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Study on Renewable Energy Quota Calculation in East Nusa Tenggara

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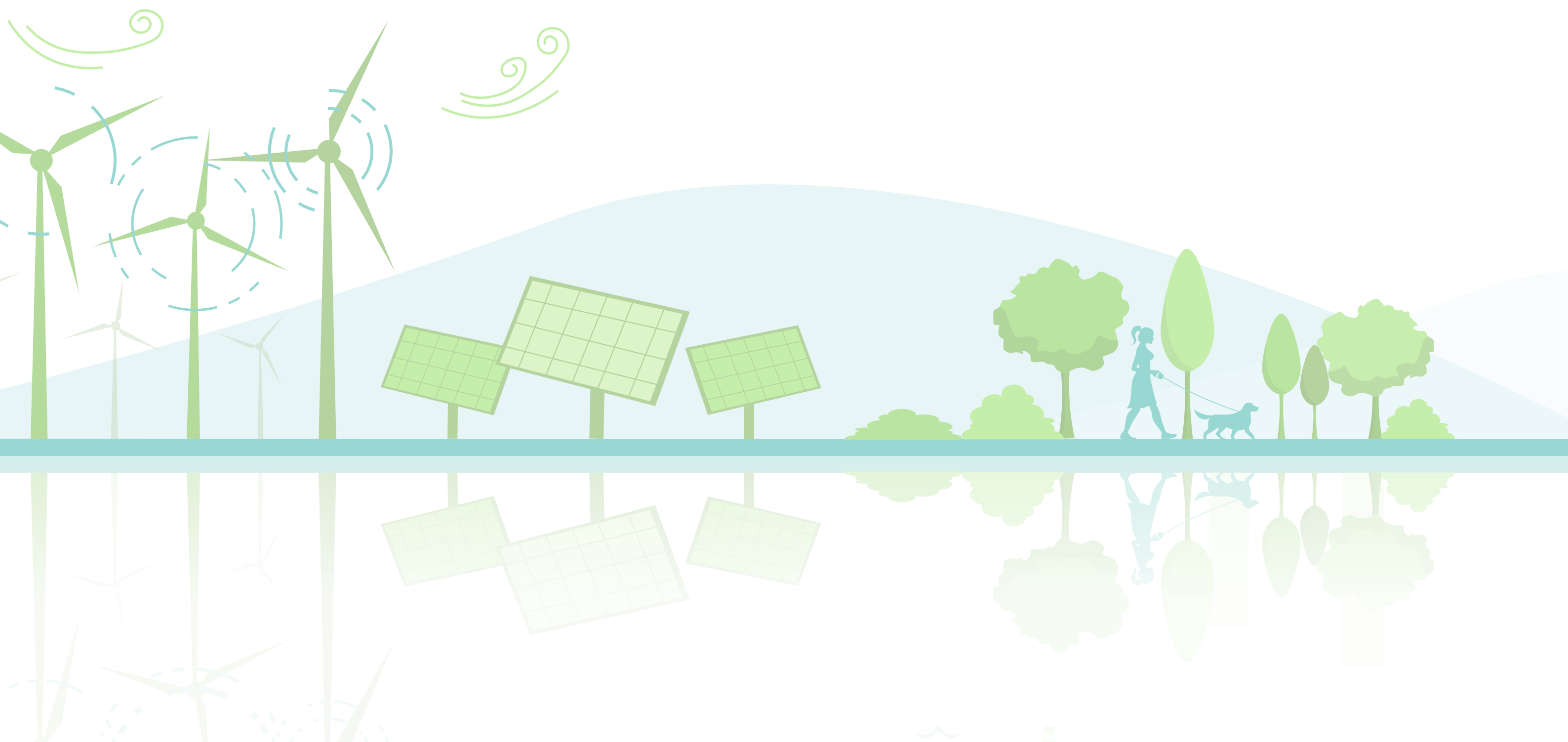


Abbreviations

AC	Alternating Current
AGC	Automatic Generation Control
ACSR	Aluminum Conductor Steel-Reinforced
BESS	Battery Energy Storage System
BPP	Generation cost in IDR/kWh
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CF	Capacity Factor
COD	Commercial Operation Date
DC	Direct Current
DFR	Digital Fault Recorder
DPL	DIgSILENT Programming Language
DSL	DIgSILENT Simulation Language
DSM	Demand Side Management
DSO	Distribution System Operator
ECE	Executive Committed Energy
EMS	Energy Management System
FACTS	Flexible AC Transmission Systems
FIT	Feed-In Tarriff
FLISR	Fault Location Isolation
FO&M	Fixed Operation and Maintenance Cost
GDP	Gross Domestic Product
GI	Substation
GI	Gardu Induk, substation
IBT	Inter Bus Transformer
IPP	Independent Power Producer
LNG	Liquified Natural Gas
LVRT	Low Voltage Ride Through
MFO	Marine Fuel Oil
MILP	Mixed Integer Linear Programming
MoU	Memorandum of Understanding
NPI	Nickel Pig Iron
NTT	Nusa Tenggara Timur
OCGT	Open Cycle Gas Turbine
OPEX	Operational Expenditure
OPF	Optimal Power Flow
PLN	Perusahaan Listrik Negara (State Electricity Company)
PLTA	Hydro Power Plant
PLTB	Wind Power Plant
PLTBG	Biogas Power Plant
PLTBM	Biomass Power Plant
PLTD	Diesel Engine Power Plant
PLTG	Gas Turbine Power Plant
PLTGM	Gas Engine Power Plant
PLTGU	Combined Cycle Power Plant
PLTM	Microhydro Power Plant
PLTMG	Gas Engine Power Plant
PLTP	Geothermal Power Plant
PLTS	Photovoltaic Power Plant
PLTU	Steam (most often coal-fired) Power Plant
PPA	Power Purchase Agreement
PSS	Power System Stabilizer
PV	Photovoltaic
PyPSA	Python for Power System Analysis
RE	Renewable Energy
REEP	Renewable Energy for Electrification, GIZ programme
RKEF	Rotary Kiln - Electric Furnace
RoCoF	Rate of Change of Frequency
RUPTL	Indonesian national 10 year energy plan
SCADA	Supervisory Control and Data Acquisition
SCOPF	Security Constrained Optimal Power Flow
SLD	Single Line Diagram
SPC	Static Power Compensator
SPJBTL	Contract for industrial load
STATCOM	Static Synchronous Compensator
Sulbagsel	Southern Sulawesi subsystem
Sulutgo	Norther Sulawesi subsystem
SVC	Static Var Compensators
TOP	Take or Pay
UIKL	PLN transmission and generation unit
UIP3B	PLN transmission operation unit
VO&M	Variable Operation and Maintenance Cost
VRE	Variable Renewable Energy

Executive Summary

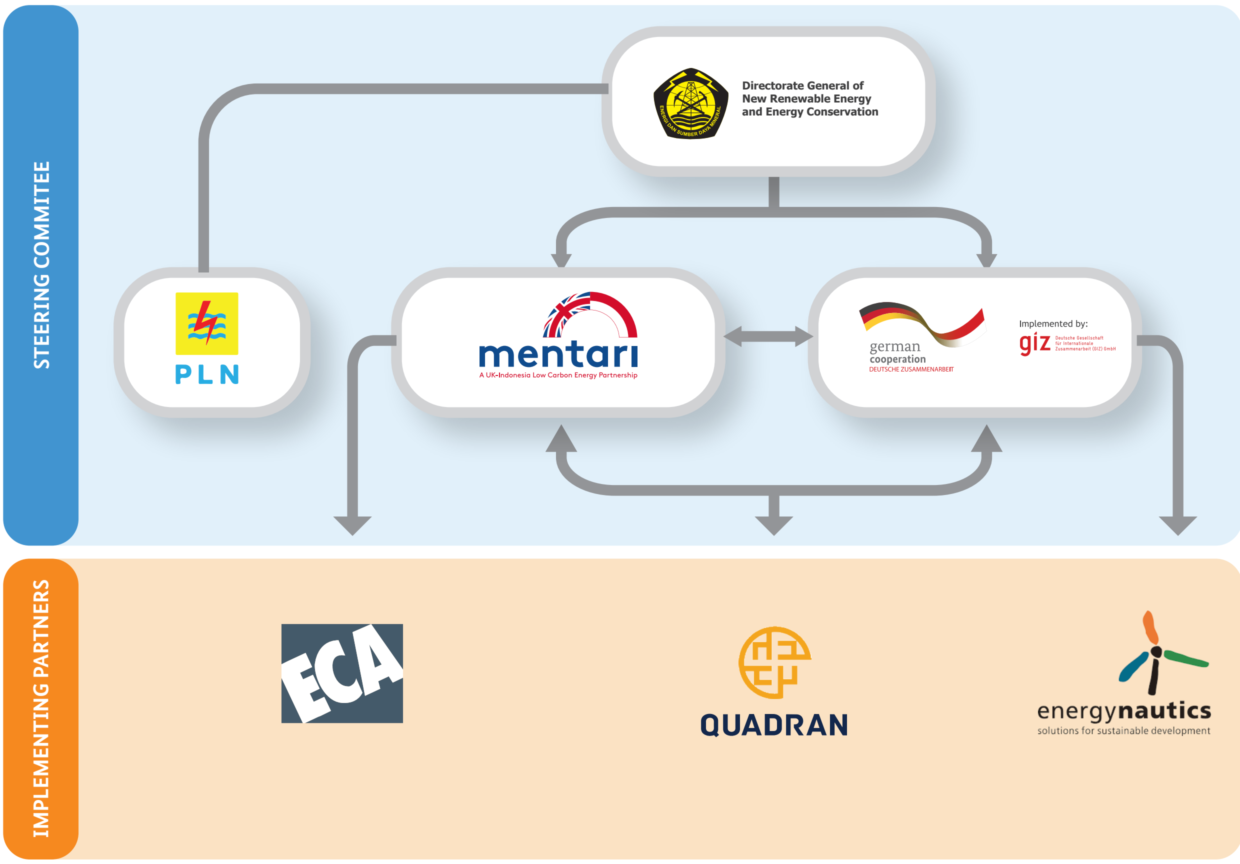
Background and Introduction

The Indonesian government has set the goal of covering 23% of electricity demand with renewable energy by 2025 in the National Energy Plan (RUEN). The Ministry of Energy and Mineral Resources (MEMR) is currently (2023) drafting a Presidential Regulation on Renewable Energy Tariffs to accelerate the development of renewable energy. This regulation will allow the Ministry of Energy and Mineral Resources to set renewable energy quotas for each region and determine the necessary tariffs to achieve this quota. Up to the end of 2022, the contribution of renewable energy in Indonesia has only reached 14.1%, and is thus far from the 2025 target. One of the efforts to accelerate the RE contribution is by putting an RE Quota on the state electricity company PLN (*Perusahaan Listrik Negara*). The necessary investments to fulfil the quota need to be identified. By understanding these costs, the government can develop strategies, allocate resources, and possibly seek partnerships or subsidies to ensure that the transition to renewable energy does not place undue financial strain on the nation or lead to significant increases in electricity prices for consumers.

As part of international support for renewable energy development in Indonesia, the two international technical cooperation programmes MENTARI (funded by the UK's Embassy to Indonesia) and REEP2 (implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development), have cooperated to conduct a long-term power system planning study in Nusa Tenggara Timur (NTT). The study was conducted between 2021 and 2023. Implementing partners were consulting firms ECA (UK), Energynautics (Germany) and Quadran (Indonesia). The project structure is shown in Figure 1.

The study is intended, on the one hand, to support the renewable energy quota calculation by MEMR, and on the other hand, to provide PLN with a good starting point for future power system planning.

Figure 1: Cooperation structure.



Current Status of NTT Province

Due to the insular topology of the province, power generation in NTT is provided by small scale generators powering a multitude of small systems, mainly using medium voltage grids to supply the load. Generation is still dominated by fossil fuels: diesel for the very small systems, coal and increasingly liquified natural gas for the larger systems. Renewable energy plays only a minor role in the form of some PV, microhydro and geothermal capacity.

The study focused first and foremost on increasing the renewable energy share in the three largest systems, Timor, Flores and Sumba, which possess the following properties as of 2023:

FLORES

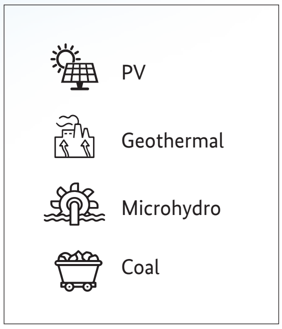
Supplied through 150 kV and 70 kV transmission. With an annual demand of 397 GWh and a peak load of 92 MW the system is slightly smaller than Timor. Generation is dominated by combustion engine power plants, supported by smaller shares of coal and geothermal generation as well as some PV and microhydro.

SUMBA ISLAND

Currently supplied by three 20 kV medium voltage systems powered by diesel generation with very small shares of PV and hydro. By 2026, the island's systems will be interconnected using 70 kV transmission to form a system with an annual demand of 119 GWh and a peak load of 23 MW.

TIMOR

Has a proper transmission system utilizing 150 kV and 70 kV voltage levels to supply an annual demand of 558 GWh and a peak load of 110 MW in 2022. Baseload generation is provided by coal, while load following and peaking are provided by combustion engine power plants. A very small share of PV is present in the system.

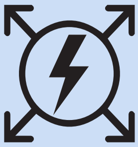


On top of good PV potential in all three systems, Timor has some wind resources, Flores has some potential for geothermal, and Sumba has some hydro resources. PLN's current plans which is considered as the "business as usual" (BAU) scenario in the study, draws mainly on biomass in Timor, geothermal generation in Flores and PV in Sumba to reach the given renewable energy target. These plans are optimised in the study to achieve the renewable energy target at the lowest overall cost.

Moreover, exemplary analyses were conducted for three smaller power systems in the single-digit MW range: Solor, Pantar and Palue. For these, PLN's current expansion plans are somewhat inadequate, and both hybridization of diesel with PV+BESS systems and fully renewable systems based on PV and battery energy storage were investigated.

Objective, Methodology and Scenarios

The study was conducted with the primary objective of identifying the least cost expansion plan that would fulfil the renewable energy target for each system. Simulations conducted consist of three interlinked parts:



- **Capacity expansion** planning, identifying which generation capacities would be needed through long - term optimization in Energy Exemplar PLEXOS;

- **Production simulation** in hourly resolution for key situations to verify feasible system operation at each expansion stage in PLEXOS;

- **Electrical analysis** in DIgSILENT PowerFactory for key situations, including power flow, short circuit and stability analysis, to ensure grid adequacy and system stability at each stage.

For each of the three larger power system, the optimised (least cost) expansion plan was benchmarked against the BAU plan derived from PLN's current plans. Even without further consideration, a high renewable scenario may emerge as the most cost effective option, given the resources of the islands. In case the least cost plan did not fulfil the renewable energy target, another optimization was run with a constraint forcing the fulfilment of the target, hence identifying the least expensive plan in line with the target.

Furthermore, all least cost and renewable energy target optimization calculations were run with and without BESS as a selectable expansion options. Those are indicated as "with battery" (WB) and "without battery" (WOB) in the following.

For the small systems of Solor, Pantar and Palue, two optimisation scenarios were run, one with the possibility of retained and added diesel generation (hybrid scenario) and one that relies entirely on renewable resources and BESS. Those were benchmarked against PLN's BAU scenarios.

Results

According to PLN's BAU scenario for Timor, the system continue to depend on coal, supported by diesel and gas engines for peaking and frequency control, with only very little renewable energy. The optimised least cost scenario results in even less renewable capacity in 2025 than the BAU scenario. The reason for that is primarily the new 2x50 MW coal unit PLTU Timor, which is already under construction and leaves very little room for variable renewable energy in the system.

However, all optimised results – both with and without renewable energy target constraint, and both with and without BESS – indicate that significant PV and wind contribution will be economically advantageous by 2031. Extremely quick action, significant support and additional investments are needed to reach the 23% target in 2025 – requiring the integration of around 125 MW of VRE capacity into the Timor system (Table 1).

Table 1: RE quota for Timor, study output using the constraint of 23% RE in 2025.

Technology	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	Unit
Wind	-	-	15	25	25	25	25	25	25	25	MW
PV	6	36.6	56.6	96.6	96.6	106.6	116.6	121.6	131.6	131.6	MWp
BESS power	-	2	2	3	5	5	5	5	6	20	MW
BESS energy	-	1	1	1.5	9.5	9.5	9.5	9.5	13.5	69.5	MWh

The situation is much clearer in the systems of Flores and Sumba. In both cases, the cheapest overall systems in both 2025 and 2031 use significant PV and BESS capacities, exceeding the renewable energy target in 2025. However, given the time constraint, integration of more than 100 MW of PV into the Flores system (Table 2) and more than 50 MW of PV and 5 MW of wind in the Sumba system (Table 3) require quick action and a solid framework for RE investments.

Table 2: RE quota for Flores, study output.

Technology	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	Unit
Hydro	3.67	3.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67	MW
Geothermal	15	18	18	29	40	40	40	40	40	40	MW
PV	2	57	67	107	122	142	162	182	202	237	MWp
BESS power	-	2	7	65	72	83	94	106	118	129	MW
BESS energy	-	8	28	260	288	332	376	424	472	516	MWh

Table 3: RE quota for Sumba, study output.

Technology	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	Unit
Biomass	-	-	1	1	1	1	1	1	1	1	MW
Hydro	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	MW
Wind	-	-	-	4.5	4.5	4.5	4.5	4.5	4.5	4.5	MW
PV	1.5	27.5	29.5	52.5	60.5	67.5	73.5	80.5	87.5	101.5	MWp
BESS power	-	3	3	21	24	31	36	40	46	53	MW
BESS energy	-	12	12	84	96	124	144	160	184	212	MWh

Table 4: RE quota for three small island systems, study output.

	Technology	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	Unit
Pantar	**PV**	0.25	1	1.25	1.75	2.25	3	4.25	5.5	7	22	MWp
	BESS power	-	-	-	-	-	0.1	0.7	1.4	2.1	16.5	MW
	BESS energy	-	-	-	-	-	0.4	2.8	5.6	8.4	66	MWh
Solor	**PV**	0.25	1.5	1.75	2.25	3.25	4.5	5.75	7.25	9	22.5	MWp
	BESS power	-	0.1	0.1	0.1	0.4	1	1.7	2.5	3.4	16.6	MW
	BESS energy	-	0.4	0.4	0.4	1.6	4	6.8	10	13.6	66.4	MWh
Pantar	**PV**	0.76	0.76	0.76	0.76	0.76	1.01	1.01	1.51	2.01	3.01	MWp
	BESS power	0.76	0.86	0.86	0.86	0.96	0.96	0.96	1.36	1.96	2.46	MW
	BESS energy	1.68	2.08	2.08	2.08	2.48	2.48	2.48	4.08	6.48	8.48	MWh

This trend is even more clearly observed in the small island systems of Pantar, Solor and Palue. For all three, PLN's current expansion plans are inadequate to cover the expected significant demand increase. In all three cases, a hybridised systems including significant PV and BESS shares are most economic. Fully renewable supply is overall more expensive. The RE quotas (Table 4) are hence derived from the hybrid scenarios. These fulfil the 23% target for 2025 and show RE shares of approx. 90% by 2031.

The results indicate that significant investment is needed for the three investigated large systems – and hence the entire NTT province – to reach 23% renewable energy by 2025. However, the results also show that for all systems, the 2031 least cost expansion necessarily contains significant RE contribution. Ambitious RE targets should hence be set. For the small systems, the cheapest and most reliable way forward is hybridisation of diesel based systems with significant shares of PV and BESS, including grid forming functionality of the BESS inverter. Key results are presented below.

KEY RESULTS: FLORES

2025 2026 2027 2028 2029 2030 2031

23% RE by 2025:

107 MWp of PV

65 MW / 260 MWh of BESS

234 million USD investment

BPP 11.67 USct/kWh

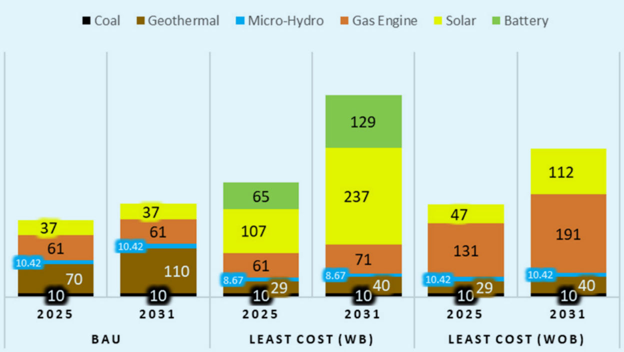
Cheapest scenario 2031:
PLN BAU scenario, 92% RE, mainly geothermal
High amount of unserved load (operationally infeasible),
BPP 9.67 USct/kWh

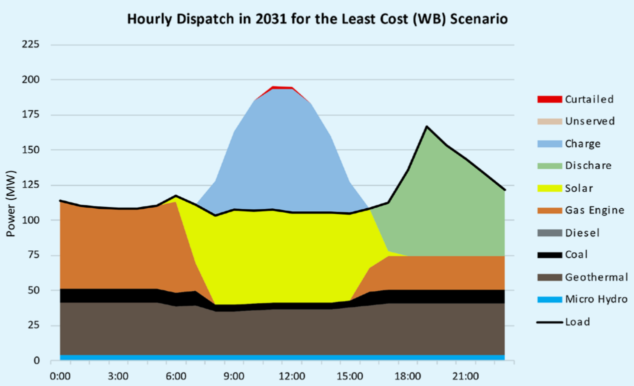
Feasible highest RE scenario 2031:
70% RE, PV + wind + BESS,
Additional cost of 34 million USD over infeasible BAU scenario,
BPP 10.32 USct/kWh

Key RE Integration Issue: No major issues

Recommended strategy: Integrate PV into the existing diesel based system and investigate BESS options as soon as possible. PV + BESS allow for high RE shares without the flexibility and acceptance issues found with PLN's current geothermal-heavy plans.

INSTALLED CAPACITY





KEY RESULTS: TIMOR

2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031

23% RE by 2025:

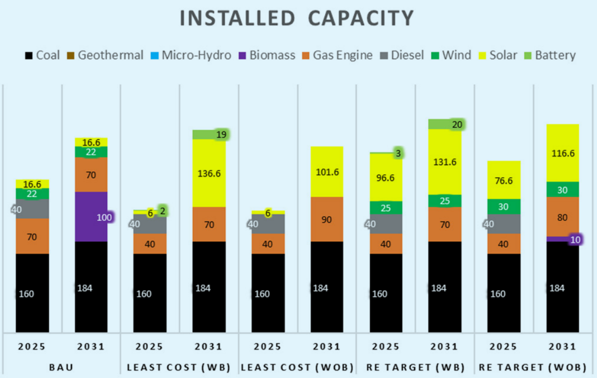
- 100 MWp of PV
- 25 MW of wind
- 3 MW / 1.5 MWh battery for frequency control
- 100 million USD investment
- BPP 12.04 USct/kWh

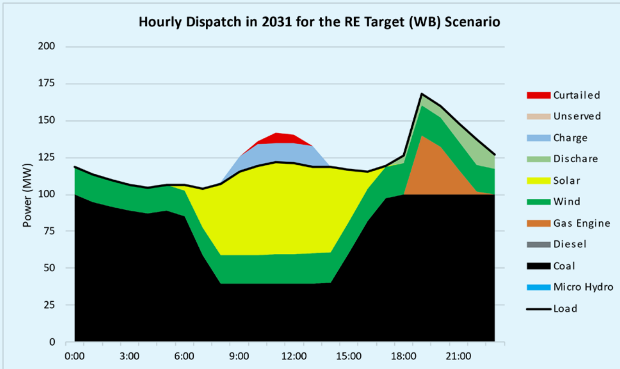
Cheapest scenario 2031:
21% RE, PV + BESS,
Saves 400 million USD over BAU scenario,
BPP 10.1 USct/kWh

Highest RE scenario 2031:
27% RE, PV + wind + BESS,
Additional cost of 47 million USD over cheapest scenario,
BPP 10.44 USct/kWh

Key RE Integration Issue:
System overinstalled with coal capacity, flexibility issues, BESS required for frequency control

Recommended strategy: Invest in PV, wind and BESS instead of biomass. Frequency control scheme needs to be revised and reduced capacity factors on coal units need to be accepted.





KEY RESULTS: SUMBA ISLAND

2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031

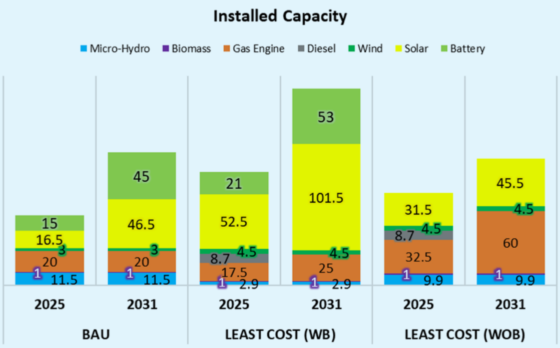
23% RE by 2025:

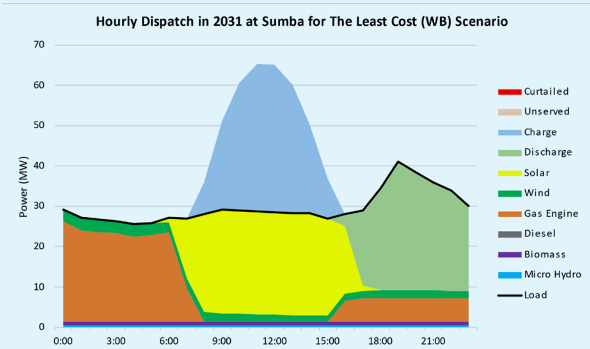
- 2.9 MW of microhydro
- 4.5 MW of wind
- 52.5 MWp of PV and 21 MW / 84 MWh BESS
- 100 million USD investment
- BPP 12.44 USct/kWh

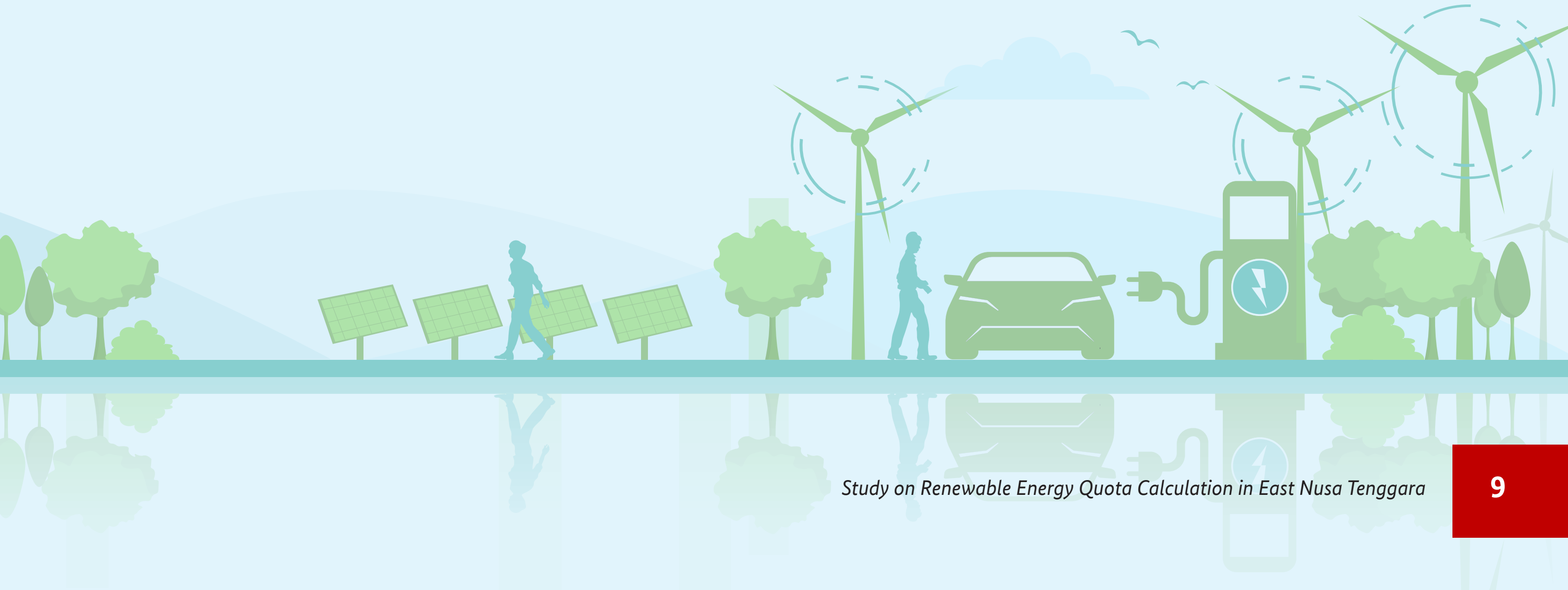
Cheapest scenario 2031:
68% RE, PV + wind + grid forming BESS,
Saves 23 million USD over BAU scenario,
BPP 12.33 USct/kWh

Key RE Integration Issue: Sumba systems are not yet interconnected, ambitious RE scenario requires immediate action.

Recommended strategy: Push for interconnection of main systems, and procure PV + BESS at the same time to already hybridise individual systems. Set grid forming capability as a requirement for BESS.







KEY RESULTS: (PALUE, SOLOR, PANTAR)

2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031

23% RE by 2025:

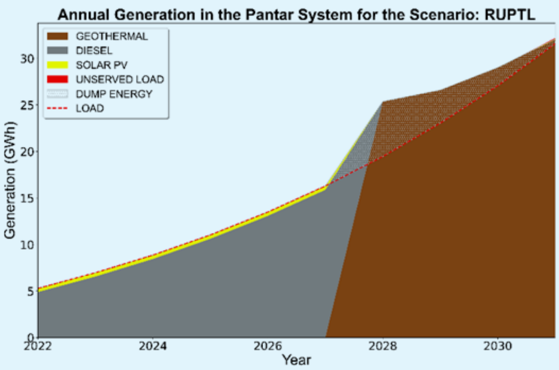
PV and BESS on all three islands.

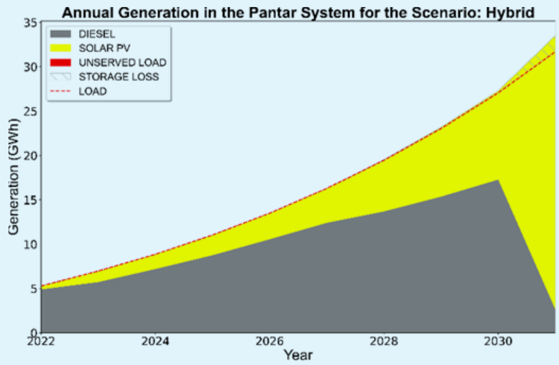
Cheapest scenario 2031:
The most cost-effective approach involves a hybridized system, achieving around **90%** of RE,

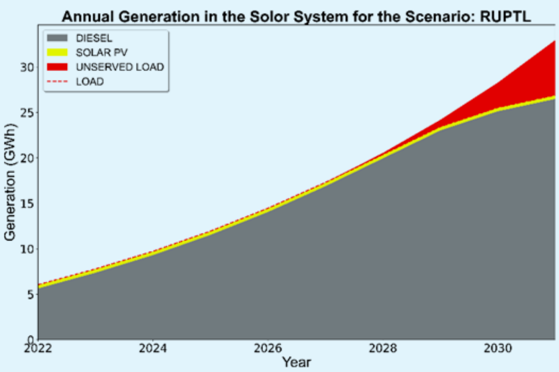
Halving overall generation cost on all islands.

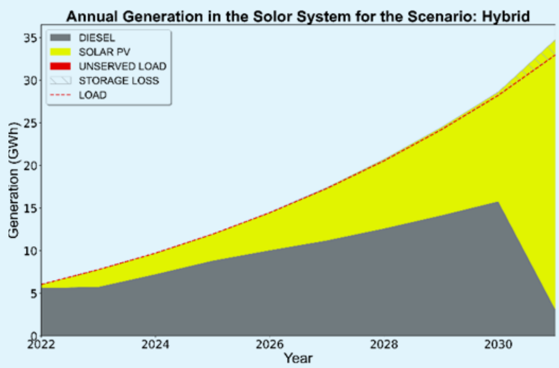
Key RE Integration Issue: Grid forming functionality required within 3-5 years (commercially available), PV deployment is required in the early stage when PV is still mainly balanced by diesel.

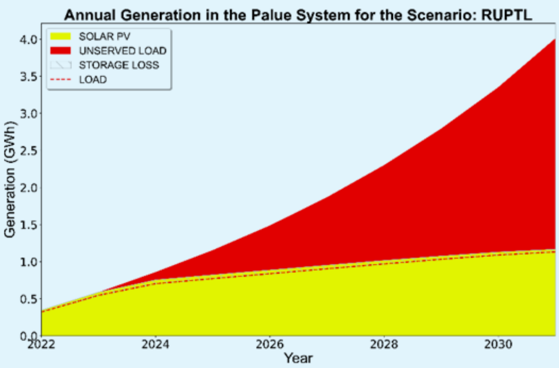
Recommended strategy: Integrate PV into diesel-based systems until 2025, then start investments into BESS with grid forming inverters.

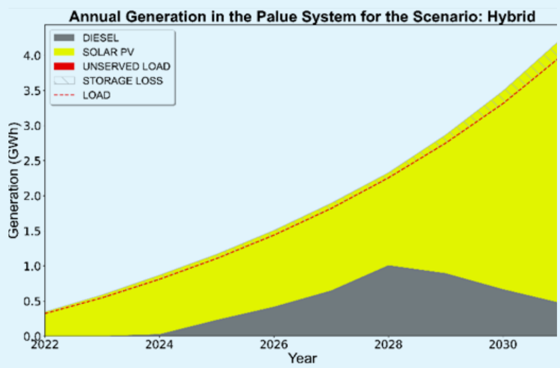












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