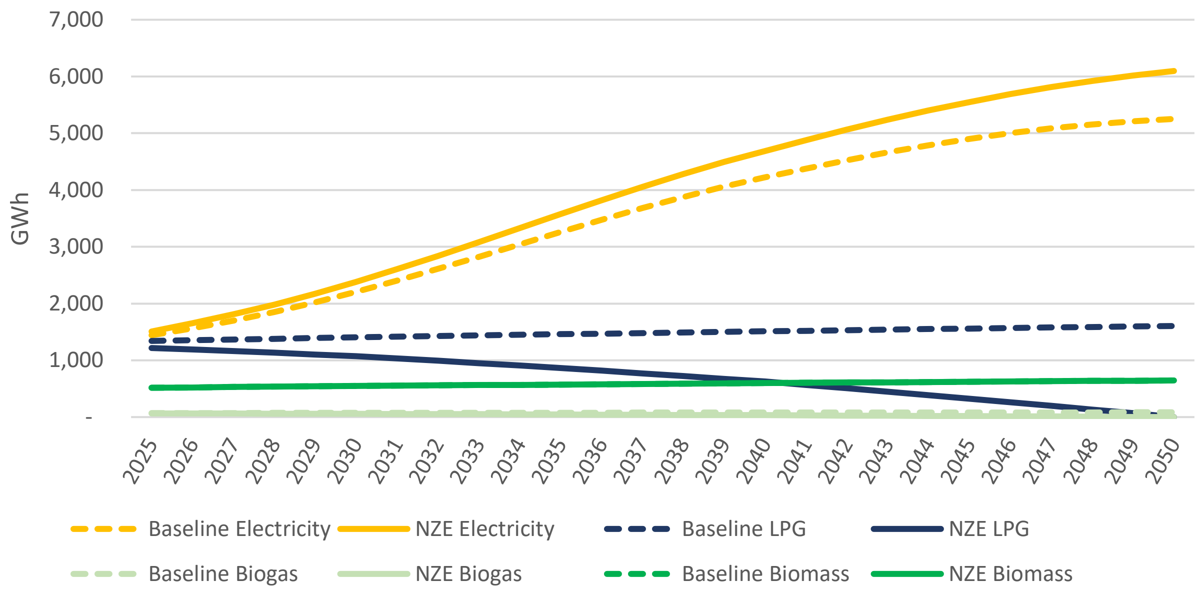


Figure 34. Residential fuel consumption in Lombok.

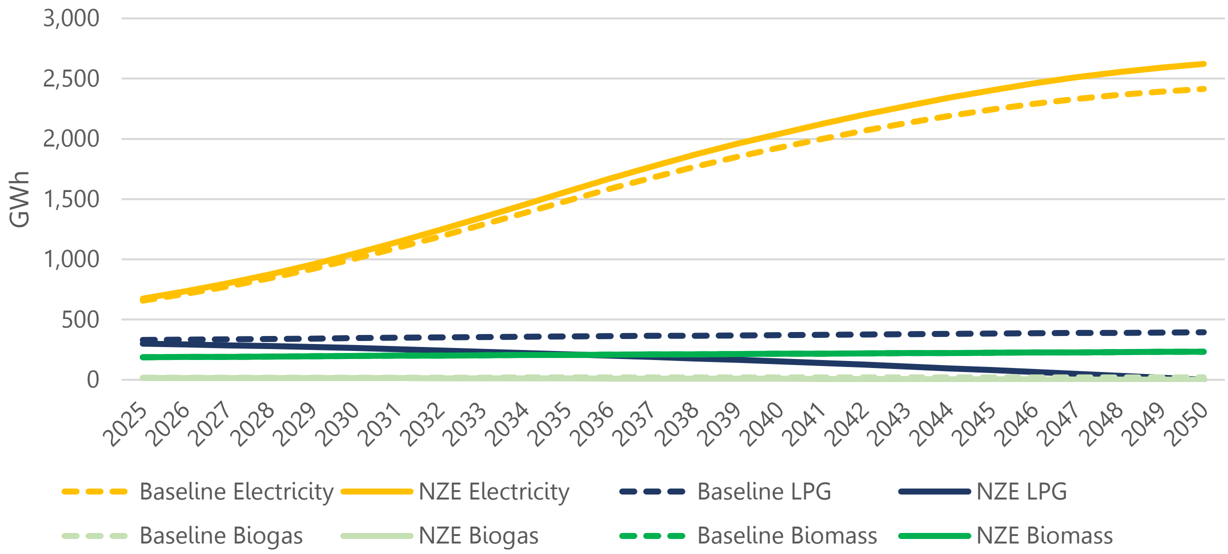


Figure 35. Residential fuel consumption in Sumbawa.

6.4 Commercial sector: Exploring low-having fruits

The commercial sector encompasses various services, trading activities and businesses, including the hospitality subsector. Trade involves retail and wholesale markets, distribution and all monetary transactions for products or services, while the different services entailed in commerce have been disaggregated as follows: finance, office buildings, social and others. This distribution follows the available BPS statistics for West Nusa Tenggara as described in 5.1 Input data – Mapping energy end-use. Overall, commerce has a similar energy consumption mix with households and the same principles and trends could be applied relatively easily in both cases.

Figure 36 presents the total end-use energy consumption by subsector for whole NTB. Commercial applications bank to grow following the provincial economic development and so does energy demand. Relative shares of total annual consumption for each field remain at similar levels between 2025 and 2050, with the hospitality sector being the main exception, as its contribution to value added of the whole sector's economic activity is expected to grow faster than other services, according also to the historical trend. NZE scenario showcases a 17% decrease of final consumption by 2050, due to more efficient appliances, materials and equipment used, as well as improved energy management in buildings.

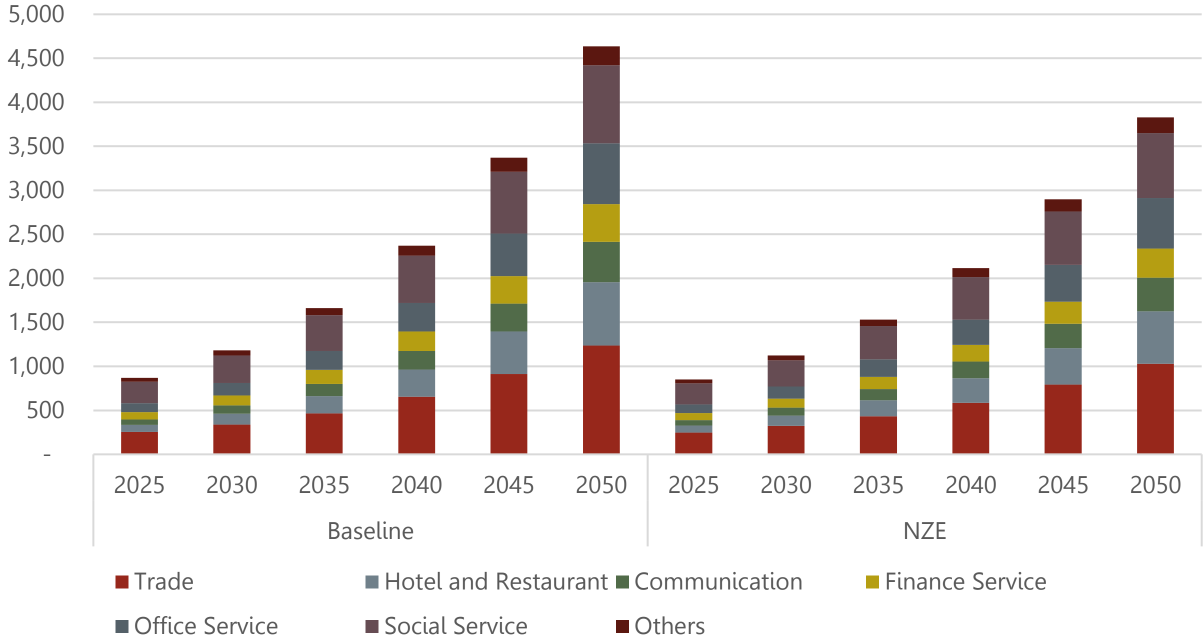


Figure 36. Commercial fuel consumption by application in NTB.

Over 85% of the fuel mix of commerce is constituted by electricity already by 2025 in both scenarios and reaches 90 and 96% for Baseline and NZE respectively in 2050. Total electricity consumption in Lombok reaches 3.3 TWh in Baseline scenario, while 375 GWh are avoided based on the aforementioned energy efficiency measures in NZE, which could be translated as a decrease of 11.3% compared to Baseline. The remainder of energy demand is covered via mostly diesel, LPG and biodiesel, as well as biomass and geothermal although at negligible levels. Baseline sees a steady but slow uptake of diesel and LPG for both Lombok and Sumbawa, which are gradually phased down in NZE, based on electricity and biodiesel substitution, while both scenarios depict a similar growth in biodiesel for both regions. Assuming that suitable retrofits on existing equipment or installation of new gas engines and boilers are made to facilitate B100 biodiesel that is sustainably produced, net-zero carbon emissions are considered feasible in NTB's commercial sector.

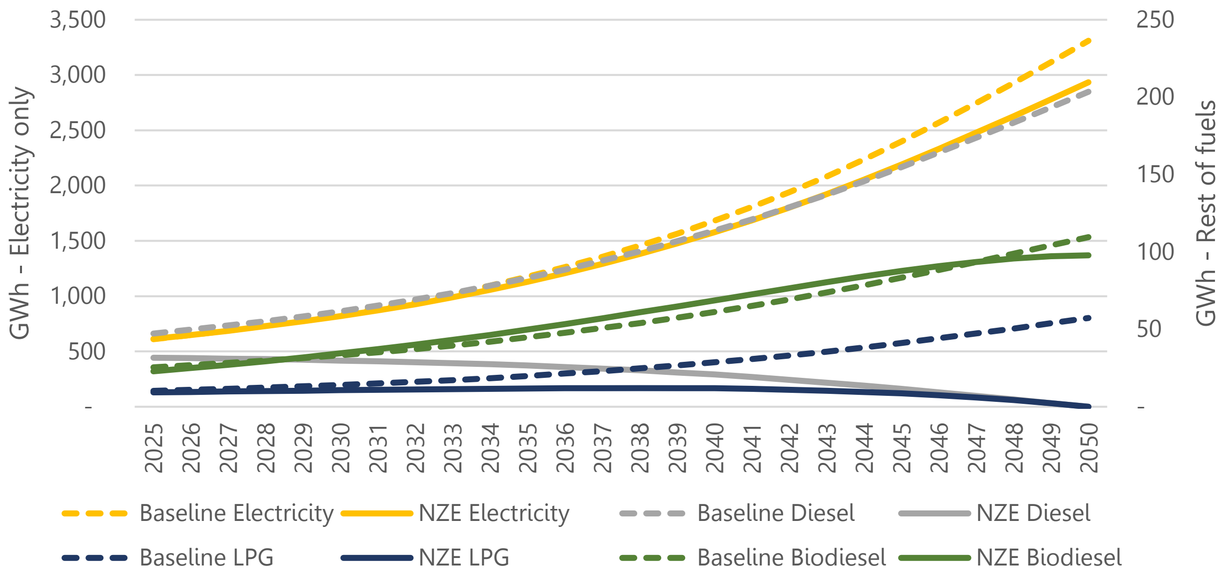


Figure 37. Commercial electricity consumption (left axis) and other fuel consumption (right axis) in Lombok.

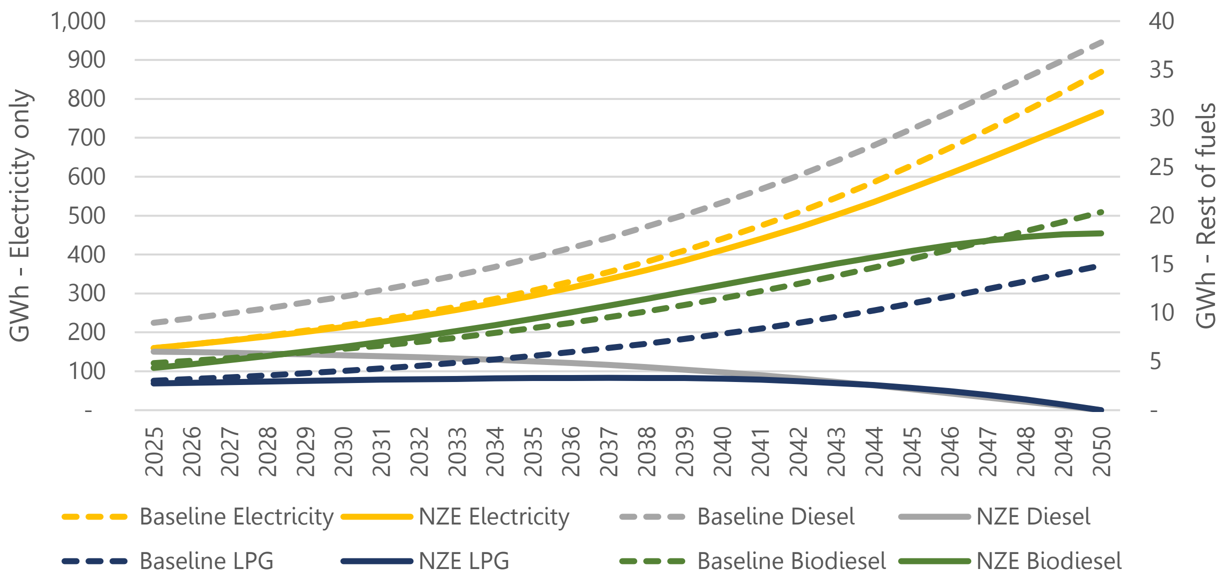


Figure 38. Commercial electricity consumption (left axis) and other fuel consumption (right axis) in Sumbawa.

6.5 Industrial sector: Electrification and biofuels pave the way

Industry is usually characterized by complex and diverse energy-intensive processes that require substantial amounts of heat and power to keep within desired operational levels and therefore is heavily relied on fossil fuels today. However, the potential for a transformation towards a low-carbon industrial future is high, as research and development evolve, and technological innovations are uplifted.

Industrial activity in West Nusa Tenggara is rather low and constitutes about 7% of total GDP for Lombok and 1.7% for Sumbawa in 2021 according to BPS. Some of the key industries in the province are food and beverage, wood, metal and non-metal and others. Mining and smelting, which are driving Sumbawa's economic growth are included in others sector along with agriculture and construction, thus not considered in this section. This classification follows the available data published by BPS. Food sector is by far the most prevalent in NTB consuming more than 60% of the total industrial fuel consumption and grows from 495 GWh in 2025 to 1770 GWh in 2050, followed by the non-metal at approximately 25%. Even though all various industrial processes are assumed to consume more year-by-year, the relative shares remain roughly the same. Slight changes on the composition of value added of each activity is based on BPS data on statistical and projected trends. Baseline total final consumption increases more than fourfold compared to 2025 levels to reach 3,4 TWh in 2050, while NZE achieves a 16.8% decrease against the Baseline value, indicating roughly 575 GWh of avoided energy demand. This could be achieved through electrification and various energy efficiency measures, e.g. the installation of state-of-the-art equipment and machineries, better process designs, circular economy practices etc.

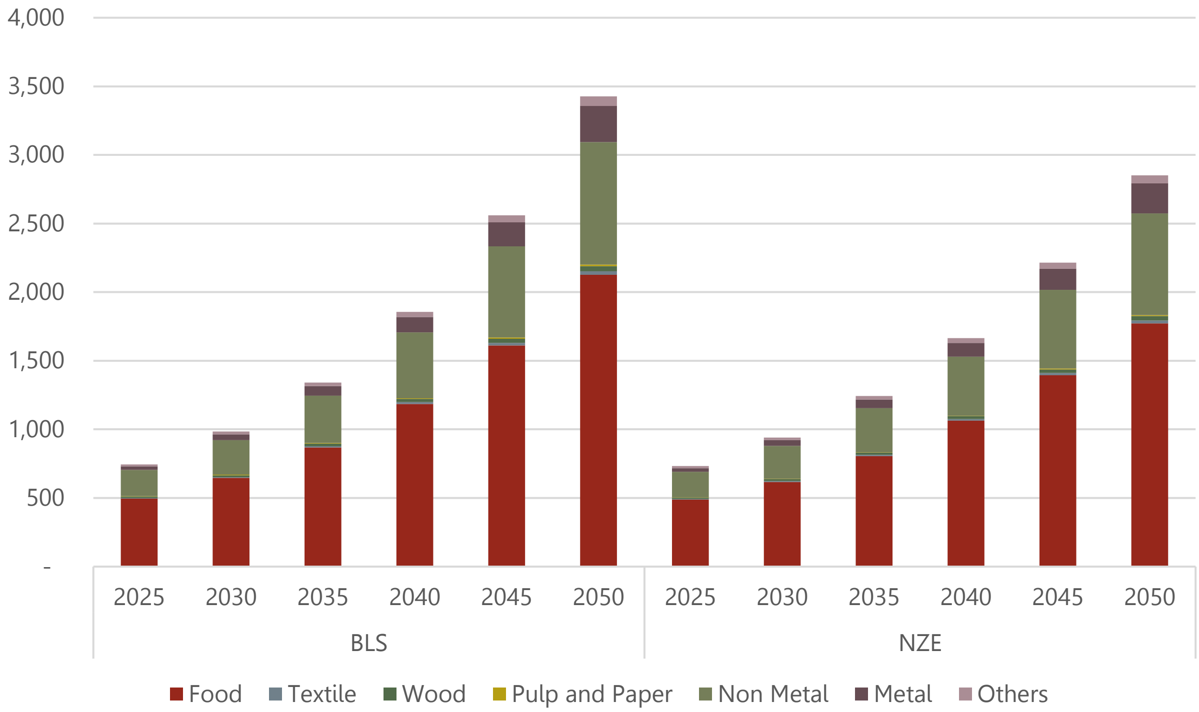


Figure 39. Industrial fuel consumption by process in NTB.

Figure 40 and **Figure 41** illustrate trajectories of the various fuels used for the industrial processes for Lombok and Sumbawa respectively. Left axis indicates the electricity consumption and right axis quantifies the rest of the fuels. All these complex industries consume a variety of different fuels to produce the end-products including electricity, diesel, gasoline, LPG, coal, biofuels, and biomass.

Zooming into Baseline scenario, fossil fuels are extensively used throughout the years in question and their consumption increases steadily, following the overall sector's economic growth. Diesel is the main driver and is constantly higher than electricity consumption. In the Lombok case, it increases fourfold between 2025 and 2050, reaching 960 GWh, which is circa 37% of the total final demand. Electricity and biodiesel are next in line and enjoy a combined share of 50% in 2050. On the other hand, NZE scenario adopts a transitional approach with higher electrification of various low-temperature industrial processes, fuel switching between fossils and biofuels and higher energy efficiency. In Lombok, electricity increases eight times reaching roughly 1.5 TWh, taking up 70% of total industrial energy demand. Biomass and mainly biodiesel replace all fossil fuel consumption that cannot be electrified, with respective shares of 12% and 17% in 2050 and the remainder less than 1% is met by bio gasoline. Although bio potential is very high in West Nusa Tenggara, the increasing biofuel demand from the industrial but also the rest of the energy sectors in the future, could stress the sustainable biomass growth of the province and measures to ensure required sustainability standards of producing, distributing, and consuming bio-based fuels is crucial. So far, NTB is a net importer of biodiesel, however, that could change in the future based on the increasing competition of biofuels on the different sectors across whole Indonesia.

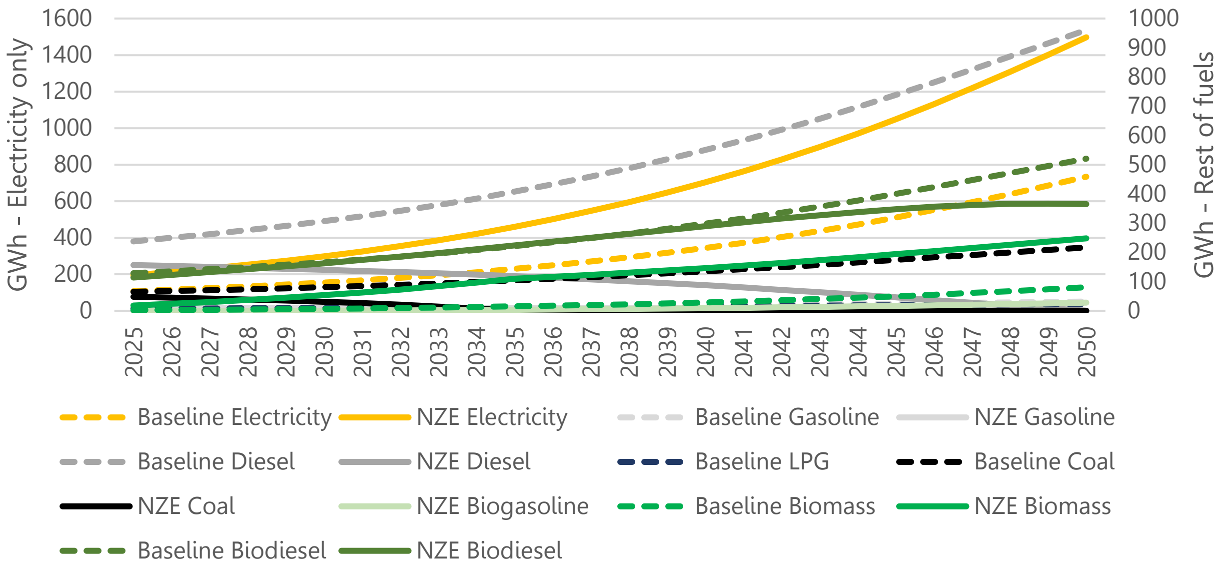


Figure 40. Industrial electricity consumption (left axis) and other fuel consumption (right axis) in Lombok.

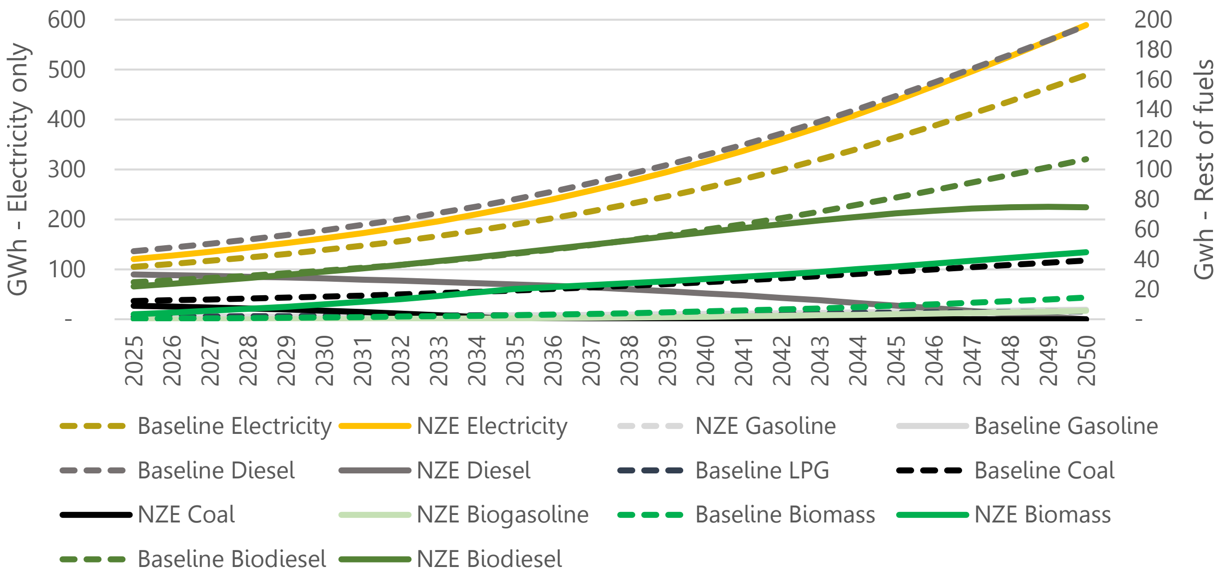


Figure 41. Industrial electricity consumption (left axis) and other fuel consumption (right axis) in Sumbawa.

6.6 Transportation sector: Domination of electric vehicles

Transportation is a cornerstone of modern society and poses great environmental impacts in West Nusa Tenggara but also whole Indonesia. As population grows and economy rises, more and more transport means are expected in all mobility aspects. The lack of adequate infrastructure and transport alternatives, as well as geographical and behavioural considerations, along with relatively low fuel prices, shapes a situation that requires immediate action.

Transforming transport is a capital-intensive process but already many countries around the world have paved the way and exemplify the need for proper incentives and behavioural changes, as well as the importance of upgrading mobility infrastructures and maritime and aviation connectivity. Also, the national government has already forced several policies for road transport, including subsidies and value-added tax (VAT) reductions for battery electric vehicles (BEV). Approximately IDR 7 trillion in the form of cash subsidies are expected to go towards BEV sales, while the levels of VAT reductions are subject to minimum local content requirements on the manufacturing processes. Local government along with PT PLN NTB have already installed charging stations as the electricity demand for electric vehicles is anticipating a large growth in the upcoming years. Those charging stations are regulated along with their electricity charging tariffs by the national government.

The most commonly in-road vehicle used is motorcycles. Indicatively more than 1.66 million were listed in whole NTB in 2021 according to BPS, compared to 105,000 passenger cars and 77,200 heavy-duty trucks. Aviation and shipping relevant growths are only expressed as value added of the whole transportation sector contribution to the economy. As transport is expected to keep increasing its economic impact, following the GDP growth, assumptions have been drawn on the evolution of the different means of transport in terms of vehicle numbers and impact or value added, as explained in **Section 5.2** Assumptions and future projections on final energy consumption. In 2021, transportation fuels included gasoline, diesel and diesel blend with biodiesel at a 30/70 and 35/65 ratio for road transport and shipping, while aviation relied solely on jet fuel or aviation turbine fuel (avtur). By 2050, the two scenarios present a 34% difference in total fuel consumption or roughly 5.3 TWh. Avoided energy consumption is linked to technological advancements on BEV's overall efficiency and optimised driving patterns, as well as the overall higher electrification rate.

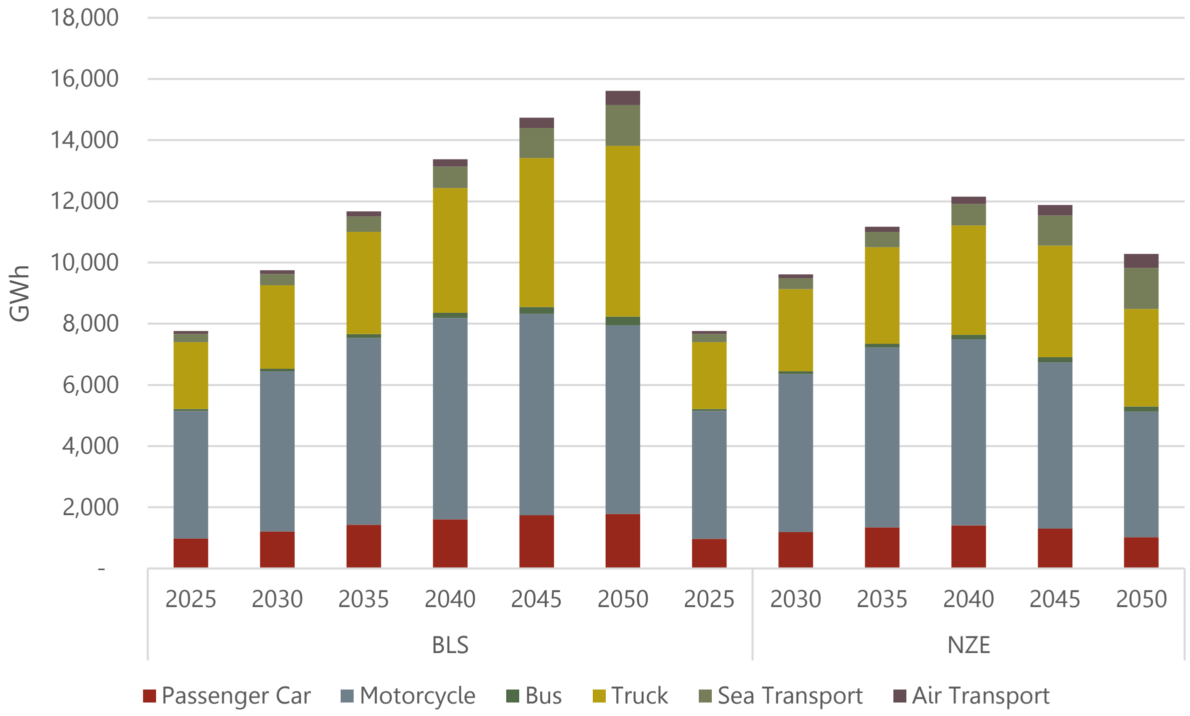


Figure 42. Transport fuel consumption by type in NTB.

Different pathways of transport development are investigated in the two scenarios. Baseline inherits some of the measures and policies adopted in NZE, in a less optimistic approach, but kept in line with existing national ambitions. By 2050, it is assumed that 50% of all motorbikes and one-fourth of all cars, trucks, and buses would be electric. Additionally, converting 10% and 20% of the fleet to hydrogen fuel cell automobiles and buses is taken into consideration. Also, shifting towards hydrogen fuel cells cars and buses at 10% and 20% of the total fleet are considered respectively. Biofuels are projected to be consumed in accordance with the B35 policy, while bio gasoline is expected to also be blended at 2% and 8% ratios in 2030 and 2050. NZE illustrates a much larger penetration of BEVs in the market, along with higher hydrogen and biofuel uptake. Electric and hydrogen vehicle sales infiltrate the market in 2023 and 2030 respectively. By 2050, road transport is assumed to run solely on electric and hydrogen vehicles, while aviation and shipping rely on biofuels for achieving deep sectoral decarbonisation. Hydrogen is assumed to be electricity-based and produced in electrolysers via electrolysis. Therefore, the energy mix of the power sector throughout the years is indicative of the emissions related to hydrogen use.

NZE scenario indicates that in Lombok and Sumbawa, the amount of electricity consumed is approximately 4.9 TWh and 2.3 TWh, respectively, making up approximately 69% and 75% of the total fuel consumed in 2050. In Lombok, hydrogen demand reaches 895 GWh, followed by biodiesel at 793 GWh, while the corresponding numbers for Sumbawa are 315 and 340 GWh. In both regions, together they represent 22% of total fuel demand on average. The remainder 7% and 3.5% is linked with aviation and shipping and is met with jet fuel, bio-jet fuel, and bio-gasoline. Avtur is the only remaining source of CO_2 emissions in transportation for NZE and the year 2050 as it is considered to be technically challenging to fully substitute with bio-jet fuel. The final step to completely decarbonise transport would require on top of biofuel use, a combination of actions, i.e. electrifying short-haul flights, retrofits to allow hydrogen combustion and the high penetration of renewable synthetic jet fuel which is produced via electricity-based hydrogen and carbon that is captured either from the atmosphere or from other emitting processes with carbon-capture technologies. Such alternative fuels have not been considered in the current analysis, only modern advances biofuels.

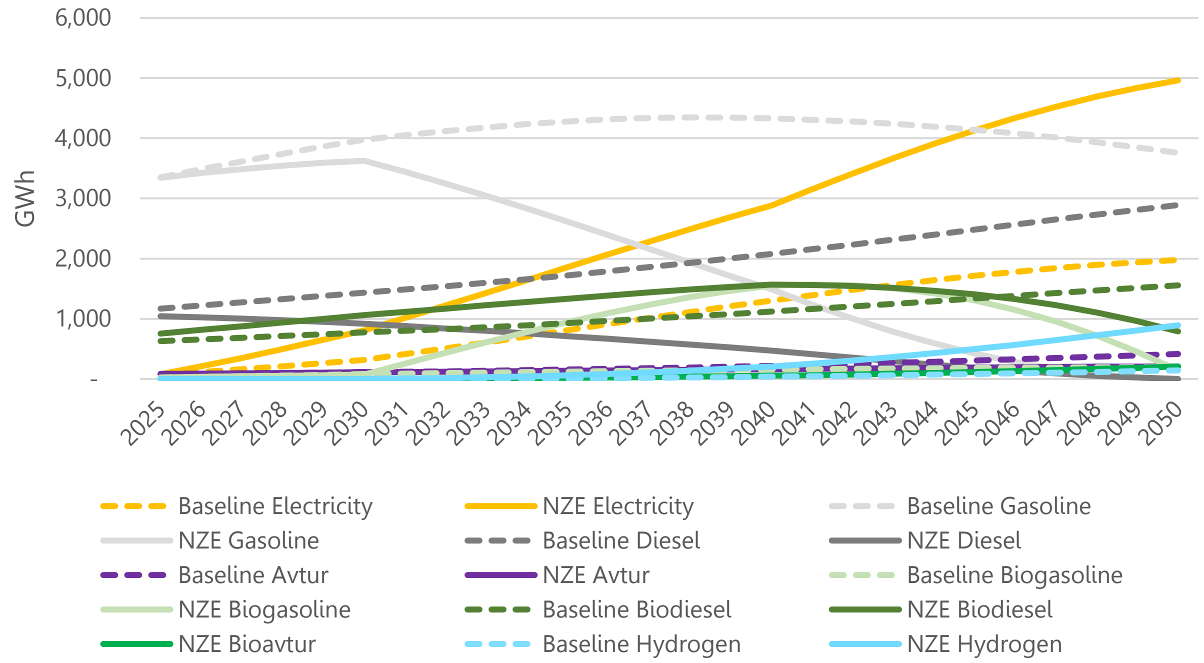


Figure 43. Transportation fuel consumption in Lombok.

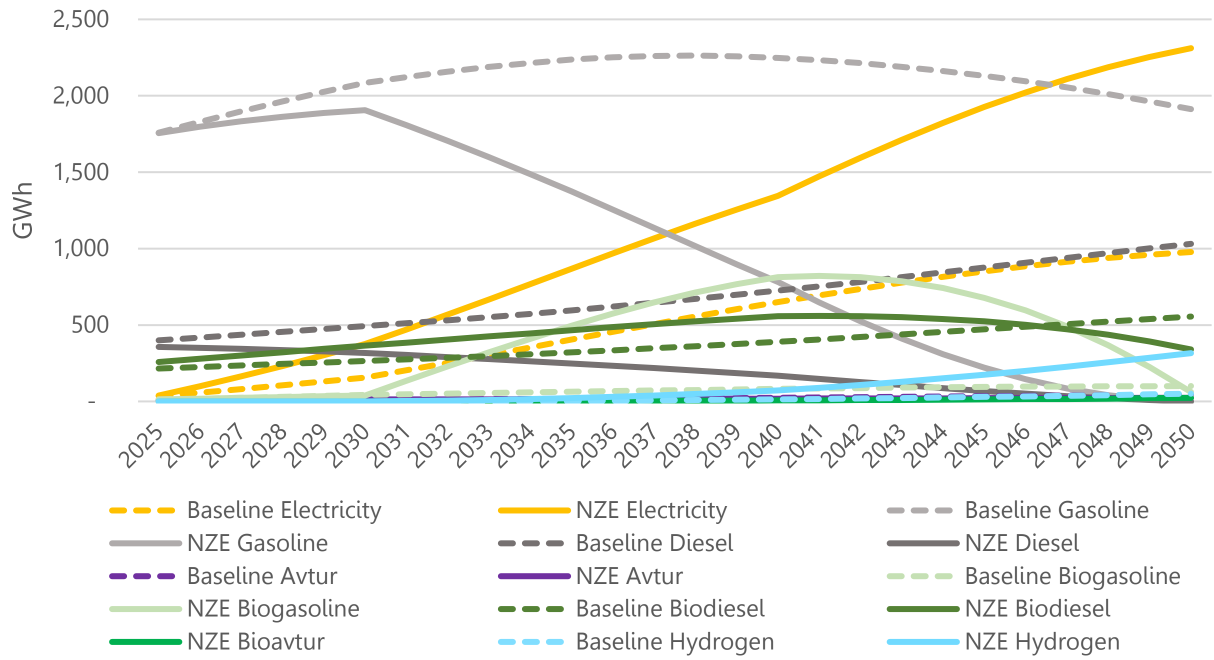


Figure 44. Transportation fuel consumption in Sumbawa.

6.7 Others sector: Shifting to alternative fuels

As described earlier, others sector encompasses agriculture, construction and mining in the case of Sumbawa. Agriculture and mining are strategic sectors for West Nusa Tenggara and of high importance. Agriculture is the source of many viable products for domestic consumption or exports to other regions and comes second in terms of economic value added for both Lombok and Sumbawa. It's also very important in terms of occupation for the province as a large number of the local population practices farming. Equally important for Sumbawa is mining activity, being the main economic driver of the area and constituting more than one third of the regional GDP. Finally, construction is expected to keep increasing over the years following the targeted economic growth and the development of the local infrastructure and services. Construction is assumed to comply fully with the GDP evolution of NTB, while mining's growth is assumed stable after 2035, due to finite mineral resources and agriculture development is factored by 0.5 against the annual economic build-up, indicating a slower expansion based on land availability and sustainability considerations.

All these difference processes that accounted for in others are highly linked to fossil fuel consumption today. **Figure 45** illustrates the trajectory of agriculture and construction for Lombok where mining activity is modest. Diesel and gasoline are the ascendant fuels consumed in the early years and their use is constantly increasing for BLS scenario along with a moderate increase of bioenergy, as a substitution mean. On the other hand, NZE adopts a more optimistic approach, where conventional fuels are slowly phased out of the energy mix, with full substitution to biofuels. In 2050, bioenergy is responsible for meeting 95% of the total sectoral demand with electricity complementing the remainder. Biodiesel covers two-thirds of total bioenergy use and then bio gasoline the other one third lying at 104 GWh. Electricity consumption is rather stable in both scenarios due to high uncertainty linked with the existing regional practices of agricultural and mining activities and lack of detailed data. However, that might be an underestimation of the electrification potential of this sector.

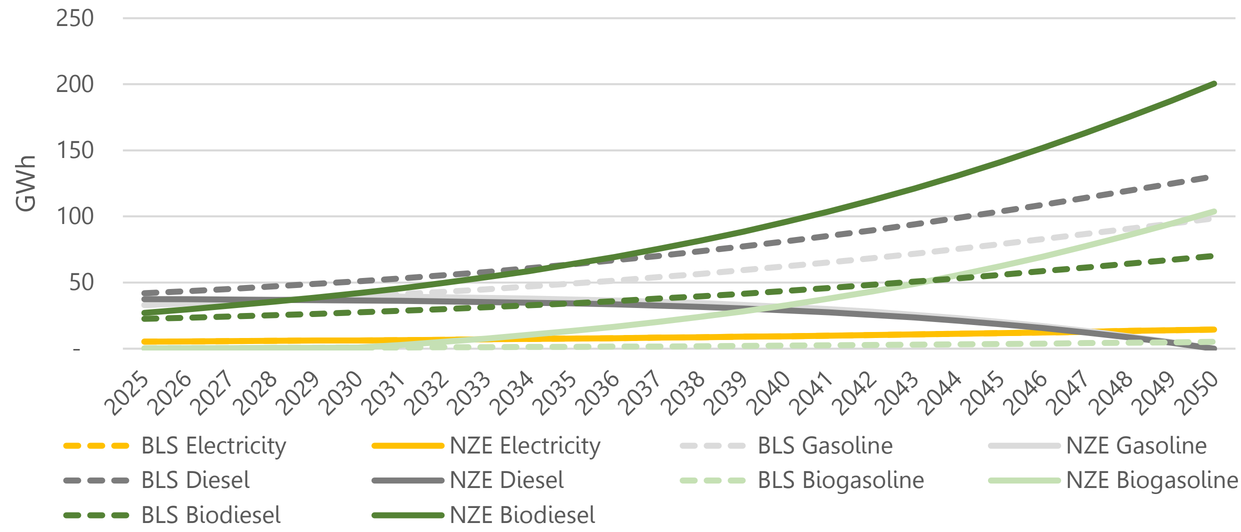


Figure 45. Others fuel consumption in Lombok.

In the case of Sumbawa, same principles are applied with the difference being on the much higher total final consumption (2,290 GWh against 320 GWh in Lombok). As aforementioned, mining activity is the main source of energy demand, where diesel is the prevalent fuel. Therefore, much higher levels of bio-diesel substitution are required in this case. In NZE it reaches 2,230 GWh which is roughly 97% of the total regional consumption and more than 10 times than the biodiesel demand in Lombok. The generally stable fossil fuel consumption, which is more evident in Baseline scenario is due to 2 major mining projects being still in exploration phase, so the only operational mining facility is expected to stay within today's levels of activity.

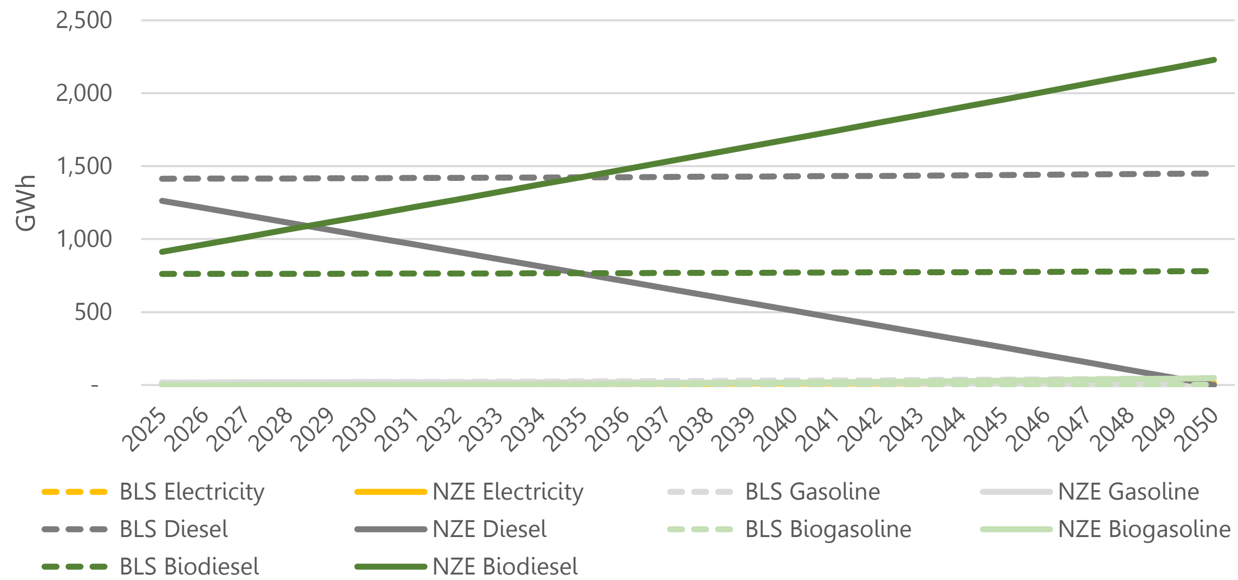


Figure 46: Others fuel consumption in Sumbawa.

6.8 Energy end-use related CO_2 emissions: A more sustainable future awaits

Understanding the different narratives of the two scenarios and their impacts in terms of CO_2 emissions is fundamental in shaping recommendations on policy-making and respective timelines. The "act now" approach that is commonly expressed on a global scale has been adopted in the NZE scenario, with measures to accelerate the energy transition in West Nusa Tenggara applied already in early years. Baseline examines a pathway that is in line with current national and regional in-place policies, however, consideration on new policies is limited.

As illustrated in **Figure 47**, transportation is by far the highest emitting sector throughout 2050 in both scenarios followed by residential and other sectors at equal levels of circa 15%. Already in 2030, a 20% reduction between Baseline and NZE is achieved, which is driven mainly by transportation and BEV market penetration. The decrease is more than tripled by 2040 reaching two-thirds of total Baseline CO_2 emissions. In 2050, Baseline reaches 4 Mt with transportation taking up 65% and residential, industrial and other sectors combine for 33% at equal contributions. In NZE scenario, 60 kilotons of CO_2 are remaining in the whole NTB energy system, linked to aviation. Reaching net-zero emissions would require negative emissions to offset the CO_2 remainder, which is technically feasible using bioenergy carbon capture and storage (BECCS) or a combination of electrifying short-haul flights, retrofit jet engines to run on hydrogen and substitution of jetcfuel with electrofuels. E-jet fuel for example could be used as a drop-in substitute of conventional jet fuel and is produced with renewable hydrogen and CO_2 captured in CCS technologies.

A fuel-based CO_2 comparison between the two scenarios is presented in **Figure 48**. Diesel and gasoline are driving carbon dioxide emissions as powering the energy system in Baseline, followed by LPG. Diesel's constantly growing consumption leads to 1.8 Mt, while gasoline-based emissions peak around 2040 and LPG lies at roughly constant levels between 2020 and 2050. In NZE scenario all fossil fuels are phased down in 2050, except of avtur as aforementioned in the previous paragraph.

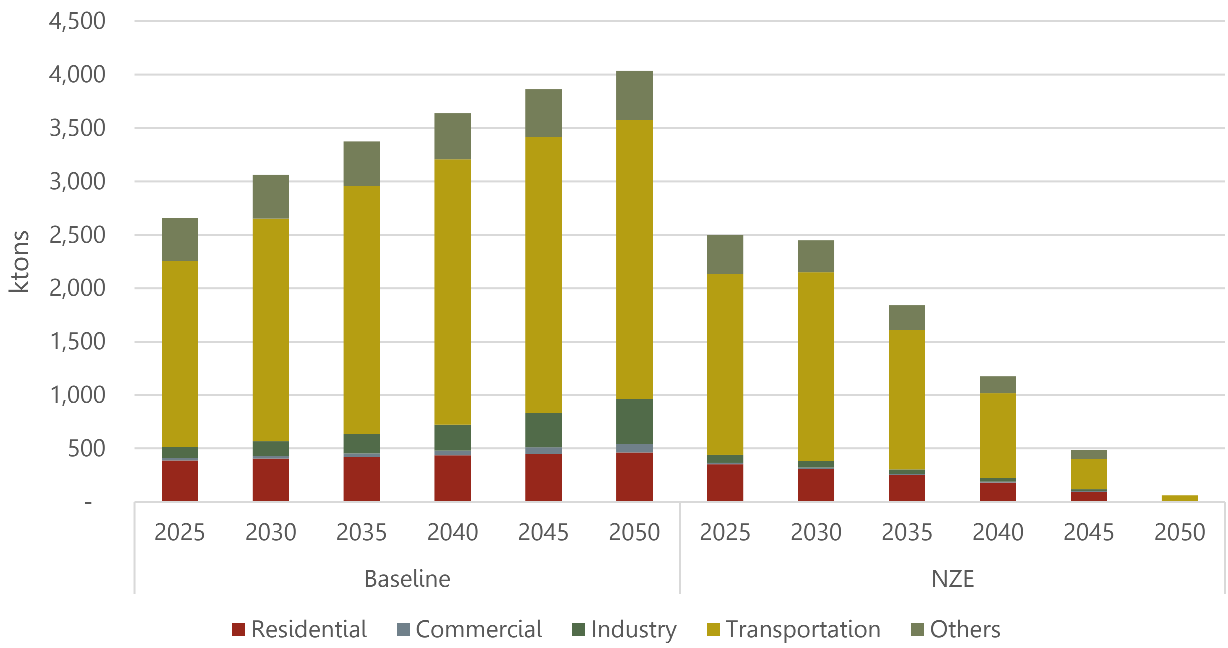


Figure 47. End-use CO_2 emissions by sector in NTB (excluding power sector).

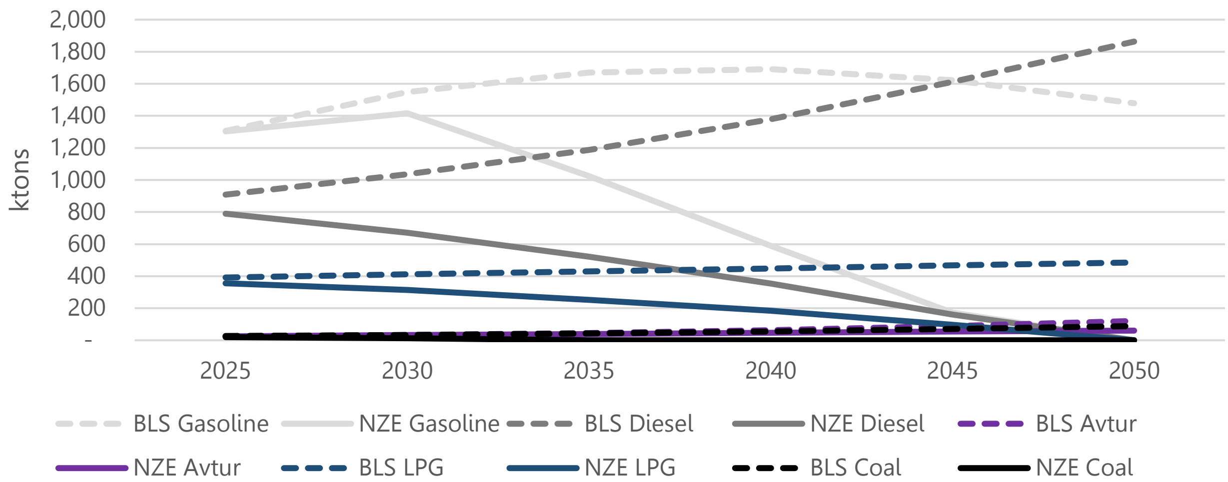


Figure 48. End-use CO_2 emissions by fuel in NTB (excluding power sector).

6.9 Key messages

All sections of this chapter illustrate two different pathways for the total final end-use energy consumption in the two under-investigation scenarios, namely Baseline and Net-Zero Emissions. The first deals with a more conservative approach, following the general national and provincial trends, as well as any official pledges made by national government. Therefore, moderate transitional policies are adopted within the various energy sectors and fossil fuels are heavily involved throughout the temporal scope of the analysis. NZE presents a much more ambitious development of the energy system, aiming to reach net-zero emissions by 2050 across all sectors and processes. That requires a full transformation of the existing system as a whole involving various different measures and strategies. Some of the key takeaways are:

- Electricity is the main driver of the energy transition and finds several applications across the majority of end-use types, activities and processes. Unlocking its full potential requires the implementation of various electrification strategies in residential, commercial, industrial and transportation sectors. End-use electricity consumption reaches 16 TWh in Baseline scenario and 21.8 TWh in NZE by 2050, which make up for 41% and 68% of total final consumption respectively.

- Energy efficiency is equally vital in achieving a prosperous low-carbon economic development. Decoupling energy intensity and economic growth is pivotal to avoid burdening the local energy and material resources. All sectors demonstrate a great potential for reduced energy consumption with the right policies, equipment and behavioural patterns in place. Sectoral results in NZE showcase avoided consumptions of up to 20% compared to Baseline in end year.

- Fuel-switching also possesses a central role in West Nusa Tenggara's energy transformation. Indonesia is generally a country with great biomass resources and has already started shifting towards modern utilisation practices. However, due to the growing interest of the different sectors towards biofuel consumption, careful considerations are required on factors such as feedstock sourcing, land-use and other sustainability matters. By 2050, bioenergy consumption in NTB, including biomass direct use, biogas, bio gasoline, biodiesel and bio jet-fuel, accounts for roughly 19% in NZE scenario, while Baseline levels lie at 13%, with biodiesel being the most frequently consumed.

- CO_2 emissions are constantly growing in Baseline indicating a rise of roughly 35% between 2025 and 2050, led by the transportation sector with a mean value of 67% of total CO_2 emitted in each year. Diesel is the fuel with the highest emission contribution. It peaks in 2050 at 1.86 Mt. CO_2 emissions peak in 2025 in the NZE scenario, however, 2030 levels are marginally lower with less than 50 kilotons difference. Compared to Baseline, NZE scenario illustrates a decrease of 20%, 68% and 98% in 2030, 2040 and 2050 respectively. By 2050, only 60 kt remain in the system for NZE which are linked to aviation and jet fuel or avtur consumption.

- Going the extra mile to achieve full decarbonisation of all end-use sectors would require the consideration of carbon capture, utilisation, and storage (CCUS) and bioenergy carbon capture and storage (BECCS) technologies, as well as the development of synthetic gaseous and liquid fuels which have not been considered in this study. Synthetic fuels, also known as electro fuels, e.g. renewable methanol, ammonia and e-jet fuel are produced via renewable pathways and are vastly examined as potential candidates to tackle remaining emissions from the hard-to-abate transportation and industrial activities, e.g. aviation, shipping and steel making.

7. Power sector development

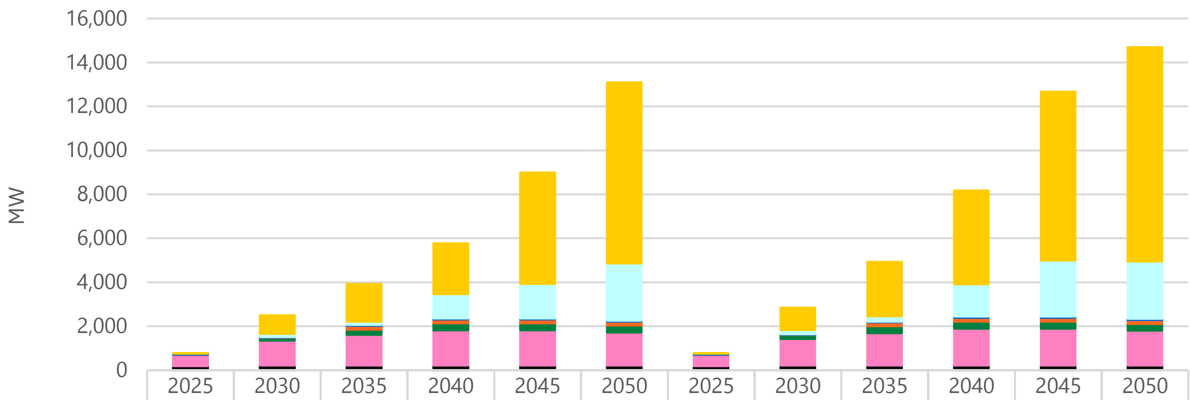
7.1 Findings for the development of the power sector towards net zero emissions by 2050

This section of the report presents the results of the optimization of least-cost capacity expansion and dispatch for the Nusa Tenggara Barat power system between 2023 and 2050, offering a comprehensive analysis of the evolving power system landscape. The transformations for the NZE scenarios are explored and analysed in comparison to the baseline scenario which reflects the development based on existing national and local planning, shedding light on the key factors influencing the power system development towards a net zero emissions by 2050.

7.2 Extensive short- and long-term capacity expansion, especially in solar and wind

Figure 49 shows the total installed capacity by source in the two scenarios. This represents the existing and planned capacity along with the model optimised capacity expansion. The capacity expansion is from 2026 onwards in both scenarios. This year is selected considering a pragmatic timeline for the earliest new development. It is important to allow for this expansion since, especially in the NZE case, the electricity demand growth is higher than originally planned for in RUPTL 21.

The capacity for power generation in Nusa Tenggara Barat goes from a generation mix mostly made up of fossil fuels, to an extensive expansion of power generation capacity, where towards 2050 renewables account the largest share of installed capacity. More precisely solar and wind constitute most of the installed capacity in the two scenarios followed by a significant natural gas capacity. Geothermal and bioenergy see a conspicuous development as well, harnessing the resource availability of the region.



	Baseline						NZE					
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Solar PV	31	841	1,718	2,318	5,063	8,231	31	1,008	2,467	4,253	7,690	9,758
Wind		143	143	1,098	1,568	2,605		188	241	1,480	2,547	2,605
Hydro	39	39	41	52	52	52	39	39	41	52	52	52
Geothermal		10	175	175	175	175		10	175	175	175	175
Bioenergy	10	122	241	316	316	316	10	174	316	316	316	316
Natural Gas	515	1,138	1,398	1,608	1,608	1,508	515	1,217	1,477	1,687	1,687	1,587
Coal	186	206	206	206	206	206	186	206	206	206	206	206

Figure 49 Installed capacity in Nusa Tenggara in the two main scenarios.

As mentioned, both scenarios require extensive investments in power generation capacity. **Figure 49** shows the cumulative investment in Nusa Tenggara, **Figure 50** illustrates the percentages of the total potential fuel sources that are utilised in the simulated years. The magnitude of the investments is most notable in the short to medium term in Lombok and long-term in Sumbawa.

In Lombok a steady increase in capacity from 2030 can be seen in both scenarios, and the expansion is similar in both scenarios. The main notable difference between baseline and NZE, for Lombok, is the additional natural gas capacity in the NZE scenario. This is a consequence of not only the higher demand in the NZE scenario, but also the requirement for dispatchable generation to support the increased solar and wind deployment in the system, as will be seen in the proceeding results.

In Sumbawa, there is an exponential growth in capacity investments in the baseline scenario, more specifically in solar PV and wind. This expansion is even more extensive in the NZE scenario, reaching almost 9 GW capacity in 2050. The extensive expansion in solar and wind capacities is a consequence of the potential for these technologies in the province along with the fact that these provide the cheapest solution for electricity production.

While there is still some potential for solar and wind expansion, the development is constrained to account for a realistic deployment and the expected development of the required supply chain. However, the resulting capacity investments is based on ideal conditions, not considering for example capital availability and land costs, which might affect installed capacities.

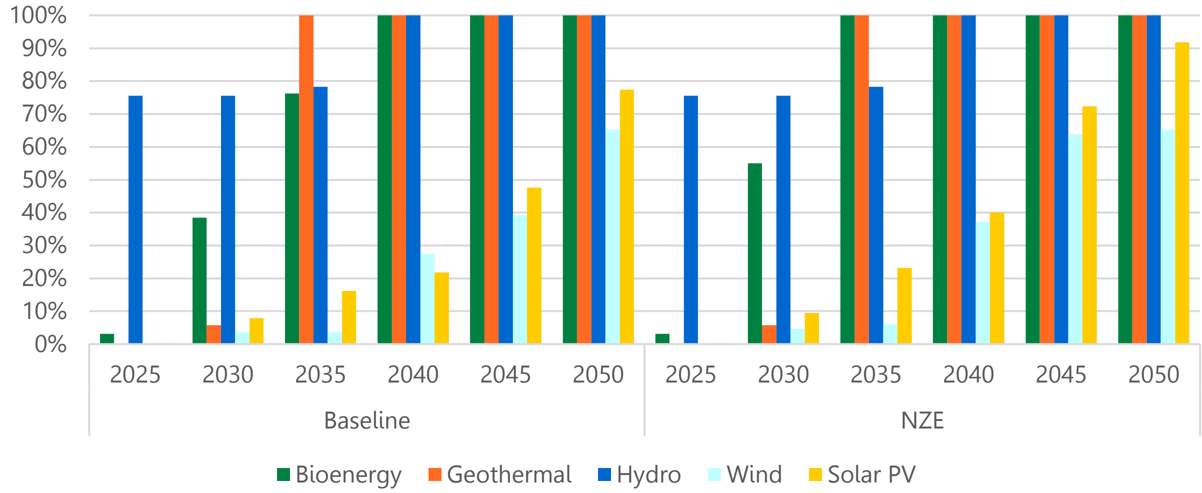


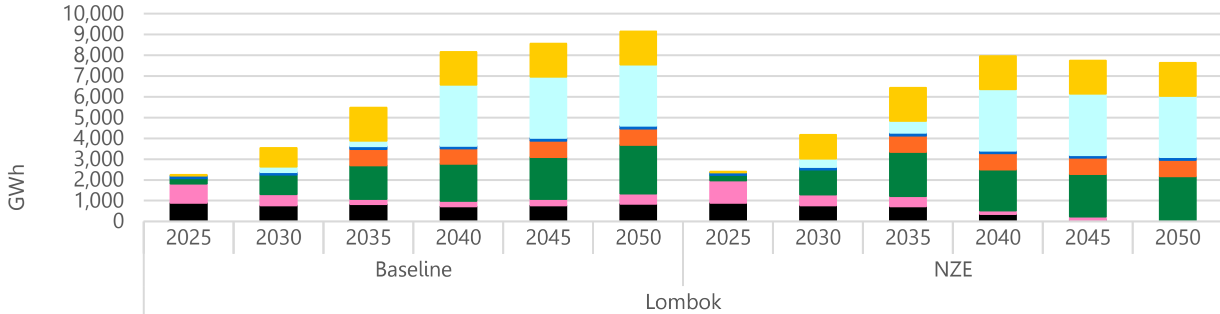
Figure 50: Share of installed capacity with respect to potential in the two scenarios.

For geothermal power, the capacity development is the same in both scenarios. Most available hydro resources are already utilised, and the rate of further expansion is the same in the two scenarios. In the NZE scenario there is an earlier expansion of investments in bioenergy capacity compared to the Baseline scenario. In the NZE scenario, the full bioenergy potential is utilised by 2034, compared to 2038 in the Baseline scenario. Most of the bioenergy capacity development is in Lombok.

The transformation of power generation capacity in Nusa Tenggara Barat reflects a significant shift from fossil fuels to renewables. Both scenarios necessitate substantial investments in capacity expansion, with the short to medium term focusing on Lombok as it is the larger demand centre, but in the long term the available potential in Sumbawa is better capitalized. This transition is crucial towards a less CO_2 intensive energy system, with a total of 13 GW renewable energy expansion in the NZE scenario.

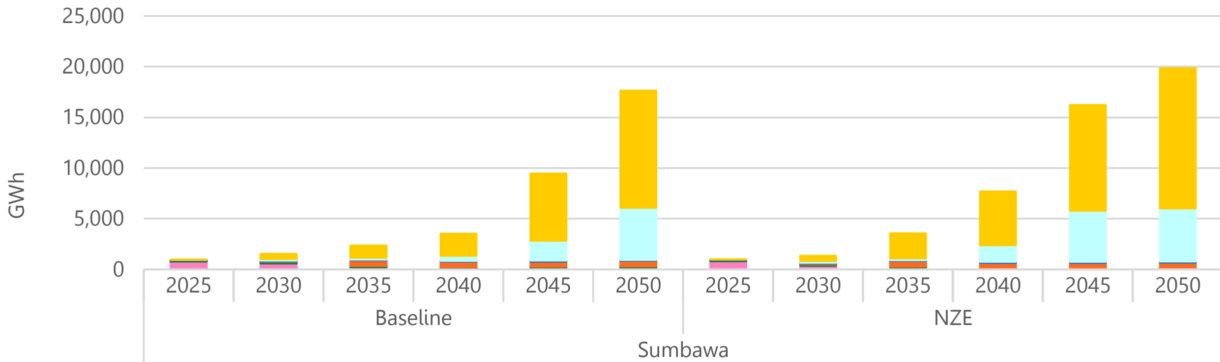
7.3 Generation: Renewable electricity dominates power generation

In both scenarios, a vast utilisation of renewable energy is seen due to the high investments. When looking at the electricity generation mix in Lombok, **Figure 51**, it is evident how the power generation mix changes more radically in the long term. Towards 2050, in case of the NZE scenario, fossil fuels are phased out of power generation. On the contrary, in the Baseline scenario the utilisation of these sources is decreasing initially till 2030 and then increasing again towards 2050. The total electricity generation in Lombok is higher in the Baseline scenario, where the absence of a CO_2 target allows for utilisation of existing assets and therefore generation of electricity from fossil fuel till 2050. The lower electricity generated in the NZE scenario is around 1500 GWh. This is an even more striking difference when the difference in electricity demand between the baseline and NZE scenario is considered. As will be discussed in proceeding sections, this difference in Lombok in the NZE scenario is covered through increased imports from Sumbawa.



Lombok	Baseline 2025	Baseline 2030	Baseline 2035	Baseline 2040	Baseline 2045	Baseline 2050	NZE 2025	NZE 2030	NZE 2035	NZE 2040	NZE 2045	NZE 2050
Solar PV	32	895	1,583	1,571	1,583	1,583	32	1,132	1,583	1,583	1,583	1,583
Wind		267	269	2,931	2,947	2,947		403	569	2,947	2,947	2,947
Hydro	126	124	131	127	131	131	126	125	131	131	131	131
Geothermal			787	744	788	788			788	788	788	788
Bioenergy	259	933	1,617	1,774	2,018	2,348	259	1,207	2,132	1,961	2,045	2,178
Natural Gas	921	534	250	269	306	483	1,084	509	484	166	152	
Coal	899	780	838	728	781	856	899	784	732	368	82	

Figure 51: Overview of generation in the two scenarios for Lombok.



Sumbawa	Baseline 2025	Baseline 2030	Baseline 2035	Baseline 2040	Baseline 2045	Baseline 2050	NZE 2025	NZE 2030	NZE 2035	NZE 2040	NZE 2045	NZE 2050
Solar PV	15	488	1,201	2,183	6,617	11,568	15	508	2,442	5,283	10,402	13,823
Wind		171	178	499	1,950	5,120		188	187	1,662	5,058	5,240
Hydro	68	65	69	90	87	89	68	67	68	87	86	91
Geothermal		73	561	536	534	557		78	562	533	524	580
Bioenergy	98	156	124	102	81	107	98	144	115	84	88	112
Natural Gas	699	426	86	20	68	53	734	219	54	14	44	
Coal	83	154	129	109	112	144	83	141	121	20	5	

Figure 52: Overview of generation in the two scenarios for Sumbawa.

In the context of Sumbawa, leading up to 2050, a notable trend emerges in both scenarios: an exponential growth in electricity generation becomes evident. The primary source of this escalating electricity production is renewable energy, with solar and wind power as primary sources, as shown in **Figure 52**.

In the baseline scenario, the reliance on fossil fuels declines until 2040, but then experiences a slight rise between 2040 and 2050. In contrast, the NZE scenario maintains a consistent and uninterrupted decline in fossil fuel usage, eventually reaching zero gigawatt-hours (GWh) of generated power by 2050. Notably, in Sumbawa, unlike Lombok, the NZE scenario sees a higher amount of electricity generated compared to the baseline. This disparity can be attributed to Sumbawa's superior potential for renewable energy sources when compared to Lombok.

It can be reasonably expected that, when comparing the two scenarios between the two islands, the attainment of NZE, particularly considering the higher demand in Lombok compared to Sumbawa, will rely significantly on the implementation of flexibility measures and the expansion of transmission lines. The additional contributing factors to attain the NZE scenario are further highlighted later in this chapter.

7.4 Gradual reduction in operation of coal and gas plants in achieving early net-zero

The capacity factor (CF), a measure of the actual output or energy production of a power plant as a percentage of its maximum potential output, is an important element to understand the utilisation of the installed capacity. In Nusa Tenggara, the CF for geothermal is close to the maximum, 90% in both scenarios. The same is also true for hydro power, where the capacity factor is close to the maximum level of 56%. In the Baseline scenario, CF for coal and natural gas are relatively higher initially. For coal it varies slightly throughout the period. The CF for natural gas reduces in the medium term and is under 10% from 2030 to 2050. In the very end of the simulated period, between 2045 and 2050, the CF increases to around 5% but does not reach the initial levels of utilisation.

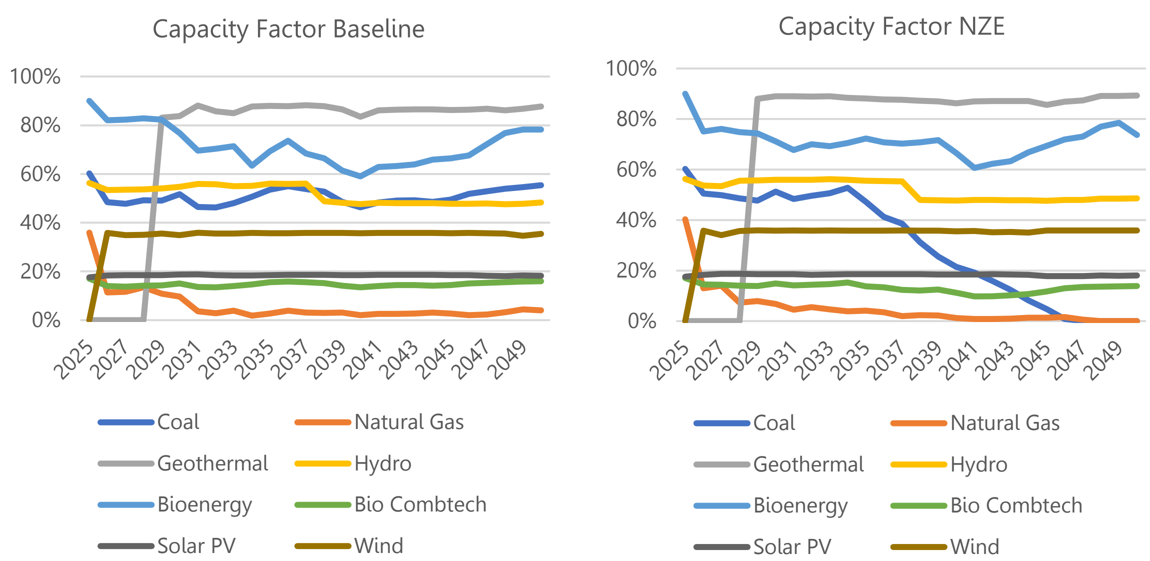


Figure 53: Capacity factors for power generation technologies in the two scenarios.

In contrast, in the NZE scenario, there is a noticeable shift towards utilisation of cleaner energy sources. Coal and natural gas capacity factors decrease significantly, reflecting a reduced reliance on fossil fuels. More specifically, the coal CF drops after 2035, showing a steady decrease in use of this source in the NZE scenario. Natural gas CF follows a similar trend in NZE and Baseline with the main difference after 2045 where in the NZE scenario reaches zero to meet the scenario's target. Geothermal, hydro, bioenergy, and bio combined technologies continue to maintain stable capacity factors in the entire period simulated, as indicated in **Figure 53**.

7.5 The rise of renewables in the electricity mix

Figure 54 depicts the share of renewable and fossil fuels covering the power generation in the two scenarios. The share of renewable power production is rapidly growing in both scenarios on both islands. Looking at Lombok, in the baseline scenario the initial share of 19% of RE in 2025 jumps to 63% in 2030 and reaches around 88% in 2040, the different CO_2 reduction goal, consisting of national net zero by 2060, coupled with the increasing electricity demand result in a slight decrease of renewable share in the power mix in 2050.

In the NZE scenario the initial lower share of RE in 2025 compared to the baseline is attributable to the higher electricity demand of the scenario. Towards 2050 the RE share in the power generation surpasses the baseline scenario. Already in 2030, the extensive investments result in a share of 69% and reaches 100% of the total power generation in 2050. Similar results can be seen for Sumbawa where for the baseline scenario the share of RE sees a steady increase till reaching around 99% of the generation mix in 2050. In the NRE scenario the renewable generation share exceeds 99% already in 2040 and reaches 100% in 2050. Overall, the increasing share of renewables in both scenarios is largely attributable to the increase in use of solar PV, primarily in Sumbawa, where the power system is fully based on renewables from 2048.

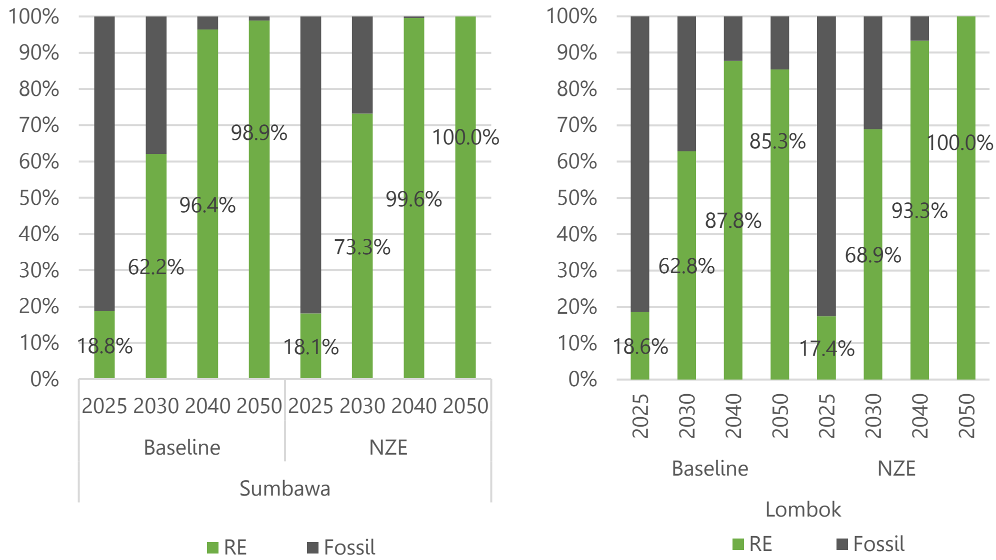


Figure 54: Share of renewable electricity in the generation mix for Lombok and Sumbawa in the baseline and NZE scenarios.

The implication of the discussion above is that a RE expansion is inherent to the achievement of CO_2 targets. Therefore, this negates the necessity of setting both an RE and CO_2 target.

7.6 Ambitious reduction to zero CO_2 emissions is achievable

Regarding CO_2 emissions, there is a constraint in the NZE scenario, capping annual CO_2 emissions, reaching zero before 2050. The net zero emissions target covers the entire economy. The power sector is a key sector, currently making up close to half of CO_2 emissions from the Nusa Tenggara Barat province.

To comprehend the impact on CO_2 emissions, it is crucial to be aware of the assumptions regarding the amount of CO_2 released per unit of fuel for both scenarios. The emissions are measured in kilograms per gigajoule (kg/GJ) of fuel consumed, with figures of 56.8 kg/GJ for natural gas and 106.4 kg/GJ for coal. Apart from the power sector, the main contributors to CO_2 emissions are other parts of the energy sector as well as the agricultural sector.

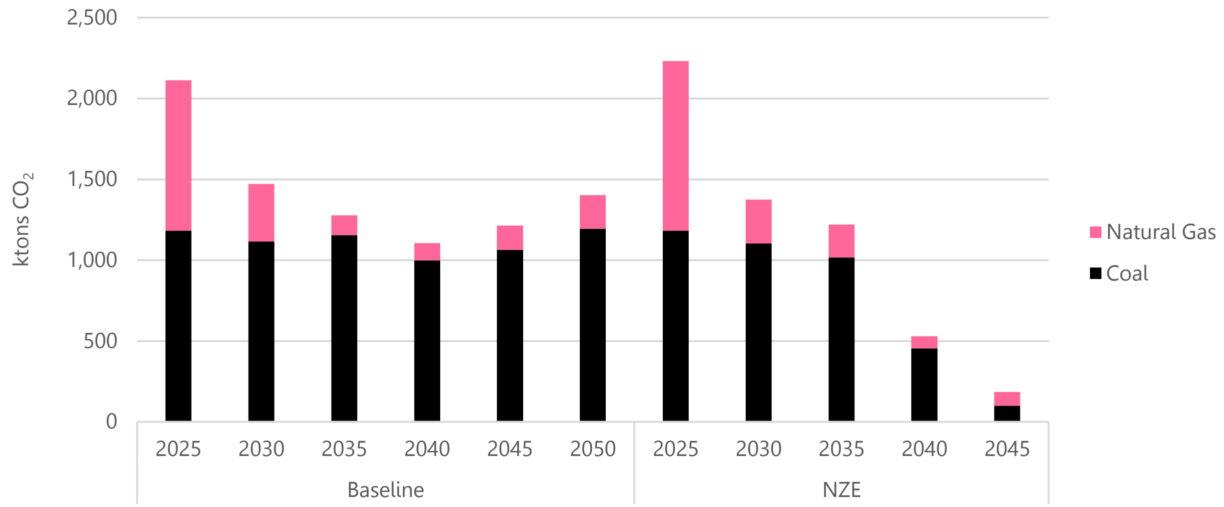


Figure 55: CO_2 emissions by fuel in the two scenarios.

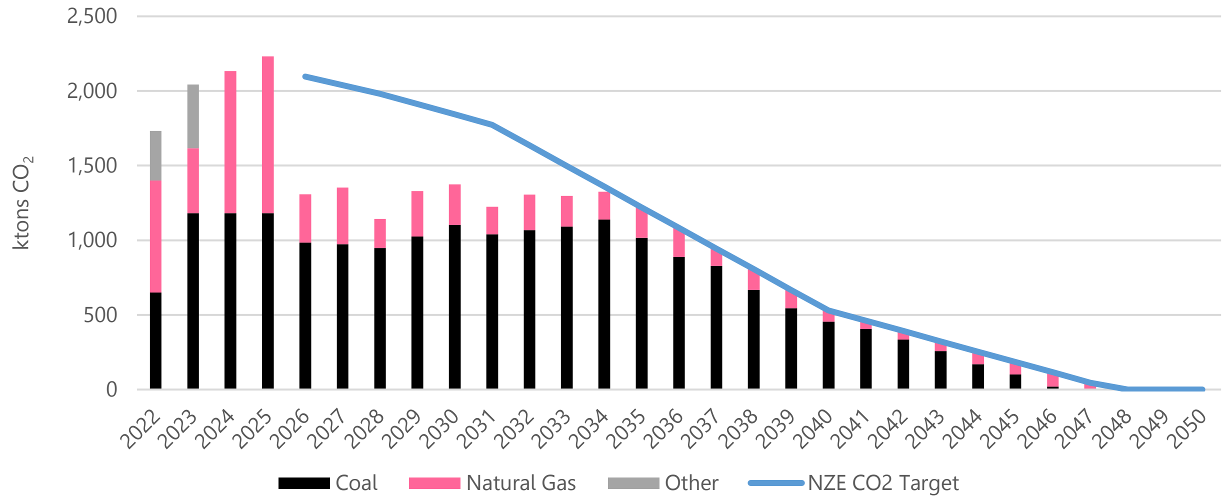


Figure 56: Overview of CO_2 emissions by fuel source in the NZE scenario, and CO_2 emissions target.

Looking at **Figure 55**, it is evident how there is a significant short-term reduction in the CO_2 emissions from the Nusa Tenggara Barat electricity sector, this is due to extensive short-term investments starting in 2026. Comparing the emissions, there are slightly lower emissions in the NZE scenario in 2030, which is before the CO_2 cap becomes binding. This is due to earlier expansion of transmission capacity in the NZE scenario (from 2028 compared to 2031 in baseline). In the medium to long term a significant reduction of CO_2 emissions in the NZE scenario starts around 2035, which is when the CO_2 target becomes binding, as seen in **Figure 56**.

CO_2 intensity represents the amount of CO_2 emitted for every unit of electricity generated in the province. The reduction is most dramatic between 2025 and 2030, but also going forward to 2040. After 2040 the CO_2 intensity for the power production stagnates in the baseline scenario but is reduced to zero in the NZE scenario following the cap for CO_2 emissions. In the NZE scenario the net zero in the power sector is reached in 2048, as electrification is a key solution to the decarbonisation of other sectors, the power sector should reach zero emission before other sectors to allow the total decarbonisation of the Nusa

Tenggara energy system. **Figure 57** summarises the trend in the CO_2 intensity per kWh of electricity generated, here it is possible to see how overall both scenarios substantially decrease the average CO_2 emitted and how only the NZE scenario reaches zero in 2050. Overall, this indicates that despite an increase in demand, in the long term, less expensive and less emissive power generation sources, like solar and wind, lead to reduced emission per unit of electricity produced.

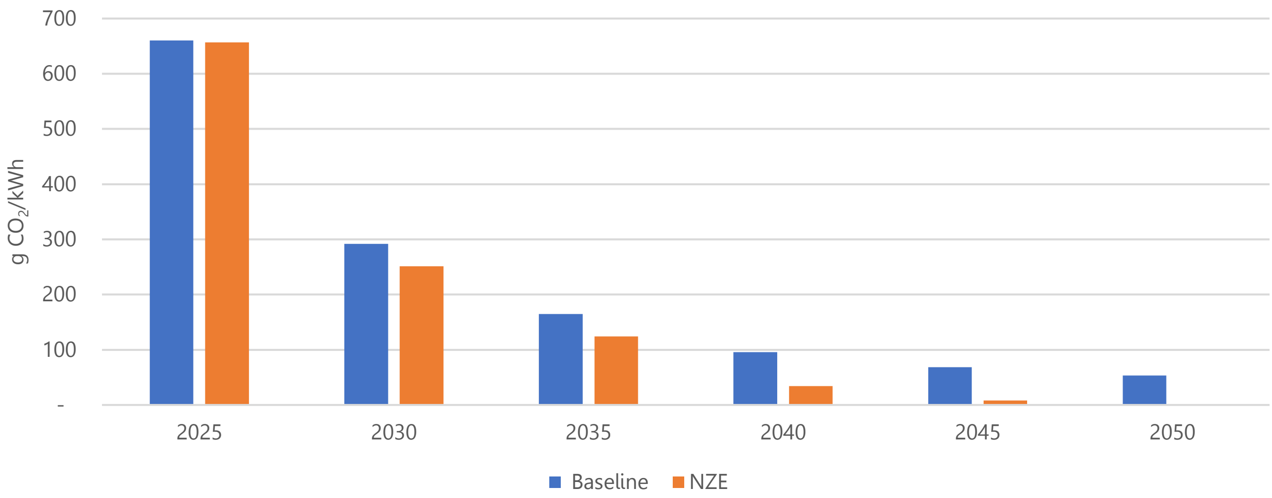


Figure 57: CO_2 intensity of produced power in the two scenarios.

7.7 Increased battery storage capacity required for enhanced solar utilisation and flexibility

A system heavily reliant on variable power production requires flexibility measures, one of which is storages. **Figure 58** shows how the investments in storages throughout the simulated period follow the pattern of variable power production which shows the investments in battery capacity in Lombok and Sumbawa, with a much larger buildout in Sumbawa. It is observed that the investment in battery capacity in the NZE scenario are higher compared to the baseline scenario. There is an evident correlation between solar capacity and storage. Additionally, as cost for storages decline investments in storages are increased. The increased storage expansion allows for better utilisation of solar generation, such that excess solar power is stored during the day and discharged during the night where the peak demand occurs. The operational behaviour of this dispatch is discussed in detail in **Section 7.9**.

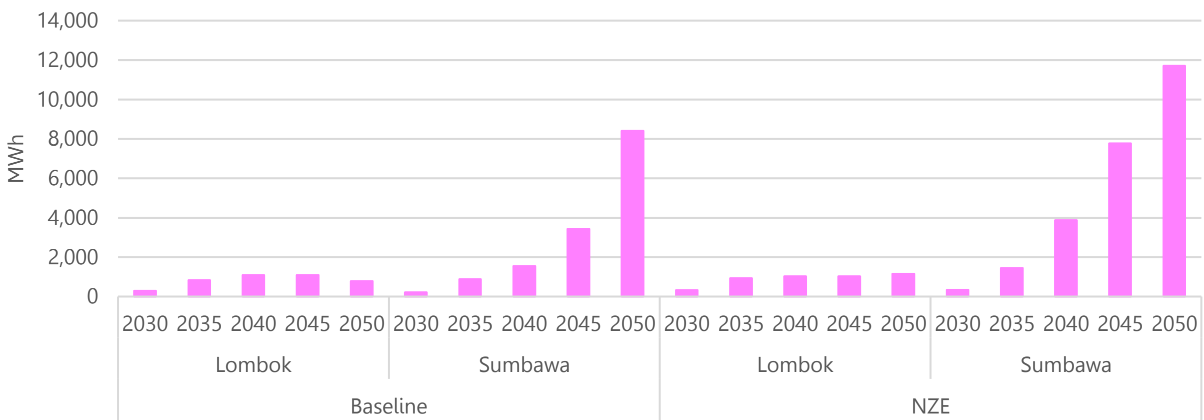
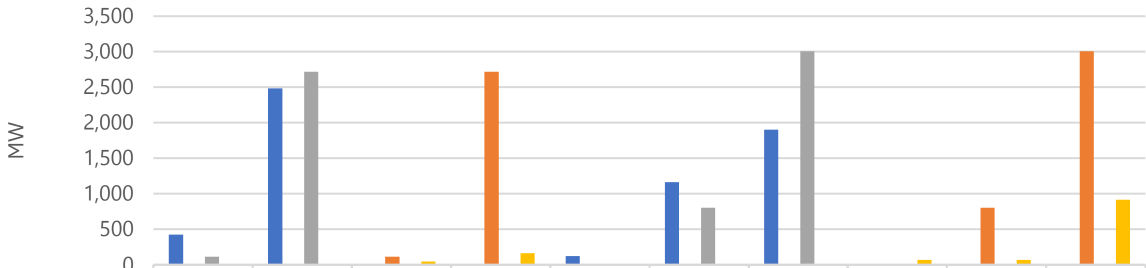


Figure 58: Overview of storage capacity in the two scenarios for Lombok and Sumbawa.

7.8 Increased interconnection improves resource utilisation and supports national decarbonisation efforts

Figure 59 shows the installed power transmission capacity between Lombok, Sumbawa and neighbouring islands. **Figure 60** shows the net flow in the interconnections in the two scenarios. The study reveals significant findings regarding the crucial power transmission connections within the region. Particularly, it underscores the importance of interconnection between the main islands as seen through power transmission links between Bali and Lombok, Lombok and Sumbawa, and Sumbawa and Flores. Owing to significantly higher demand growth in the NZE scenario, the transmission capacity expansion is allowed from 2028, keeping in mind that it would pragmatically take at least 5 years before any such interconnection projects can be realized. For the baseline scenario, the earliest year for this expansion is 2031, keeping the transmission capacity in line with RUPTL21 until 2030.

The connection between Bali-Lombok: In the both scenarios, there is a noticeable increase in the transmission of power from Lombok to cater to the high-power demand in the Java-Bali system. By 2050, while there is a large expansion in the transmission capacity between Lombok and Bali in both scenarios, the baseline scenario sees a bigger connection size. In both cases there is a transfer of excess power from Sumbawa to the Java-Bali system via Lombok. The low-cost solar resource availability in Sumbawa allows for the system balance at a national level. This is further examined in **Section 7.9** Change in operational behaviour: Increasing VRE and storage transforms the energy dispatch.

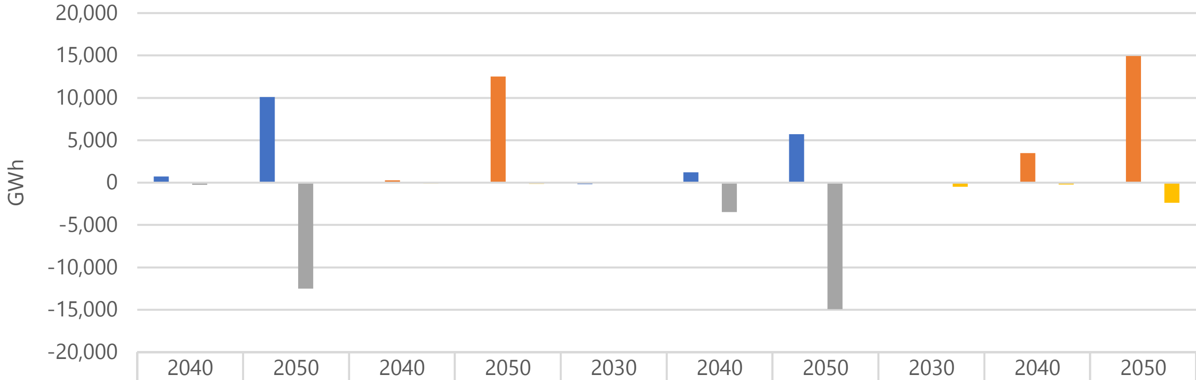


	Baseline				NZE					
	Lombok		Sumbawa		Lombok			Sumbawa		
	2040	2050	2040	2050	2030	2040	2050	2030	2040	2050
Bali	424	2,482			125	1,165	1,902			
Lombok			116	2,717				13	802	3,006
Sumbawa	116	2,717			13	802	3,006			
Flores			46	164				70	70	918

Figure 59: Installed power transmission capacity in the two scenarios.

Apart from the transmission flows to Bali, there is an extensive interisland power transmission from Sumbawa to Lombok, this is to allow for better utilisation of the high potential of solar resources on Sumbawa. Notably, despite a higher energy transfer from Sumbawa to Lombok in the NZE scenario, the flow towards Bali is lower because the electricity from Sumbawa goes into feeding the higher demand in Lombok due to the NZE criteria.

On the other hand, in the NZE scenario it is possible to see how the flow from and to Nusa Tenggara starts earlier and how the electricity transmission is on average higher in all the transmission lines. The CO_2 reduction goal is in fact translated in higher need of connection as form of flexibility and therefore in higher investments in transmission lines. As it is evident in **Figure 60**, that in both scenarios, the surge in electricity demand leads to interconnection between these two islands and with neighbouring regions. The variation in the overall flows over the years is also seen in how the transmission capacity is developed by 2050.

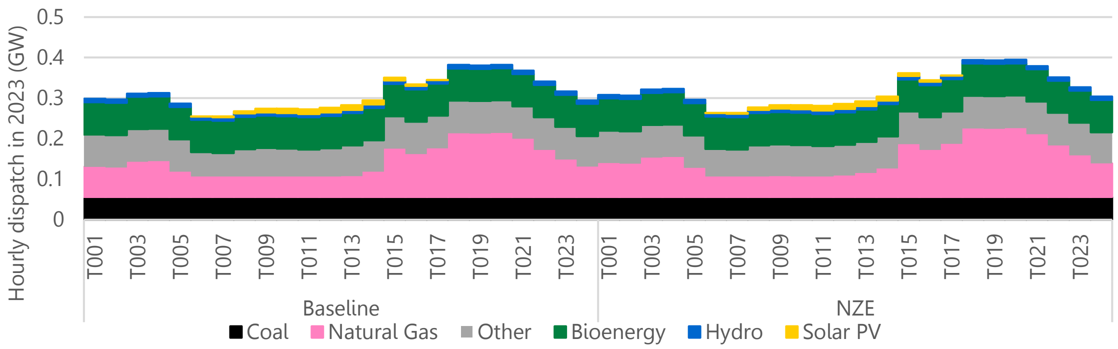


	Baseline				NZE					
	Lombok		Sumbawa		Lombok			Sumbawa		
	2040	2050	2040	2050	2030	2040	2050	2030	2040	2050
Bali	738	10,107			-168	1,210	5,734			
Lombok			265	12,513				5	3,473	14,949
Sumbawa	-265	-12,500			-5	-3,470	-14,934			
Flores			-107	-126				-480	-207	-2,392

Figure 60: Overview of transmission flows to and from Lombok and Sumbawa.

7.9 Change in operational behaviour: Increasing VRE and storage transforms the energy dispatch

This section aims to shed light on the operational behaviour of the power sector. This is done using the results from the model run where the optimisation of the dispatch is carried out at an hourly level with unit commitment constraints. **Figure 61** shows the development of the dispatch for base year (2023), medium term (2035) and final year (2050). The dispatch shown is for a day (24 hours) from an average week for Nusa Tenggara Barat.



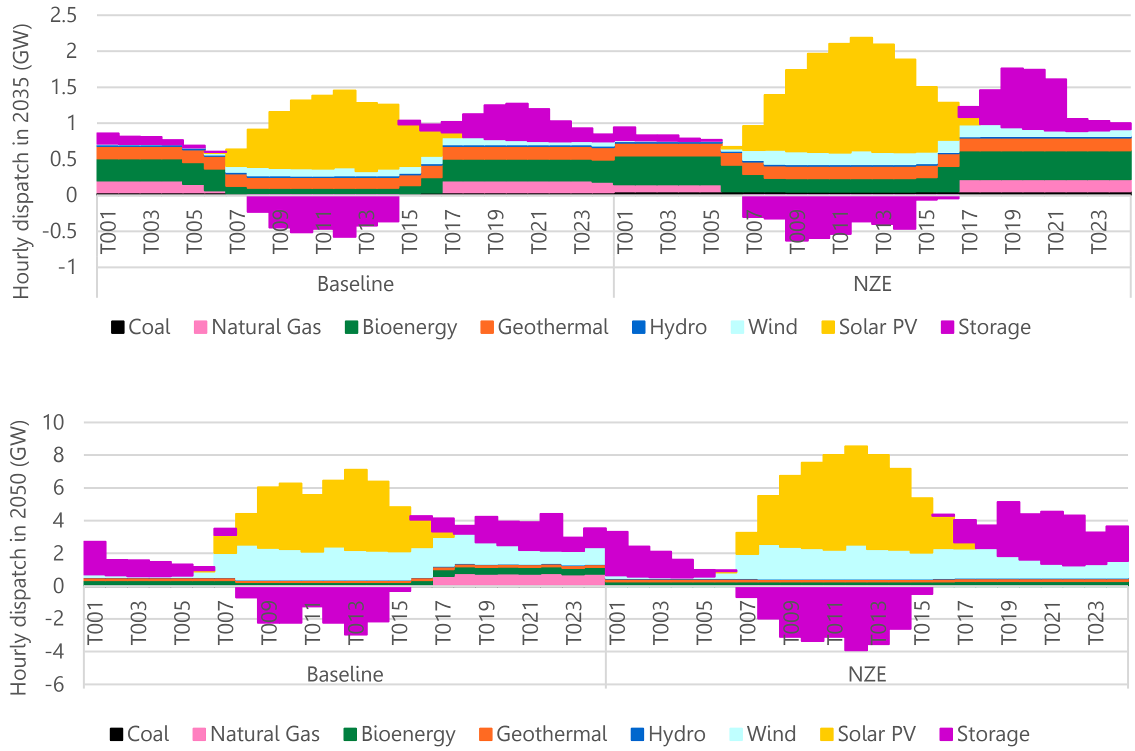


Figure 61: Hourly dispatch in Nusa Tenggara Barat for a day in an average week for the years 2023, 2035 and 2050.

In the base year (2023) there is no difference seen between the baseline and NZE scenario. Moreover, the dispatch also shows how the current dispatch mainly comprises of generation from coal, natural gas, diesel (other) and biomass, with small contribution from hydro and solar.

The most significant change seen in the energy mix for the medium term (2035), compared to the base year, is that there is an increase in the generation from solar, geothermal and biomass, with storage playing a key role. This allows for displacement of generation from expensive and emissive fuels like coal and natural gas, especially in the middle of the day when peak solar resources are available. Additionally, the loading of storage technologies (seen as negative in the plot) coincides with higher availability of solar based generation, and this stored energy is discharged later in the day around the peak demand hour. This allows for optimal utilisation of solar energy. There is also an increase in power generation from wind as compared to the base year. Another thing to observe is that with the increase in annual demand the level of generation in each hour has also increased. Furthermore, all these trends are amplified in NZE results as compared to baseline. This is reflected in much higher solar, wind and biomass-based generation, as a consequence of not only the higher demand in the NZE scenario, but also the restriction on emissions.

In the final year (2050), the trends discussed above continue. The dispatch in both scenarios is predominantly composed of solar and wind along with greater utilisation of storage. The key difference between the baseline and NZE (in addition to the magnitude, due to a difference in demands) is that there is no coal or gas-based generation in NZE, reflecting the net-zero for the power sector. Since the restriction on emissions is not applied to the baseline, some generation from gas and coal is still seen.

7.10 In the medium-term ramping of thermal capacity provides flexibility and supports integration of solar

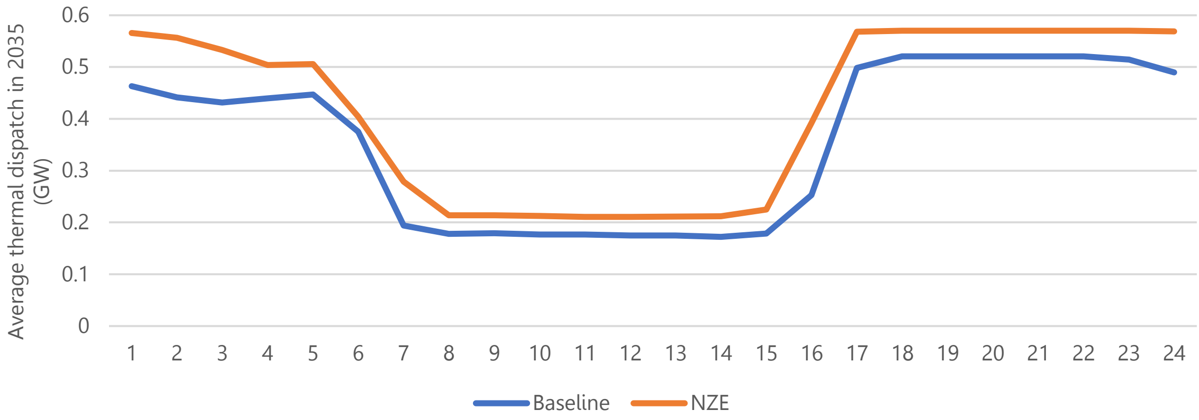


Figure 62: Average thermal dispatch in Nusa Tenggara Barat for 2035.

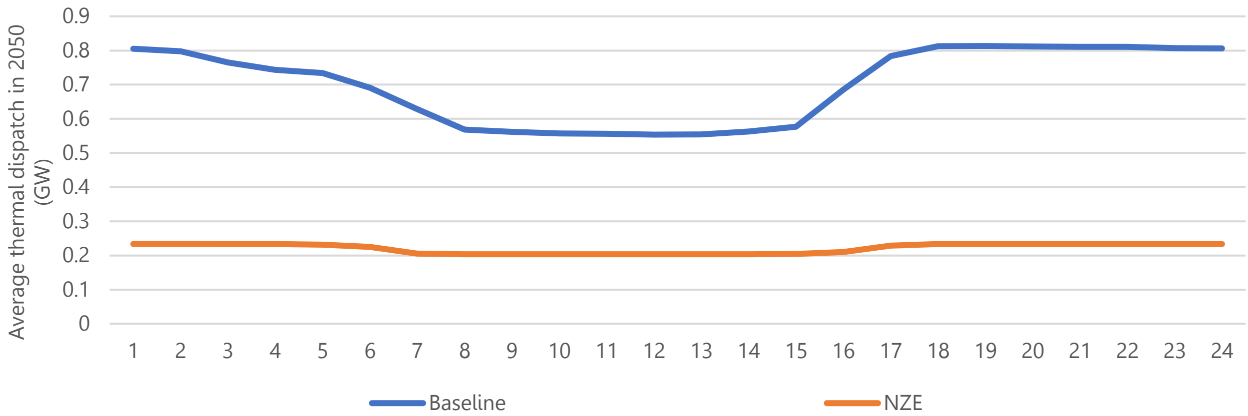


Figure 63: Average thermal dispatch in Nusa Tenggara Barat for 2050.

Figure 62 and **Figure 63** represent a daily average operation of thermal dispatchable generation (includes coal, natural gas, diesel, and biomass). This shows that on an average the thermal capacity is being utilised at a higher level in the hours where there is less or no solar generation, and the plants get ramped down during the solar peak hours. While in baseline 2050 the operational behaviour stays the same, just with an increased level of generation; in the NZE scenario the thermal capacity (consists of only biomass-based generation by 2050) is used at a flatter rate, with a small ramping around solar hours.

This change in operational pattern in the NZE scenario is compensated for by increased charging and discharging of storage technologies, as seen in **Figure 64**. These operational patterns reflect the importance of flexibility either through dispatchable technologies and/or storage in the increased integration of VRE sources. It becomes increasingly critical when the possible fluctuations and errors with solar generation forecasting are taken into account, to ensure security of supply.

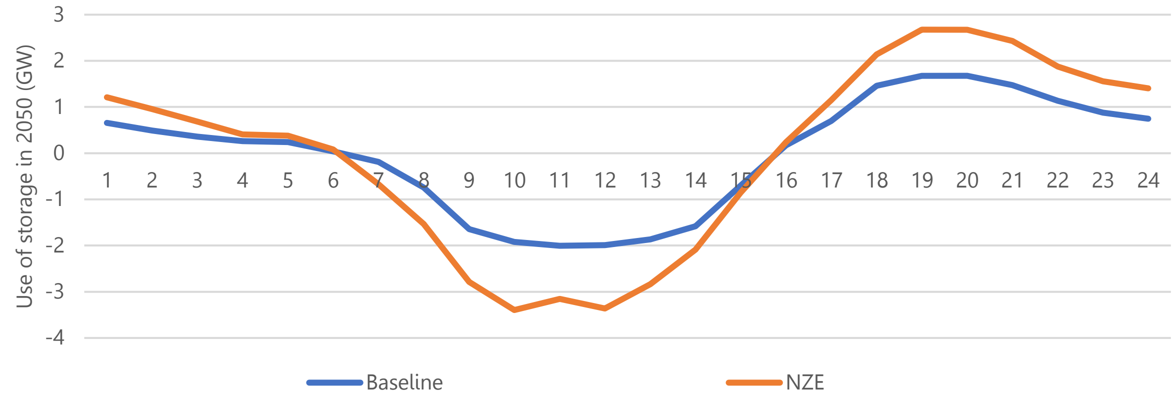
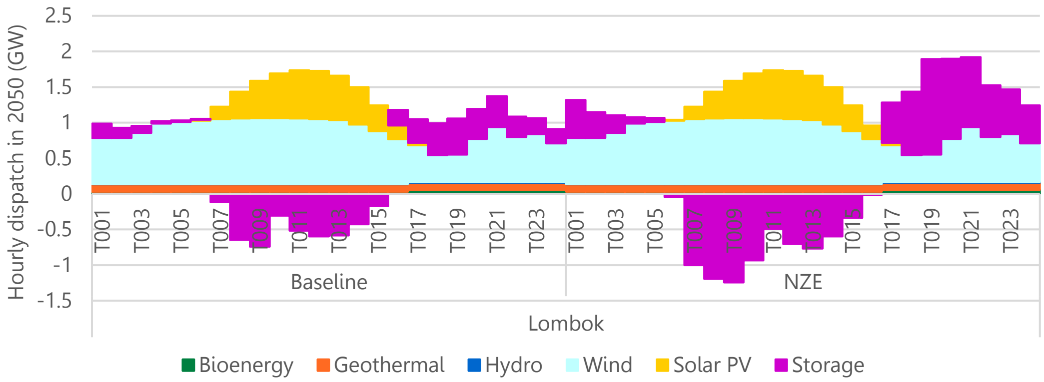


Figure 64: Average daily storage charging and discharging pattern for Nusa Tenggara Barat in 2050.

7.11 Difference in the daily operation between a day with high VRE available and a day with low VRE in 2050



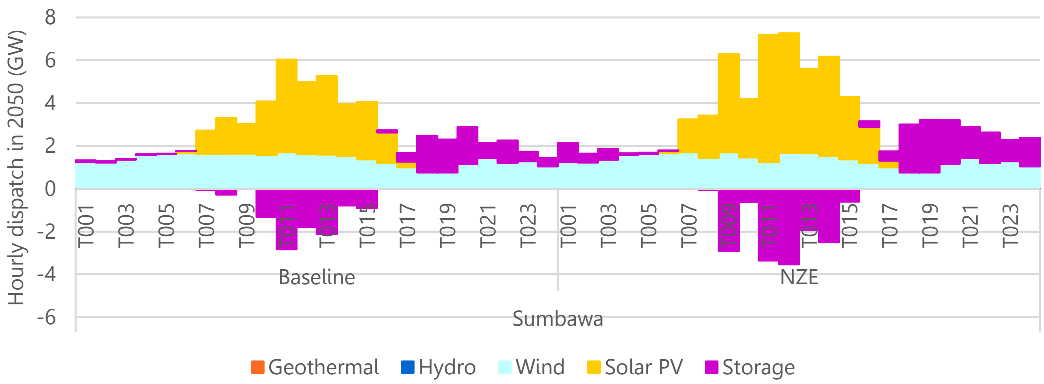


Figure 65: Daily dispatch in 2050 on a high VRE potential day.

Figure 65 shows the dispatch from a day with one of the highest solar and wind generation in 2050. Here, it is seen that all the demand in the province is met by VRE sources in combination with storage and some support from geothermal and biomass, in both scenarios. Lombok sees a similar level of electricity generation when comparing baseline and NZE, with a higher charging and discharging of storage. Compared to Lombok, Sumbawa has a significantly higher generation from solar and wind, as expected based on the resource availability and capacity expansion. Furthermore, the level of charging and discharging of storage is also higher. These differences become even more interesting when the import and export flows are analysed, as seen in **Figure 66**.

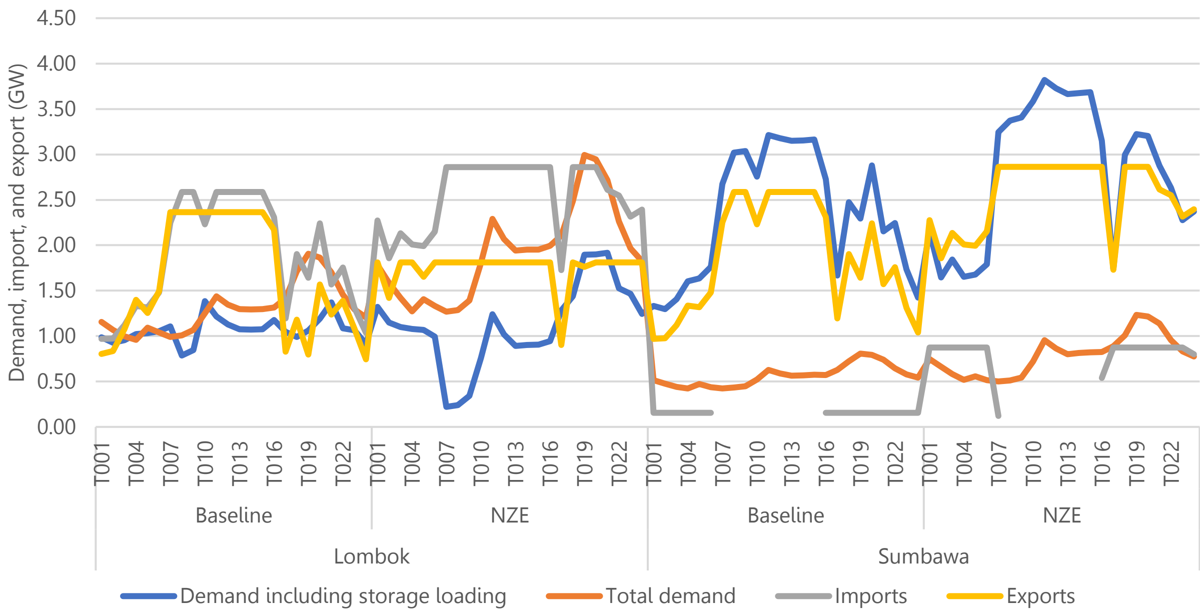
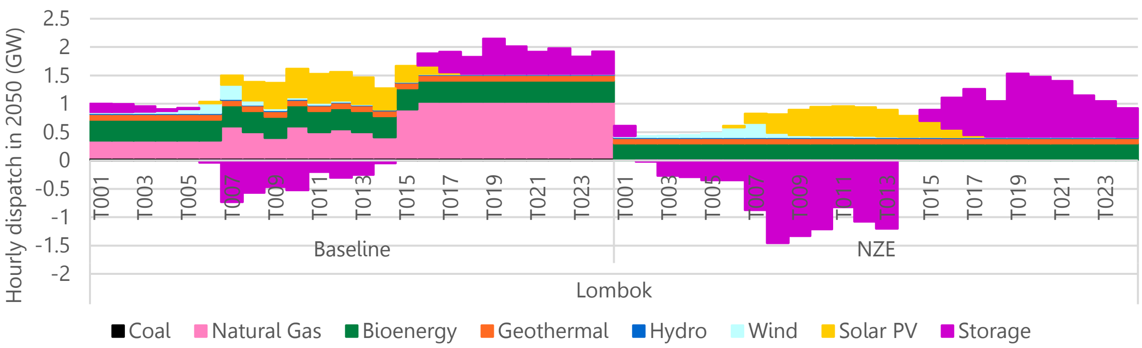


Figure 66: Comparison of demand, imports, and export with and without the effect of storages.

In Sumbawa, the generation (in blue) is significantly higher than demand (in orange), creating an excess of power. Therefore, there is a high level of export (in yellow) seen, especially in the hours with solar generation. This power can be seen as imports (in grey) for Lombok, where the generation is lower than the demand, creating a deficit. However, the excess of power from Sumbawa is more than enough to not only cover the deficit in Lombok, but further allow for exports from Lombok to Bali to cater to the high demand in the Java-Bali system. In the NZE scenario, while the amount excess power in Sumbawa, and hence the export to Lombok is higher than in the baseline, the exports to Bali are much lower due to the higher demand in Lombok to achieve NZE. **Figure 67** shows the same measures, but for a day with low VRE availability.



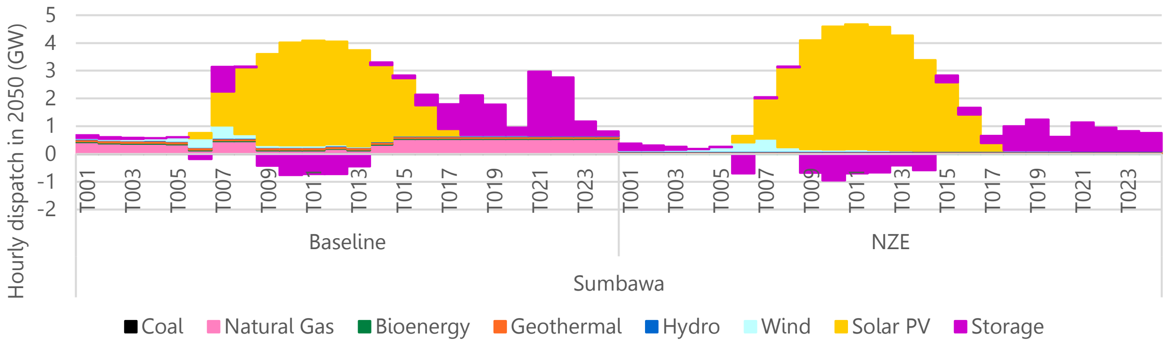


Figure 67: Daily dispatch in 2050 on a low VRE potential day.

In this situation the significantly lower VRE contribution (especially wind) is complemented by increased generation from coal, natural gas, biomass and geothermal compared to the previous example, especially in Lombok for the baseline scenario. In Sumbawa as well, the reduction from wind is compensated by natural gas, but solar generation is still high owing to capacity installed and good resource quality. The situation changes in NZE due to the restriction on emissions, not allowing for fossil fuel usage. The high solar generation in Sumbawa, means that these restrictions don't have a pronounced effect. Whereas, in Lombok, there is a drastic change in usage of storage as compared to baseline.

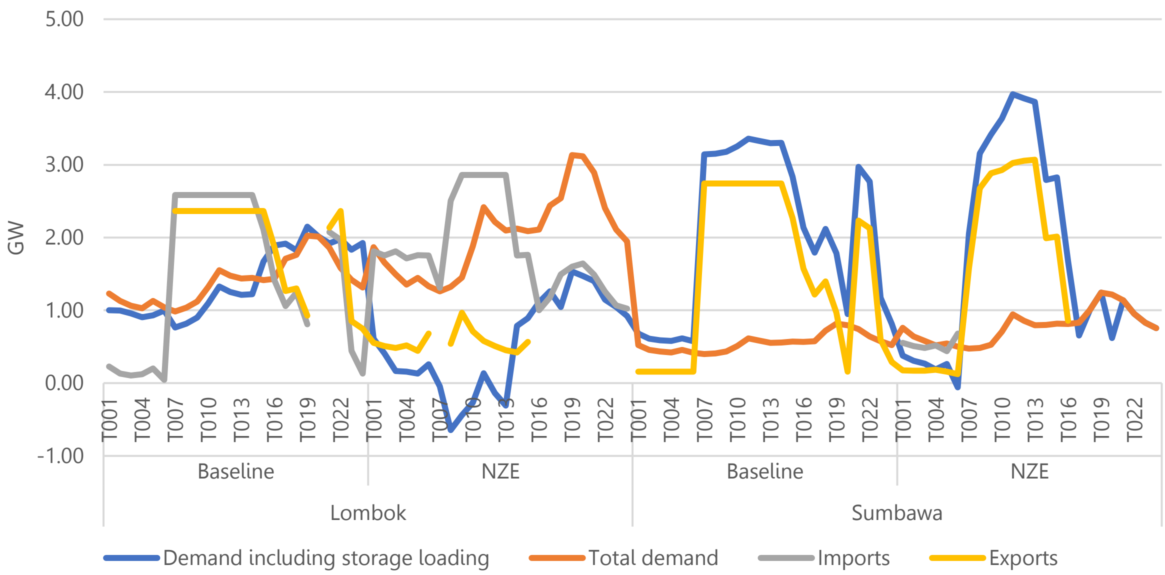


Figure 68: Comparison of demand, imports, and export with and without the effect of storages.

The story becomes clearer when exports and imports are taken into the picture, shown in **Figure 68**. In Sumbawa there is not a significant change owing to the low demand and high generation, which allows for high exports during the solar generation hours. The deficit between generation and demand in Lombok in the baseline case is not very large, owing to the possible usage of gas generation. This means still a significant level of exports to the Java-Bali system.

However, in the NZE case, Lombok sees some interesting behaviour in the system balance with a big gap between generation and demand. In the first half of the day, the system can meet its demand through a combination of generation and imports from Sumbawa, along with charging up the storage available. The charging of the storage is reflected overall as the lower and negative generation values in the plot. This still leaves some power to be exported to the Java-Bali system. But in the second half of the day there are no exports, and the peak levels of demand are met with a combination of imports and discharging of storage.

In summary, the above section shows how VREs like solar and wind transform the system towards a less emissive one. However, this is only possible with the support of dispatchable technologies (especially biomass) and high storage deployment. Together these allow for increased security of supply. Furthermore, it is seen how Nusa Tenggara Barat, as province, can have a net surplus of energy, owing to the resource availability of Sumbawa. The interconnection to Lombok from Sumbawa, and further to Bali play a critical role in balancing the system at a national level.

7.12 Increased VRE and storage reduces high load hours that need dispatchable generation, and increases exports

A duration curve shows the number of hours in the year (x-axis) when the load was above a certain power (y-axis). Basically, it shows hourly demand throughout the year in a descending order of magnitude. It provides a convenient way to visualize the effect VREs (solar and wind) and storage have on the system. **Figure 69** illustrates the following three curves:

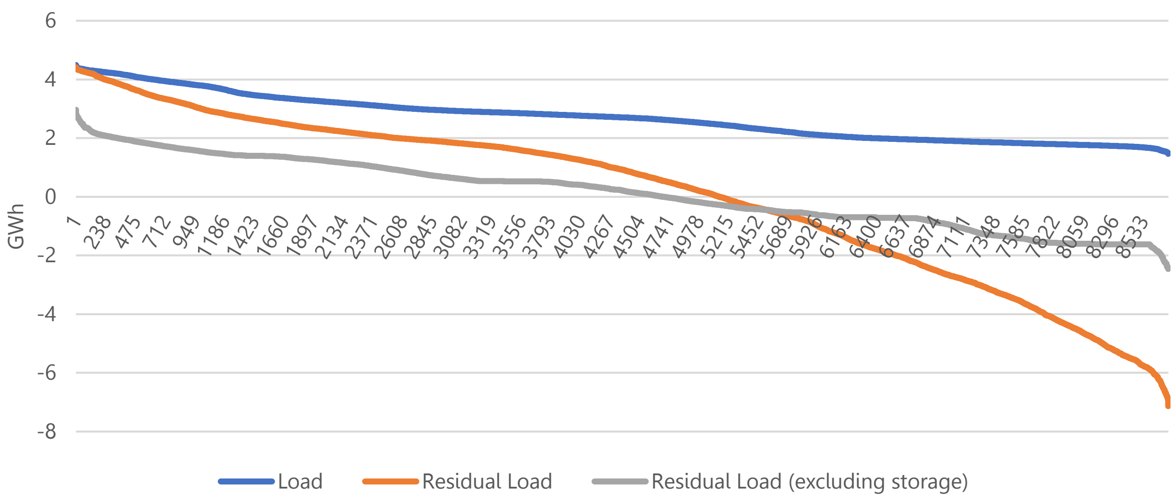


Figure 69: Duration curves in 2050 for the NZE scenario in the NTB province.

Load duration curve: This shows the total electricity demand of Nusa Tenggara Bara for each hour in the year in descending order. The hours with a higher demand are seen to the left, predominantly clustering the daily peak value. Overall, it shows that the demand in the province varies gradually from 4.48 GW to 1.46 GW in 2050 in the case of NZE scenario. This reflects a rather steady load profile with no sharp variations.

Residual load duration curve: Residual load is the load minus the generation from VRE sources such as solar and wind. As can be seen, the peak value in a few hours does not shift much in the residual load. This is because the peak occurs in the evening, where it can be shifted by either wind or storage. While in a fraction of the hours with very high peaks the residual load is high, in most hours a combination of solar and wind lead to a significantly lower load. The negative values in the curve here indicate the hours of storage charging and exports (which are not a part of the provincial demand).

Residual load duration curve excluding storage: When storage charging and discharging values are further removed from the residual load, the curve shows significant reduction in the high load hours. This reflects the role of storage discharging especially in the evening when the demand is higher. The remaining positive values show the load met using biomass, geothermal and hydro. Furthermore, the negative values in this curve now show the number of hours with a surplus of power from wind and solar which is then exported to the Java-Bali system.

7.13 Smarter electric vehicle charging enhances system flexibility

Another operational aspect playing a key role in the power system balance is the electric vehicle charging. The modelled system allows for increased flexibility through shifting the electric vehicle charging demand. There is an EV charging profile given, based on normally expected charging behaviour. The average daily profile can be seen in **Figure 70**.

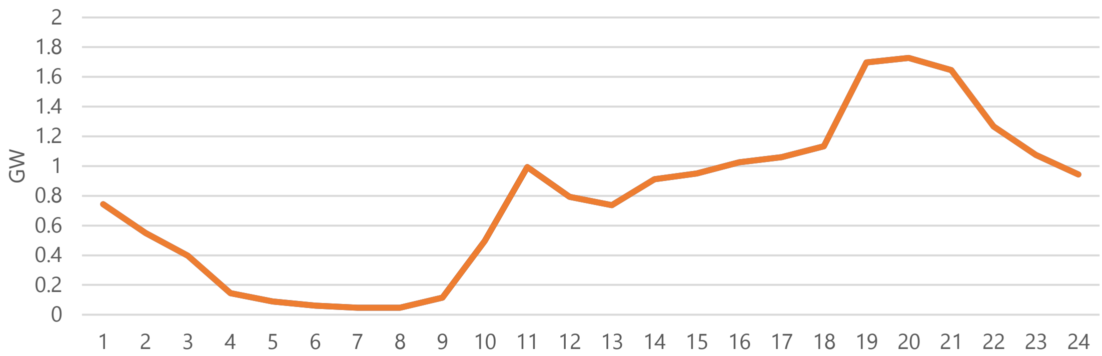


Figure 70: Average daily EV charging profile.

However, the model is allowed to shift a share of the EV charging demand to optimise the system and reduce the cost. This volume of smart charging is set to increase over the years and assumes that in the long term it is possible that technology will allow for consumers to charge their vehicles in response to the power availability and cost. This possible behaviour is better illustrated in **Figure 71**.

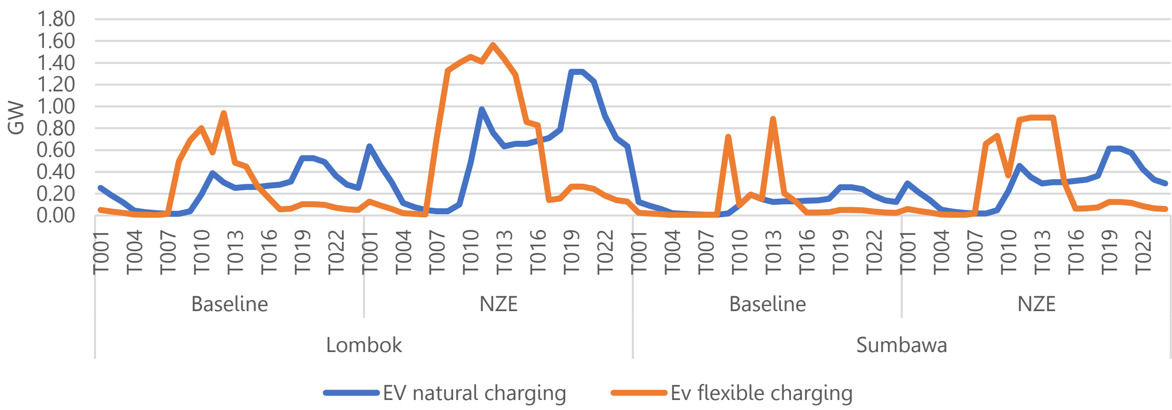


Figure 71: Comparison of the effect of flexible operation in EV charging.

This plot is from a day from an average week in 2050. The blue line in the figure above shows the expected normal charging pattern for the electric vehicle demand, while the orange line shows how the charging pattern is optimised. In both the scenarios for Lombok and Sumbawa it is seen that the demand is shifted from the evening peak hours to the hours where there is most solar generation. This is a consequence of the high availability of low-cost solar energy in those hours, making it more price optimal for the consumer and a better option for system balancing. This not only allows for better utilisation of solar power but also alleviates some of the system stress from the peak hours in the evening. On an annual level the use of this system flexibility between the baseline and NZE scenarios, can be seen in **Figure 72**. Owing to the difference in demands there is a visibly higher magnitude of demand shifting seen in the NZE scenario compared to the baseline.

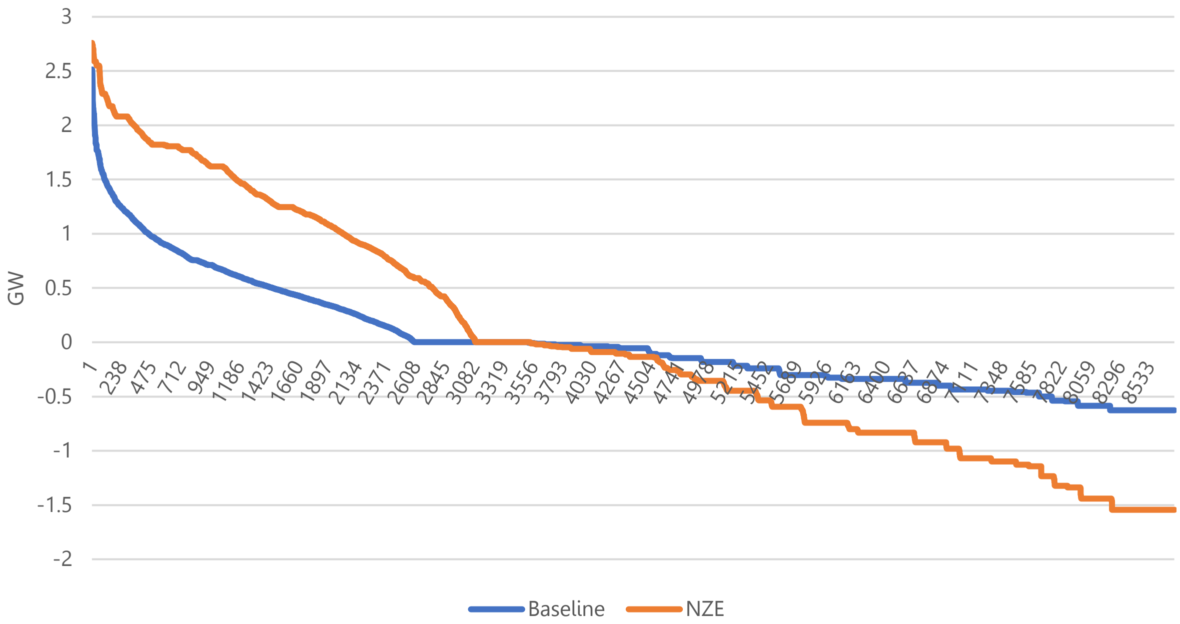


Figure 72. Comparison of the effect of flexibility measure in the two scenarios.

7.14 Key messages

This chapter has presented and discussed results for the power sector in a baseline scenario where the energy system going towards zero emissions on a national level by 2060 and one scenario with a specific provincial net zero emissions targets for 2050 applied to Nusa Tenggara Barat. The results show that the ambitious provincial level NZE target by 2050 is achievable but requires extensive investments in renewable energy production as well as making use of a full scope of flexibility measures. These encompass flexible dispatchable generation, transmission, and storage. The following are the key takeaways from the analysis:

- Strategic Planning for Demand Surge: Addressing the substantial increase in electricity demand in Lombok necessitates strategic planning and robust infrastructure development. This includes extensive investments in power generation as well as transmission. Here, a rapid expansion of Solar PV generation capacity is key, which is possible with the current assumptions on land and technological availability. This could be subject for a future sensitivity analysis to study the uncertainty and limitations of the Solar PV buildout. Short-term investments are seen in both scenarios and before the CO_2 cap becomes binding in the NZE scenario, meaning that these investments are of least-cost to the system.

- Dynamic Technological Shift: In the transition to an NZE scenario, there is a pronounced shift towards VREs, particularly solar and wind. The adoption of storage technologies becomes crucial in this scenario, playing a pivotal role in facilitating the integration of VREs into the energy mix. As a result, coal and gas-based generation undergoes a phased-out reduction. The impact of VRE dominance is evident in duration curves, highlighting solar and wind as key contributors in catering to most of the load. Furthermore, storage not only supports the effective utilisation of VREs but also proves instrumental in mitigating high load hours, thereby contributing to the establishment of a more stable and sustainable load profile in the NZE framework.

- Flexibility and Security Through a Combination of technologies: The expansion of storage and optimised EV charging patterns emerges as crucial flexibility measures, enhancing the adaptability of the power system. Furthermore, dispatchable technologies consisting in bioenergy in the later years of the analysis and storage demonstrate their importance in ensuring flexibility and security of supply, particularly in the NZE scenario, where fossil fuel dependency is completely reduced to zero.

- Efficient Power Transmission and Interconnection Dynamics: Optimised power transmission connections play a crucial role in addressing higher demand growth, contributing to a more efficient and balanced system. Additionally, Sumbawa exports excess power to Lombok, emphasizing the crucial role of interconnection inside the province. Surplus power from Sumbawa supports Lombok and is in turn exported to Bali, illustrating the importance of system balancing.

8. Financial estimates of power system costs and project viability

The West Nusa Tenggara (NTB) province has set a target for net-zero emissions across all energy sectors by 2050. These ambitions exceed national climate targets and establish NTB as a potential leader in sustainable power system development in Indonesia. However, translating these goals into reality requires a clear and comprehensive roadmap. The present report explores financial aspects of realizing the NZE by 2050 target for NTB province. It is based on energy system modelling results and insights where the NZE scenario is contrasted to a baseline scenario. The baseline scenario includes a national NZE target by 2060. While commendable, the national target falls short of the more ambitious provincial NZE by 2050 target, included in the NZE scenario.

A central aim of this report is to prioritize and categorize actions required to achieve the NZE target. This prioritization identifies both the "low-hanging fruits" that yield immediate results and the more intricate energy solutions that demand detailed planning. The costs in this report cover power generation and transmission. No investments or costs related to end-use consumption are considered. Thus, the costs do not cover for example charging infrastructure or any costs associated with increased use of biofuels. All monetary values are in USD 2019.

8.1 Power system costs

The calculated power system costs are made up of capital costs, fixed and variable operation and maintenance costs, and fuel costs related to electricity generation and transmission assets. The following costs are accounted for in the estimation of system costs:

- Capital costs cover the investment costs for plants and transmission capacity.
- The fixed operation and maintenance costs (FO&M) cover expenses required to operate and maintain power generation and transmission assets, ensuring their efficiency and reliability.
- The variable operation and maintenance costs (FO&M) cover usage-dependent costs within power generation and transmission, which fluctuate with the level of activity or production.
- Fuel cost covers expenses for fuel used for power production.

8.2 Power system costs set to increase fourfold by 2050 in both scenarios

There is a profound growth of system costs in both the Baseline scenario, shown in **Figure 73**, and the NZE scenario, shown in **Figure 74**. Due to the significant level of investments required in generation assets, power system costs double by 2034 in the NZE scenario and by 2036 in the Baseline scenario. In 20 years, by 2045, the power system costs are triple in the Baseline scenario and in the NZE scenario they are 3.5 times higher than 2025 system costs continue to grow, as the demand for power increases, to the end of the studied period. By 2050 the system costs reach 1,838 MUSD in the NZE scenario and 1,750 MUSD in the Baseline scenario. Looking at the distribution between costs, the Baseline scenario is more fuel dependent as the reliance on fossil fuels persists for longer than the NZE scenario, where fossil fuels are phased out from power generation by 2048.

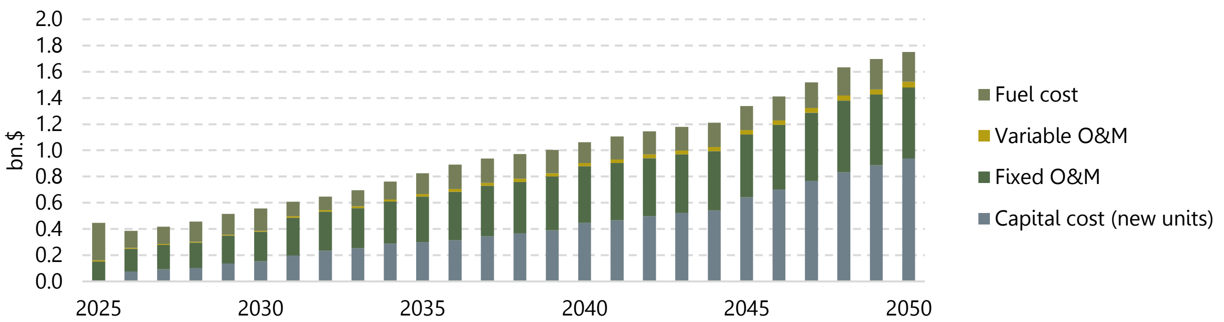


Figure 73: Annualized system costs for the Baseline scenario.

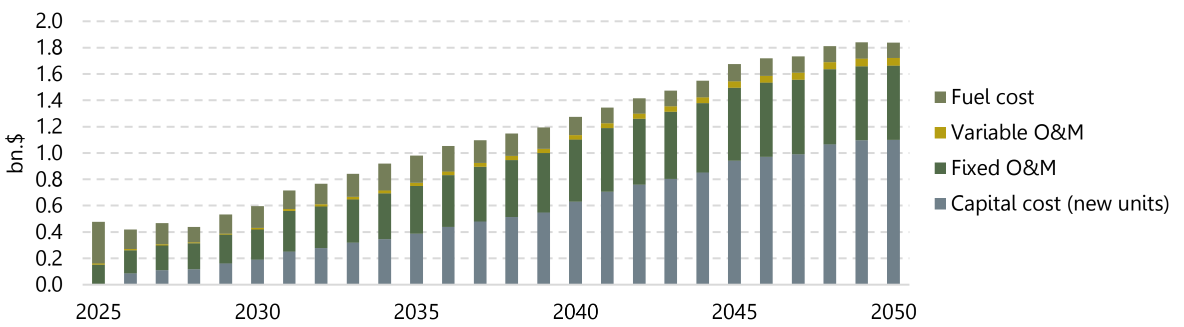


Figure 74: Annualized system costs for the NZE scenario.

8.3 Despite higher demand and system costs in the NZE scenario, the average generation cost in the medium term is higher in the baseline scenario

Despite the higher demand leading to higher system costs in the NZE scenario, the average generation cost per kWh is similar to the Baseline scenario. The NZE scenario system costs, compared to the Baseline scenario system costs, are shown in **Figure 75**. When comparing the Baseline scenario to the NZE scenario, it is evident that the reduced dependence of fossil fuels in the long-term results in lower fuel costs. As the NZE scenario is associated with higher electricity demand, the total system costs are higher in the NZE scenario, this is primarily made up by increased capital expenditure from new units. The difference in system costs between the scenarios reduces after 2044 as investments in VRE generation pay off with low O&M costs.

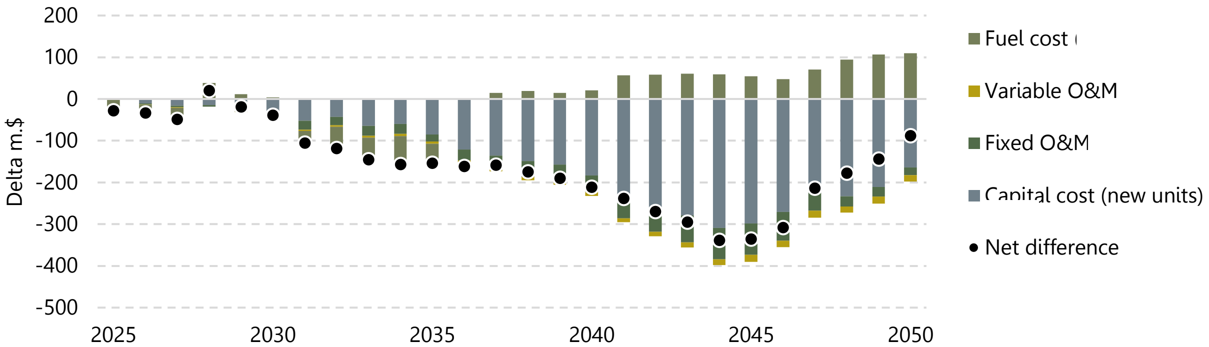


Figure 75: Overview of difference in system costs between the NZE and Baseline scenarios. Negative values mean higher system costs in NZE.

The total system costs do not reflect the additional production of electricity in the NZE scenario. Therefor an important metric is the electricity generation cost (biaya pokok produksi - BPP). Comparing the BPP in the NZE scenario to the Baseline scenario in **Figure 76** shows a generally lower electricity cost in the NZE scenario. The cost difference between the scenarios is limited, with a small difference seen in the years before and after 2040.

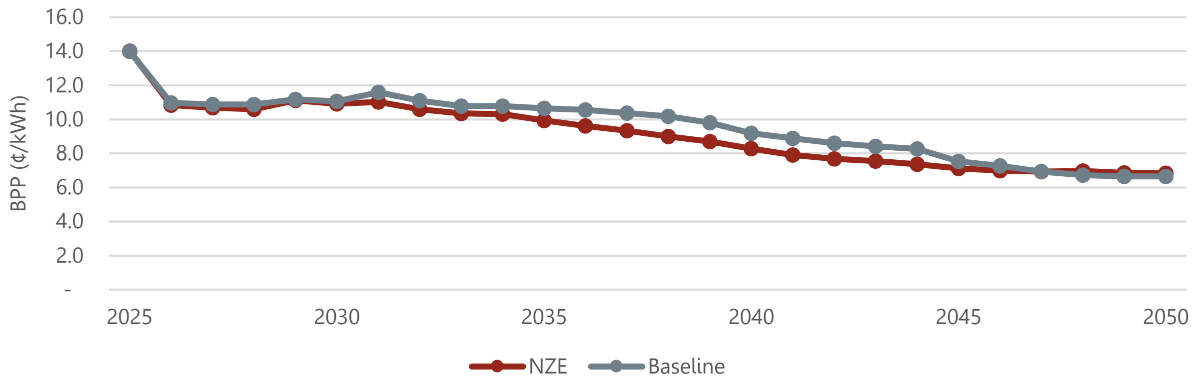


Figure 76: Costs in US cents per kWh (BPP) for the two scenarios.

8.4 Accounting for CO_2 costs enhances attractiveness of achieving NZE by 2050 in terms of system costs

The system costs shown in the main scenarios do not include any externality costs. Incorporating CO_2 costs into fossil fuel prices is a means to account for the environmental and societal impacts of carbon emissions. This approach encourages cleaner energy choices and contributes to the transition towards an NZE energy sector. Here, CO_2 costs from the IEA World Energy Outlook 2023 are used.

The cost of CO_2 starts at 38 USD/t CO_2 when first introduced in 2030, whereafter it increases to 104 USD/t CO_2 in 2040 and to 151 USD/t CO_2 by 2050. **Figure 77** shows the system costs with CO_2 costs included. This shows that by 2048 the NZE scenario costs less compared to the Baseline scenario, when CO_2 costs are included, despite the additional electricity demand in the NZE scenario.

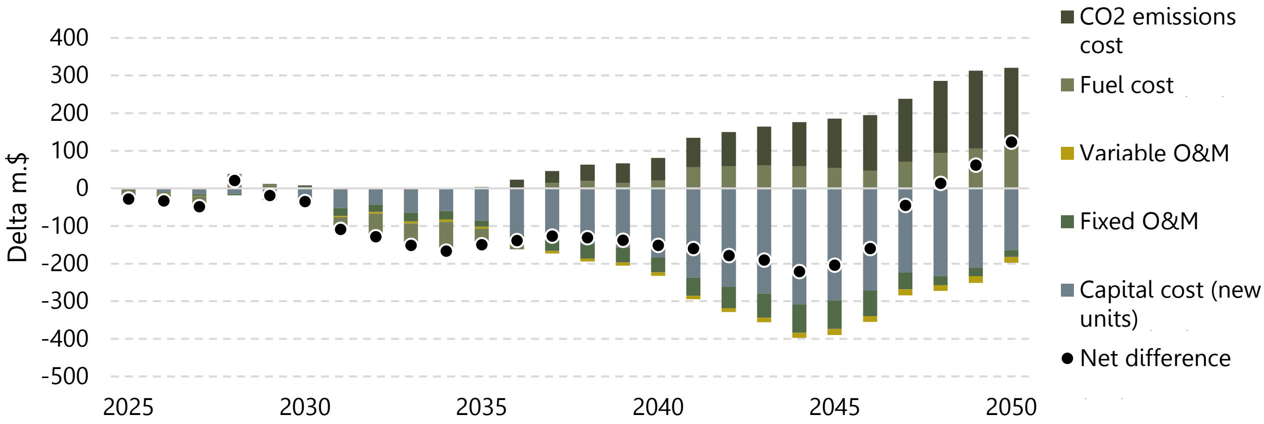


Figure 77: Difference in system costs between NZE and Baseline including CO_2 cost. Positive values mean lower system costs in NZE.

Fuel costs play an important role in shaping the economic analysis and the subsequent results of energy projects. The price of fuel can fluctuate significantly over time, impacting the system costs. In the main scenarios Domestic Market Obligation (DMO) fuel prices are used. These prices may not fully align with market prices as they are often set by regulatory authorities to ensure affordability and accessibility to domestic consumers. This means that DMO fuel prices can differ significantly from international market prices. As demand for fossil fuels is expected to decline the market fuel costs will be reduced in the long term. The fuel price projections from IEA World Energy Outlook 2023 are used to compare the DMO prices to market prices. In the short term the DMO prices are lower than the IEA fuel prices. However, this changes by 2027 for natural gas and 2029 for coal, whereafter the expected lower demand for fossil fuels will lead to reduced fossil fuel market prices, lower than DMO prices. With the low cost of fossil fuels, the difference between the NZE and Baseline scenarios is reduced, as shown in **Figure 78.** The system costs are lower in the NZE scenario compared to baseline in the long term despite higher generation in the NZE scenario.

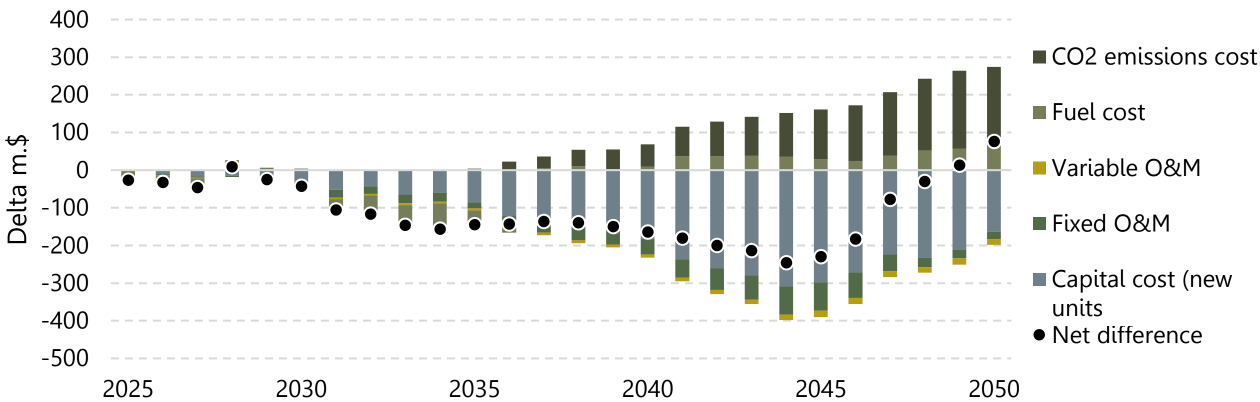


Figure 78: Difference in system costs between NZE and Baseline using market fuel prices and CO_2 cost. Positive values mean lower system costs in NZE.

8.5 Financial feasibility of wind and solar

This section of the report delves into the essential financial aspect of realizing the NZE by 2050 target for NTB province. It focuses on the application of Net Present Value (NPV) calculations to assess the financial feasibility of wind and solar power projects. NPV is a critical financial tool that enables us to gauge the long-term profitability and viability of these renewable energy initiatives. It accounts for the time value of money, ensuring that the future cash flows generated by these projects are evaluated.

By exploring NPV calculations for wind and solar power, we aim to provide key insights into the financial implications of adopting these technologies, offering a roadmap for effective financing strategies. The purpose of this analysis is to not only aid in making informed investment decisions but also for shaping the policies and regulatory framework necessary to accelerate the transition towards sustainable energy in West Nusa Tenggara Province.

The key assumptions for the NPV calculations are listed in **Table 17**. The feed-in-tariffs (FiT) used stem from the presidential regulation 112-2022. These FiTs are made up of two tiers, the first tier covers the initial 10 years of operation and the second up to and including the 30th operational year. The full load hours for each technology and location are results from the energy system modelling presented in Chapter 7.

Table 17: Overview of key assumptions for the NPV calculations for NTB region, considering a 1.2 location factor for FiT levels.

Key assumptions for NPV calculations		General	
Inflation		2%	
Tax rate		20%	
WACC		11.1%	
Technology specific		Wind	Solar PV
Operating lifetime		30 years	30 years
Construction time		1 year	1 year
Feed-in-tariffs			
≤ 10 MW	Tier 1	116 USD/MWh	93 USD/MWh
	Tier 2	69 USD/MWh	56 USD/MWh
≤ 20MW	Tier 1	116 USD/MWh	90 USD/MWh
	Tier 2	69 USD/MWh	54 USD/MWh
≤ 50 MW	Tier 1	108 USD/MWh	79 USD/MWh
	Tier 2	65 USD/MWh	47 USD/MWh

8.6 Solar PV

There is plentiful Solar PV potential in the NTB region. These need to be utilised in an NZE scenario, starting with investments in 2026. Investing in a large-scale Solar PV plant in Sumbawa in 2026 with the current FiT scheme not profitable, which is shown in the negative NPV in **Figure 79** suggesting need for additional support in the short-term.

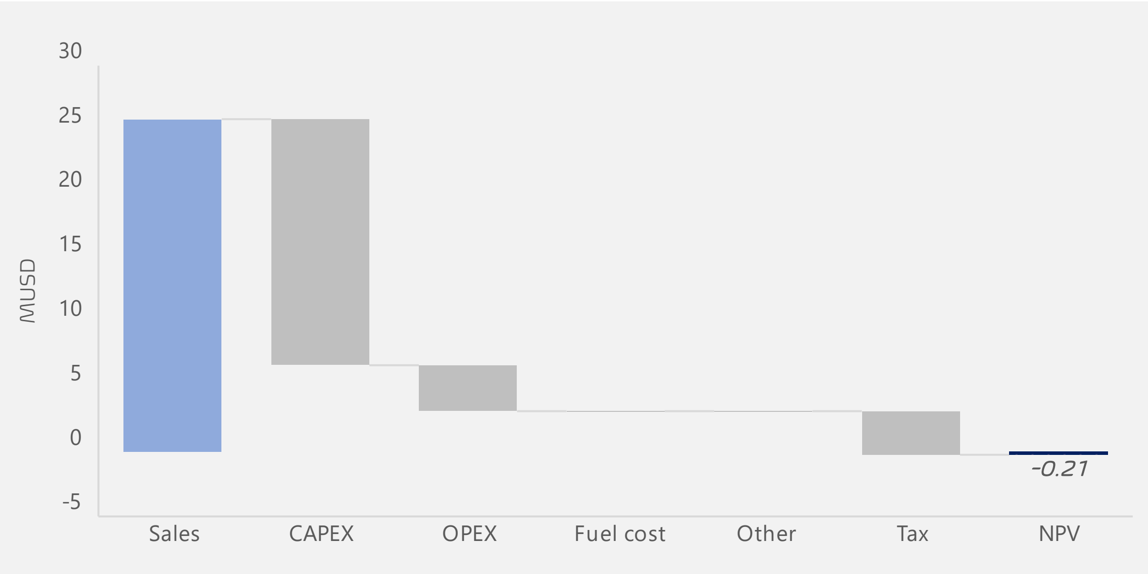


Figure 79: Overview of NPV for 50 MW Solar power capacity installed in Sumbawa in 2026 in NZE scenario.

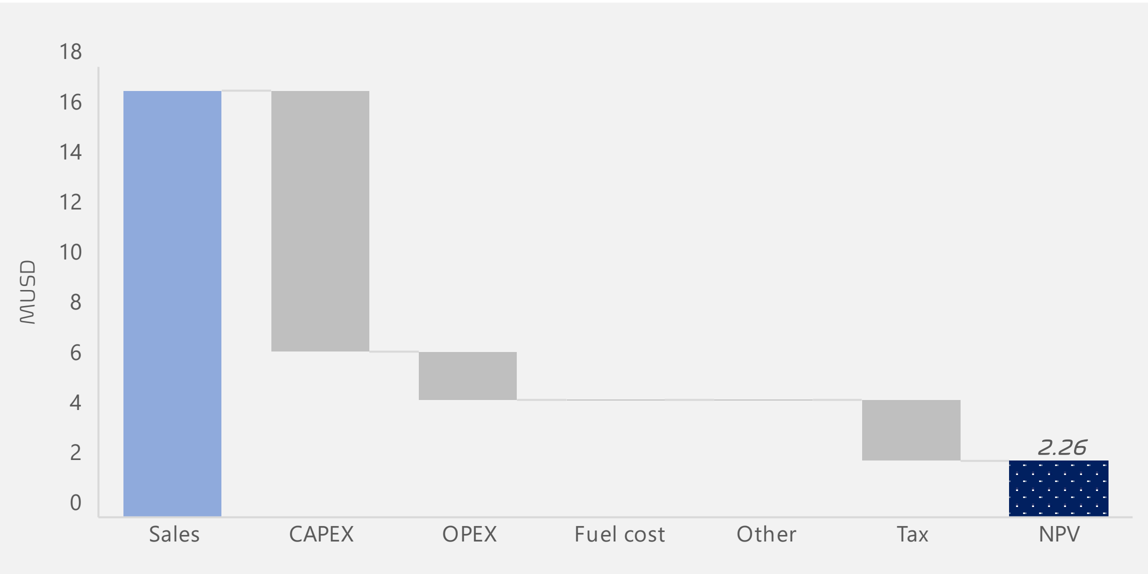


Figure 80: Overview of NPV for 50 MW Solar power capacity installed in Sumbawa-Bima in 2030 in NZE scenario.

Looking ahead to 2030, CAPEX is expected to reduce and the NPV for a large-scale Solar PV park installed in Sumbawa-Bima in 2030 can expect a revenue of 2.26 MUSD during the lifetime of the park as it is possible to see in **Figure 80**. Two thirds of the project costs are from CAPEX and the income from electricity sales covers costs and provide a profitable business case. It should be noted that the used FiT levels are the cap-levels. Meaning that the specific FiT for a project is subject to negotiation and might very well be lower than the cap.

8.7 Wind

Figure 81 shows the case for onshore wind power installed in Lombok in 2026. It shows that during the lifetime of the wind power park the project will make a revenue of 17.56 MUSD. As expected, the highest costs are the capital investment costs. The conditions used in this example provide a very profitable case for installation of wind power generation in Lombok. Again, the sold electricity includes cap-level FiT, which will be subject to negotiation.

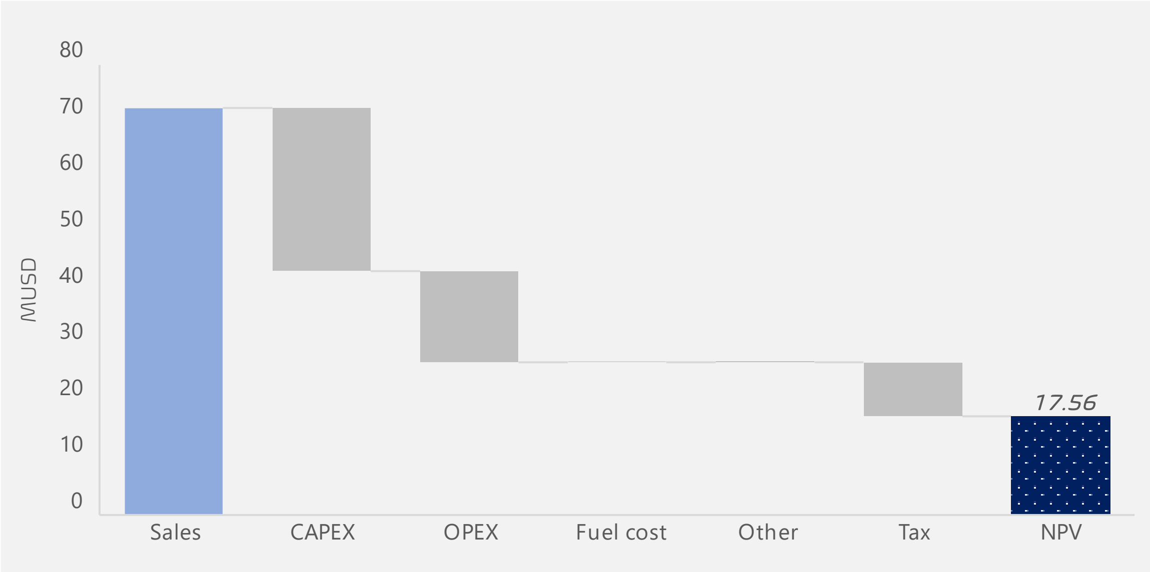


Figure 81: Overview of NPV for 50 MW onshore wind power installed in Lombok in 2026 in NZE scenario.

When looking at a smaller wind power project in 2030, this also shows a profitable. **Figure 82** shows an example of 10 MW installed in Lombok in 2030.

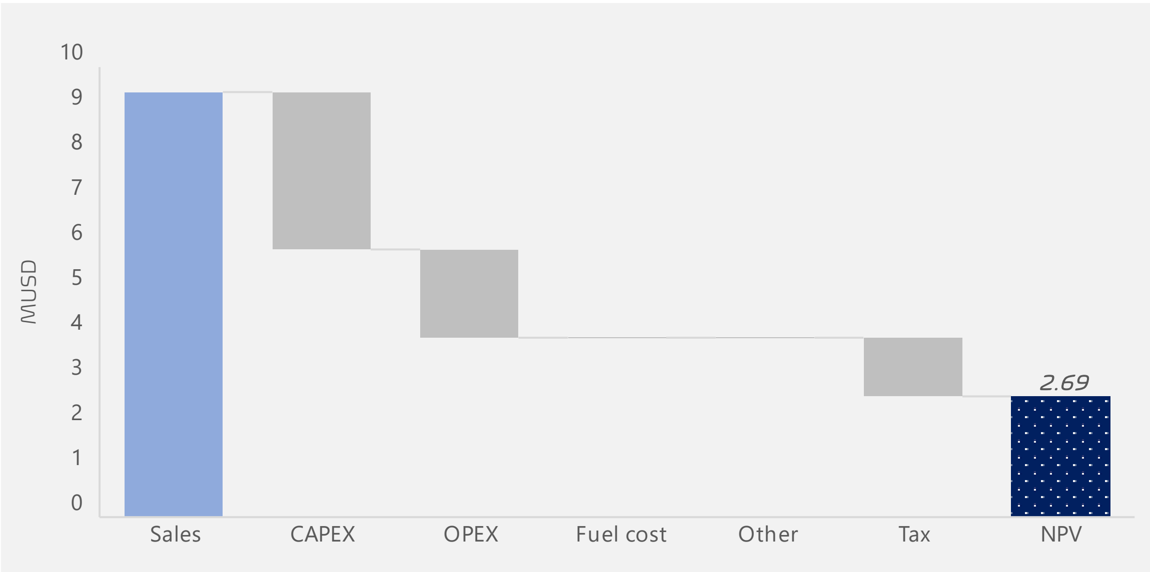


Figure 82: Overview of NPV for 10 MW onshore wind power installed in Lombok in 2030 in NZE scenario.

These positive outlooks for wind and solar investments are sensitive to changes in CAPEX. While local content requirements can support the Indonesian economy and technology development, they may challenge CAPEX due to increased costs, specifically in the short-term before the industry is well developed.

8.9 Financial needs conclusions and key messages

Nusa Tenggara (NTB) needs significant investments in the power sector to reach its goal of net-zero emissions across all energy sectors by 2050. The Net Zero Emission (NZE) scenario results in higher costs due to increased capital investments for new units and higher fixed operation and maintenance expenses. However, these costs are partially offset by reduced fuel expenses and potentially avoided CO2 costs. Implementing a CO2 cost could make the NZE scenario more economically viable. Investments in wind and solar PV yield positive NPVs, indicating their feasibility and attractiveness. However, the economic analysis could be influenced by uncertainties related to the cost of capital, particularly local content requirements.

8.10 Key messages

- The power system costs in the NZE scenario are higher than the Baseline. This is largely due to increased electricity demand. However, the average generation costs are similar to the Baseline scenario. The reduced reliance on fossil fuels in the NZE scenario leads to lower fuel costs. The difference is expanded when a CO_2 cost is added to fossil fuels, which lead system costs being lower than the Baseline scenario in the long term.

- The NPV feasibility examples for solar PV showed positive results for installations in 2030, while the short--term investments would require additional support. For wind power the examples for 2026 and 2030 both have a positive NPV. This does not consider uncertainties regarding cost of capital which might be elevated due to local content requirements. The FiT level which is considered is the cap, meaning that the actual FiT would potentially be lower, resulting in a less profitable business case.

- Local content requirements may slow down development and create bottlenecks for the transition by hindering the deployment of essential energy infrastructure.

- Power System Costs & Comparative Generation Costs: NZE scenario doubles costs by 2034, while Baseline triples costs by 2045. Comparative analysis reveals similar average generation costs, emphasizing reduced fossil fuel reliance in NZE.

- System Costs Sensitivity & Financial Feasibility of Wind and Solar: sensitivity analysis includes externality costs, favouring NZE scenario by 2048 with CO_2 costs. Financial feasibility assessed through NPV calculations for wind and solar projects in NTB. Solar PV potential noted, with wind projects in Lombok profitable in 2026 and 2030, sensitive to CAPEX and local content requirements.

- Financial Needs Summary: achieving net-zero by 2050 in NTB demands extensive power sector investments. NZE scenario incurs higher expenses, balanced by reduced fuel costs; CO_2 costs enhance economic viability. Difference in costs between scenarios may extend beyond 2050.

9. Conclusions and policy recommendations

The purpose of this report is to analyse the current situation and challenges of the energy sector in the Indonesian province of West Nusa Tenggara (NTB) and to provide conclusions and policy recommendations for a sustainable and low-carbon transition of the energy sector. The report provides a comparative analysis of two scenarios that explore different development pathways for NTB's energy system, with a shared temporal resolution that extends to the year 2050: A Baseline scenario that illustrates a development based on existing policies and trends and an NZE (Net Zero Emissions) scenario which is mainly driven by a provincial target of reaching net zero CO_2 emissions in the entire energy sector by 2050. **Figure 83** shows the total emissions from all sectors as an outcome from both these scenarios. The NZE scenario theoretically achieves the set target for zero emissions. The conclusions from the analysis on how this can be achieved, and relevant policy recommendations are presented in this section.

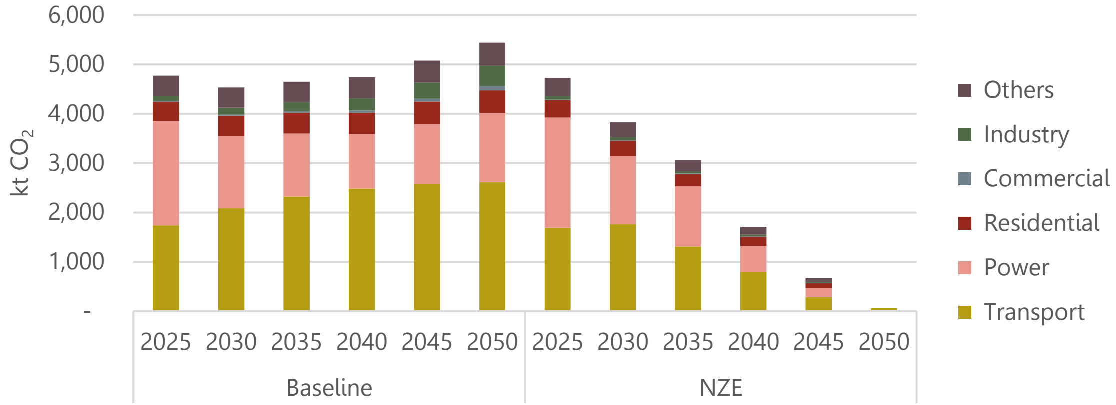


Figure 83: Overview of CO_2 emissions in the NTB energy sector in the Baseline and net-zero emissions (NZE) scenarios.

On the demand side, there is a need for sector specific policies to enhance energy efficiency. This includes electrification of household appliances as well as expanded electrification of the transportation sector. As bioenergy will play a central role in shifting away from use of fossil fuels, net least in the transport sector, there is a need to ensure sustainable practices regarding the use of bioenergy. Adding to these initiatives, businesses need to be supported in their transition, ranging from energy audits to fuel switching. To fulfil the NZE scenario there is a need for this long-term target to shape policies. For the transition of the power supply, shaping the path for the transition needs to be based on reliable resources and financial incentives, as well as a clear institutional set-up is needed for development of renewable power production. For a future clean energy system based on solar and wind, investments are needed in grid and transmission infrastructure as well as storage as a transformation of the power sector operations necessitates grid expansion, flexibility, and stability. With these aspects in place a NZE scenario is possible at low system cost.

9.1 The Evolution of Energy Demand

- Electricity consumption increases rapidly for all end-use sectors in both scenarios. The residential sector shows the highest electricity demand, while the largest growth is in the transportation sector. The two scenarios have varying paths, due to differences in energy efficiency policies and electrification.

- Electricity consumption increases rapidly for all end-use sectors in both scenarios. The residential sector shows the highest electricity demand, while transportation enjoys the largest growth. NZE scenario exceeds the RUPTL21 projections already by 2026 due to high BEV market penetration and reaches 21.8 TWh, roughly a 5.8 TWh difference to Baseline levels in 2050. That reflects a 68% and 40% share of electricity against the total fuel consumption for NZE and Baseline respectively.

- The residential sector exhibits great potential to shift away from fossil fuels with relatively modest financial implications. Since it is currently run mainly on electricity, LPG, and biomass; alternating towards electric appliances and clean cooking is essential to bring down energy intensity and carbon emissions. There is a reduced energy consumption in the residential sector for the NZE scenario of 11.5% in 2050 compared to Baseline, as a result of electrification and the installation of highly efficient appliances. Achieving these required financial incentives, and subsidies are needed for households to transition to electric appliances while prioritising clean cooking. Collaborating with financial institutions to create affordable financing options for households investing in electrification should be considered as a part of the solution to achieve the required transition.

- The commercial sector experiences steady growth in energy demand aligning with the expected provincial economic development. In the baseline scenario, electricity, LPG, and biodiesel consumption increases consistently, with electricity making up 85% of this consumption by 2025. In the NZE scenario there is a reduced electricity consumption in 2050, which is 11% less than Baseline leading to a 17% decrease in final energy consumption due to energy efficiency measures and improved energy management in buildings. Here businesses should be encouraged to conduct energy audits and provide incentives for implementing energy-efficient technologies in commercial buildings. Additionally, tax credits or grants should be introduced for businesses investing in renewable energy sources, with a focus on reducing reliance on LPG and biodiesel.

- Despite the heavy reliance on fossil fuels in the current condition, the industrial sector in West Nusa Tenggara holds significant potential for a low-carbon transformation, driven by research and development, technological innovations, and the adoption of best practices on energy efficiency. In the Baseline scenario, fossil fuels, particularly diesel, dominate industrial energy consumption, steadily increasing alongside the targeted economic growth. NZE presents a transitional approach with higher electrification, fuel switching, and enhanced energy efficiency, notably in Lombok where electricity takes up 70% of total industrial energy demand by 2050 and biofuels replace fossils wherever electrification is not feasible. Here streamlined application processes should be developed for businesses willing to adopt renewable energy technologies and offer grants and funding for industrial research and development focused on low-carbon technologies to facilitate faster uptake. Financial incentives provided for industries adopting electrification, fuel switching, and energy-efficient practices along with improved communication and setting up educational platforms can all enable an accelerated transition.

- The most energy-intensive sector today in NTB is transportation, which is powered by diesel, biodiesel, and gasoline, thus posing a lot of environmental issues. In the Baseline scenario, existing policies, like BEV subsidies and tax reduction are considered, which leads to 50% of motorbikes and 25% of other vehicles to be electric by 2050. Additionally, there are small contributions from fuel cells and biofuels. The more optimistic NZE scenario envisions full electrification of motorcycles with higher BEV penetration, as well as increased use of hydrogen in trucks and buses and biofuels for aviation and shipping. Achieving a high electrification of the transport sector as well as transitioning away from fossil fuels requires strengthening of policies supporting EV adoption by providing additional incentives, allocating funds for research on alternative fuels like hydrogen and electrofuels. Moreover, the increased adoption of EVs also requires planning of charging infrastructure to ease the transition and change in behaviour. For such developments, especially in hydrogen and electrofuels, the government can take part in foreign collaborations and assist in initiating pilot projects. This will not only support local development, but also allow for participation in improving these technologies globally, as the learning from early projects will factor into eventual commercialization.

- Other sectors that include agriculture and mining are of strategic significance for the province and the overall regional economic prosperity, however, their total final consumption share is relatively low. Being highly reliant on fossil fuels, biofuels are expected to have a key role in minimizing their CO_2 emissions. The use of biofuels in agriculture and mining needs to be incentivised by providing subsidies for equipment modification and fuel procurement and raise awareness about cleaner technologies and their effective use.

- Bioenergy plays a central role in the provincial energy transformation. In 2050, bioenergy consumption will account for 19% of the NZE scenario, surpassing the 13% levels of Baseline, with biodiesel leading the way. Currently, NTB is a net importer of biodiesel, however, as demand grows this might change in the future making biofuels a solid business case. Therefore, ensuring sustainable practices in cultivating and procuring biofuels is essential for the energy transition. Establishing a certification program for sustainable biofuel practices can ensure environmental and social standards. Funds for research and development of bioenergy technologies should be allocated to enhance efficiency and minimise environmental impact.

- When comparing the two scenarios in terms of end-use CO_2 emissions, transportation emerges as the primary emitter for both scenarios throughout, followed by the residential sector. By 2030, NZE achieves a 20% reduction compared to Baseline, mainly driven by decreases in transportation through BEV adaptation. This number is more than tripled by 2040. In 2050, Baseline scenario reaches 4 Mt, while NZE's very few remaining emissions come from aviation and represent 1.5% of Baseline's footprint, which could be offset by negative emissions through BECCS or the substitution with synthetic jet fuel. To keep track of the development a dedicated task force should be established to regularly review, and update in-place policies based on technological advancements and actively engage with stakeholders, focusing on the voices of the local community, businesses, and academia, through regular forums and consultations.

9.2 Power Sector Development

- NZE scenario requires larger investments in renewable energy sources, especially solar and wind, to meet the higher demand and the CO_2 reduction target. This scenario achieves a complete phase-out of fossil fuels and CO_2 emissions by 2050, while Baseline scenario still relies on some natural gas and coal consumption. To support the transition to a low-carbon power system outlined in the NZE scenario, the government requires alignment of financing needs and policy impacts with the national and local planning and adopt the NZE target as a long-term vision to enable holistic planning aiming at this NZE target. Furthermore, tracking progress of deployment, and updating the plan on a periodic basis to accommodate latest developments in technologies and their costs, is necessary to the target from vision to reality.

- The electricity mix of the NTB power system undergoes a rapid transformation from fossil fuels to renewables in both scenarios. The electricity mix also varies between the two islands of Lombok and Sumbawa, which have different resource availability, land constraints, and electricity demand. Sumbawa has a higher share of solar and wind, while Lombok depends more on bioenergy and natural gas. Furthermore, there is an increased dependency on Sumbawa as it is expected to export electricity towards fulfilling Lombok's demand and further transmitted to the Java-Bali system to meet the demand gap there while reducing CO_2 emissions. Such a crucial system development requires improved resource potential quantification to enable informed prefeasibility studies and better assess the viable options for the transition of the power sector, not least considering land availability constraints.

- Storage and electricity transmission provide important flexibility measures to support the integration of variable renewable energy sources, especially solar and wind, in the NTB power system. The NZE scenario requires more investments in battery storage and interconnection capacity than the Baseline scenario in meeting the higher demand and the ambitious CO_2 reduction target. This is especially true for the Sumbawa system, where optimal utilisation of solar resources is made possible through battery storage systems. Furthermore, increased interconnection capacity facilitates capitalisation of this abundance through exports within the province and to the national system. The role of storage and transmission cannot be emphasized enough in this ambitious journey to net zero emissions. To ensure the reliability and security of these critical power system elements, investments in smarter grid infrastructure and robust interconnection, as well as promoting the development demand response technologies will play a pivotal role.

- The capacity factor of renewable energy sources, such as geothermal, hydro, bioenergy, solar, and wind, remains high and stable across the years in both scenarios, reflecting high utilization of the installed capacity. The capacity factor of fossil fuels decreases significantly especially in the NZE scenario, indicating a reduced reliance on coal and natural gas for power generation. To facilitate the initial deployment of renewable energy sources, especially solar and wind, which are yet to be made mainstream, the government would need to provide incentives and subsidies for investors. Streamlining the permitting and licensing processes for renewable energy projects would also catalyse the accelerated deployment required. Additionally, the development of new biomass-based capacity can be facilitated by increasing the attractiveness of selling biomass feedstock from local suppliers and farmers. This would allow optimal utilisation of existing local resources, along with a boost to the local economy.

- The operational behaviour of the power sector is expected to change significantly in both scenarios, due to the increased integration of variable renewable energy sources. This also implies that thermal dispatchable technologies, such as coal, natural gas, and biomass, play an important role in providing flexibility and balancing the power system, especially during the hours when solar generation is low or absent. Thermal power plants maintain electricity system stability with their large rotating mass and voltage support. A future system with higher shares of intermittent power production puts additional requirements on improving stability of power grid. The green transition and electrification necessitate the expansion of the electricity grid and the introduction of new technologies for system security.

- The increasing adoption of Battery Electric Vehicles (BEVs) in the transport sector electrifies the largest contributing sector to NTB's energy system emissions. This puts additional demand on the power sector, but also creates an opportunity for the power supply side; by implementing smart charging, VRE resources can be utilized through flexible EV charging. This demand response approach enhances grid flexibility. To support the surge in EV adoption, it is crucial to concurrently develop intelligent charging infrastructure. This involves installing smart chargers that leverage the flexibility offered by EV storage. Educating EV users on participating in demand response can further enhance cost savings.

- Despite higher system costs in the NZE scenario, the average generation costs are similar to the baseline scenario due to reduced reliance on fossil fuels. The financial feasibility of the solar and wind assets when assessed through Net Present Value (NPV) shows positive economic viability of the NZE scenario in the context of long-term sustainable development. The benefits and social acceptance of renewable energy projects can be enhanced by the authorities by involving local communities and ensuring a more engaged stakeholder involvement in the planning and decision-making processes.

- When factoring in the cost of CO_2 emissions into the total system cost of electricity supply, it enhances the attractiveness of achieving Net Zero Energy (NZE) sooner. Therefore, plans to implement a carbon tax need to materialize sooner. This will not only offer financial benefits but also improve the overall living conditions for citizens. Additionally, the increased revenue can be directed towards supporting the accelerated deployment of Variable Renewable Energy (VRE)-based supply. Similarly, the artificial subsidy that current power plants receive on fuel costs due to DMO pricing for coal and natural gas needs to be reevaluated. Shifting to market prices will accurately reflect the true economics of these plants, demonstrating their higher cost for consumers. This adjustment provides an additional incentive to transition away from the current fossil fuel dependency.

- The NTB power system faces several challenges today and in the future development, such as the uncertain economic condition, and how to ensure a just and inclusive energy transition. To ensure the just and inclusive energy transition, the NTB government should mitigate the negative impacts on the workers and communities affected by the coal phase-out by providing retraining and reskilling programs, social protection measures, and alternative livelihood opportunities. Here the local content requirements can be part of creation of jobs related to renewable projects.

9.3 Concluding remarks

The analysis conducted, the conclusions drawn, and the recommendations made, all contribute to the formulation of a concrete roadmap. This roadmap aims to guide the initiation of development towards achieving a net-zero emissions energy system in Nusa Tenggara Barat. The primary goal has been to establish actionable and realistic targets in line with the vision. However, the transition from ideation to execution necessitates further comprehensive analysis and consideration from a holistic perspective.

The challenge of addressing climate change, intended to be resolved through this initiative, encompasses multifaceted implications for social, environmental, and economic aspects. Consequently, the solution requires a holistic approach, considering the system's various dimensions, including technical limitations. This study offers a comprehensive understanding of initial steps and directional choices, guiding the province toward an enhanced energy framework that not only improves lives but also generates a significant positive impact.

It is crucial to acknowledge that this masterplan should be periodically updated based on actual developments and changes in the system. Therefore, while this marks the conclusion of the report, it signifies the commencement of a marathon toward establishing a net-zero emissions energy system in Nusa Tenggara Barat. It is anticipated that this effort will not only spur more ambitious development within other provinces but will also resonate at the national and global levels, contributing to a sustainable future for the world.

References

Bappenas. (2020). Rencana Pembangunan Jangka Menengah Nasional (RPJMN) 2020-2024. Retrieved from: https://perpustakaan.bappenas.go.id/e-library/file_upload/koleksi/migrasi-data-publikasi/file/RP_RKP/Dokumen%20RPJMN%202020-2024/Batang%20Tubuh%20RPJMN%202020-2024.pdf

Danish Energy Agency. (2021). *Technology Data for the Indonesian Power Sector Catalogue for Generation and Storage of Electricity February 2021*. Retrieved from: https://ens.dk/sites/ens.dk/files/Globalcooperation/technology_data_for_the_indonesian_power_sector_-_final.pdf

Danish Energy Agency, EBTKE. (2021). *Renewable Energy Pipeline*. Retrieved from: https://ens.dk/sites/ens.dk/files/Globalcooperation/renewable_energy_pipeline.pdf

Electricity and Renewable Energy Authority, Danish Energy Agency. (2021). *Vietnam Energy Outlook Report 2021.* Retrieved from: https://www.ea-energianalyse.dk/wpcontent/uploads/2022/06/vietnam_energy_outlook_report_2021.pdf

Energy Research Institute of Chinese Academy of Macroeconomic Research. (2021). *China Energy Transformation Outlook 2021.* Retrieved from: https://ens.dk/sites/ens.dk/files/Globalcooperation/2021-11-04_ceto21_summary_en-final_0.pdf

IEA (2022). An Energy Sector Roadmap to Net Zero Emissions in Indonesia, IEA, Paris https://www.iea.org/reports/an-energy-sector-roadmap-to-net-zero-emissions-in-indonesia, License: CC BY 4.0. Retrieved from: https://iea.blob.core.windows.net/assets/b496b141-8c3b-47fc-adb2-90740eb0b3b8/AnEnergySectorRoadmaptoNetZeroEmissionsinIndonesia.pdf

IEA (2023), World Energy Outlook 2023, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2023, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A). Retrieved from: https://iea.blob.core.windows.net/assets/42b23c45-78bc-4482-b0f9-eb826ae2da3d/WorldEnergyOutlook2023.pdf

IESR (2022). Indonesia Energy Transition Outlook 2023: Tracking Progress of Energy Transition in Indonesia: Pursuing Energy Security in the Time of Transition. Jakarta: Institute for Essential Services Reform (IESR). Retrieved from: https://iesr.or.id/wp-content/uploads/2022/12/Indonesia-Energy-Transition-Outlook_2023.pdf

IRENA. (2022). Indonesia energy transition outlook, International Renewable Energy Agency, Abu Dhabi. Retrieved from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Oct/IRENA_Indonesia_energy_transition_outlook_2022.pdf?rev=b122956e990f485994b9e9d7075f696c

PT PLN. (2021). Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) 2021-2030. Retrieved from: https://gatrik.esdm.go.id/assets/uploads/download_index/files/38622-ruptl-pln-2021-2030.pdf