



Flexibility in Power System Development Sulawesi Case Study

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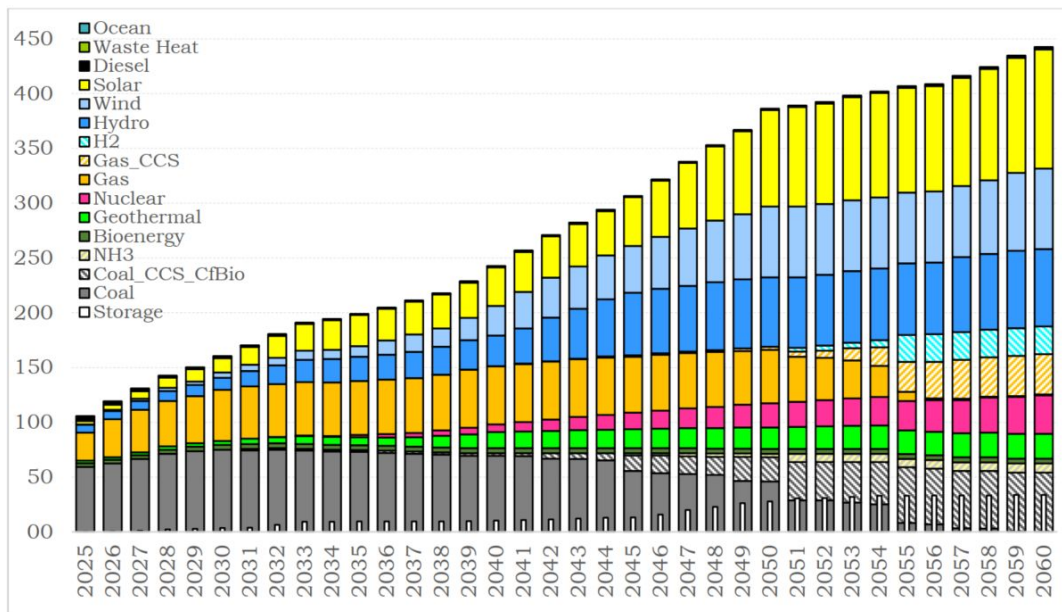


Introduction and Background



Indonesia Decarbonisation Strategy - RUKN

National Capacity Expansion Projection



Increase in renewable capacity is one of the main strategies for decarbonising Indonesia's energy system

In 2060:

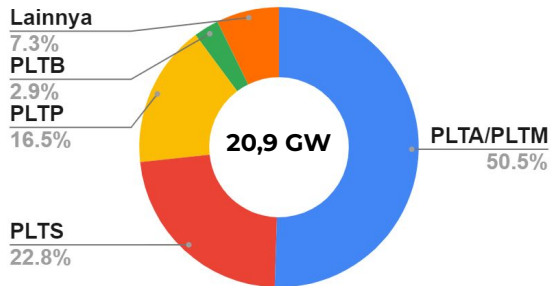
- 58.5% dispatchable capacity
- **41.5% VRE capacity**

Indonesia Decarbonisation Strategy - RUPTL



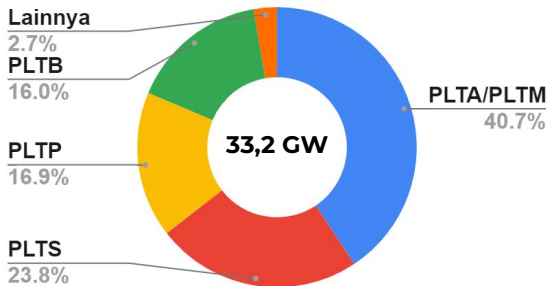
“The Greenest RUPTL”

Target Penambahan Pembangkit EBT dalam RUPTL 2021-2030

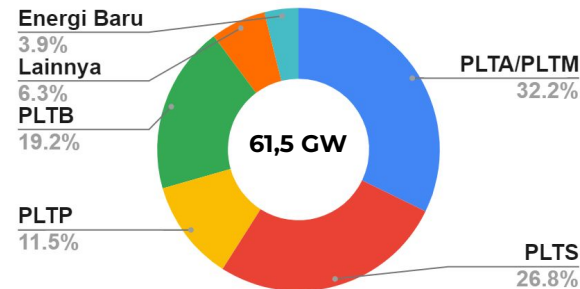


“Beyond the Greenest RUPTL”

Target Penambahan Pembangkit EBT dalam DRUPTL 2024-2033 (ARED)



Target Penambahan Pembangkit EBT dalam Skenario ARED 2024-2040



Renewable capacity increases, especially Variable Renewable Energy (VRE) like solar PV and windpower, alongside the development of smart grids and **flexible power system operations**.

Indonesia Decarbonisation Strategy - CIPP



What it takes to implement JETP scenario

Target by 2030:
250 MT CO₂ emission (on-grid)
44% renewable generation share



14% VRE in 2030!

US\$97.3 billion needed for just transition pathways until 2030

400+ priority projects (US\$66.9 billion investment needed) to start by 2030

Positive socio-economic impact throughout the energy transition process



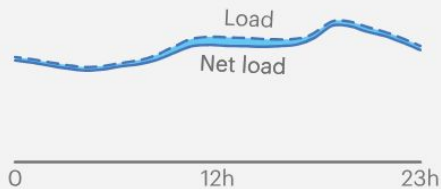
Urgency of a Flexible Power System

IEA's Phases of VRE Integration

Phase 1

Load versus net load

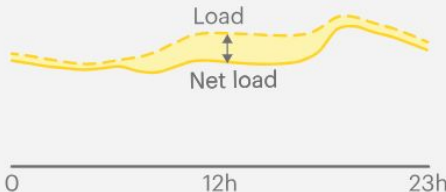
The difference between load and net load is **minimal**



Phase 2

Load versus net load

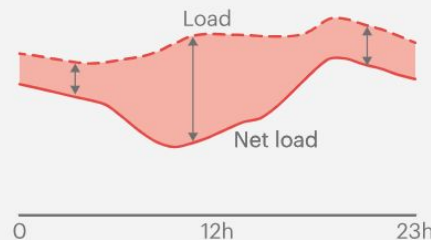
The difference between load and net load is **noticeable**



Phase 3

Load versus net load

The **"duck"** curve starts emerging, suggesting that more pronounced and longer ramps are required

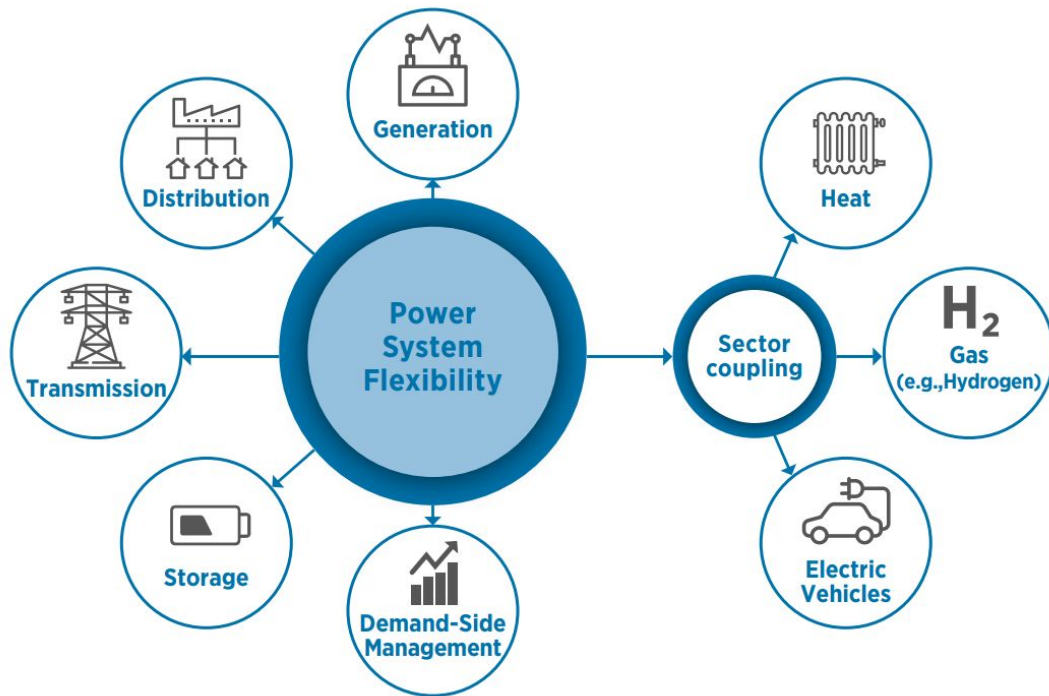


Increased Variable Renewable Energy Integration to the Power System

"VRE determines the operation pattern of the power system and **increases the uncertainty and variability of net load**.

Greater swings in the supply-demand balance prompt the need for a **systematic increase in flexible operation of the power system** that often goes beyond what can be readily supplied by existing assets and operational practice." (IEA, 2024)

Options for Flexibility Sources



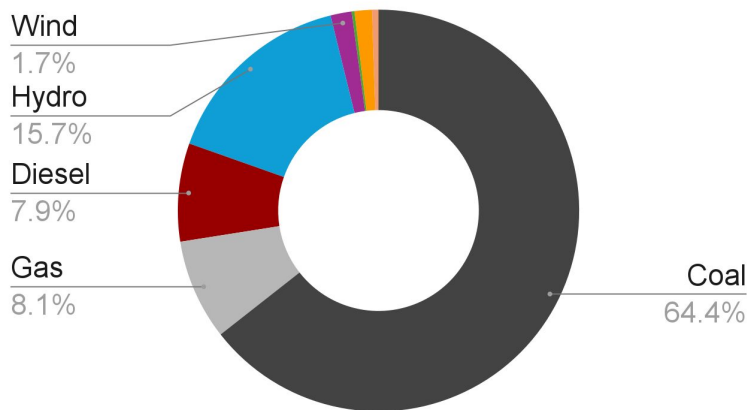
Synergize flexibility source options with current Indonesia planning documents and needs:

- **Flexible generation:**
flexible coal operation (retrofit/repurpose)
- **Flexible transmission:**
balancing supply/demand across large areas (supergrid plan)
- **Energy storage:**
multi-duration storage options to address different timescales

Source: IRENA, 2018

Sulawesi as Case Study: Future Planning

Sulawesi Installed Capacity Mix, 2023

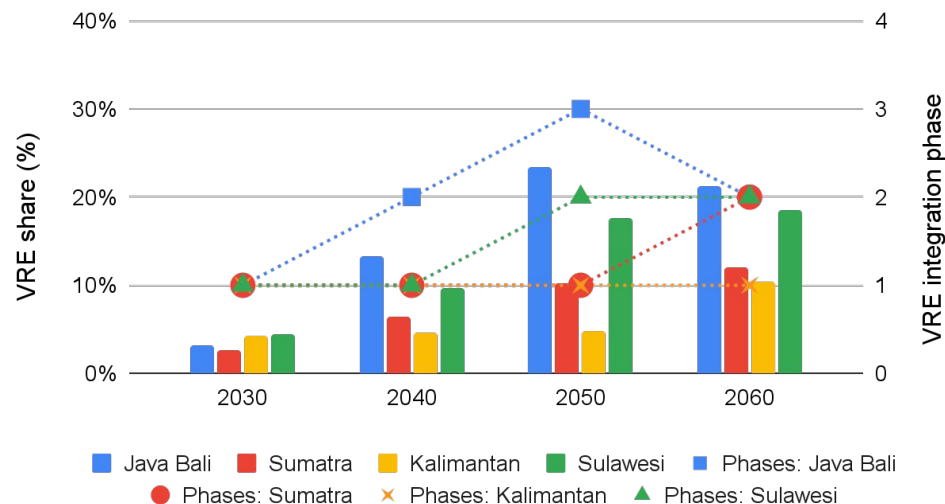


Source: Statistik Ketenagalistrikan 2023 (ESDM, 2023)

Other factors:

- Industrial demand growth
- 35.3% VRE capacity in 2060

The Projected VRE Penetration and the Integration Phases of Power Systems in Indonesia



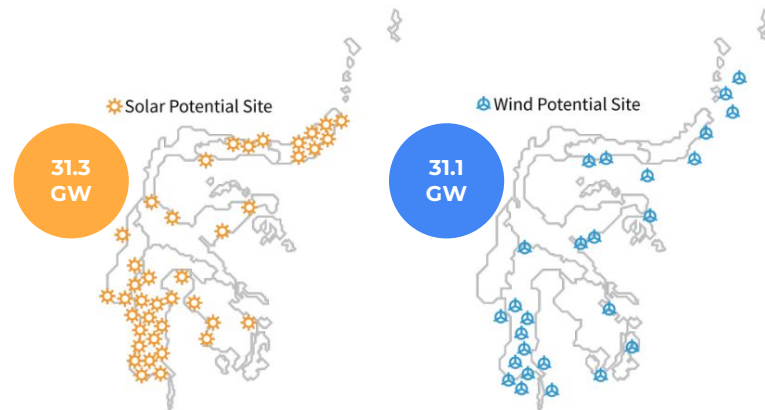
Source: IESR analysis from RUKN 2025-2060

Sulawesi as Case Study: RE Potential

Sulawesi RE Potential Capacity (MW)

Provinsi	Panas Bumi	Air	Surya	Bioenergi	Angin
Sulawesi Utara	838	51	12	500	2783
Sulawesi Tengah	833	1373	41	448	1174
Sulawesi Selatan	516	822	65	1202	8345
Sulawesi Tenggara	318	230	86	214	1795
Gorontalo	160	78	7	483	137
Sulawesi Barat	406	422	20	515	651

Potential Locations for Solar PV and Wind Power Development in Sulawesi with EIRR >7%



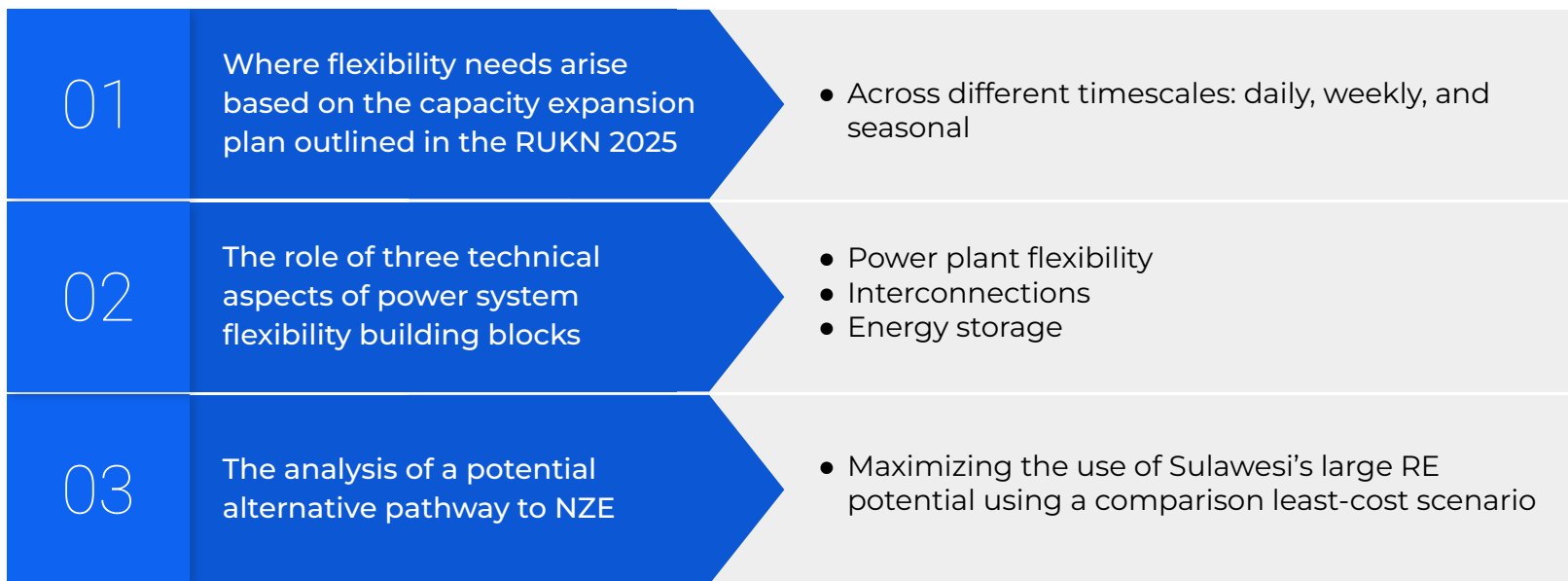
Source: IESR (2025)

System reliability and grid strength are often cited as reasons for limiting VRE integration, while other energy sources, such as nuclear, biomass, and hydrogen, have emerged in recent planning documents as alternative solutions to meet part of the electricity demand. However, these alternative energy sources also involve a high degree of uncertainty. Meanwhile, limitations on VRE utilization and concerns over reliability may, in fact, stem from a lack of comprehensive studies on system flexibility that consider a wide range of flexibility options.



Study Objectives

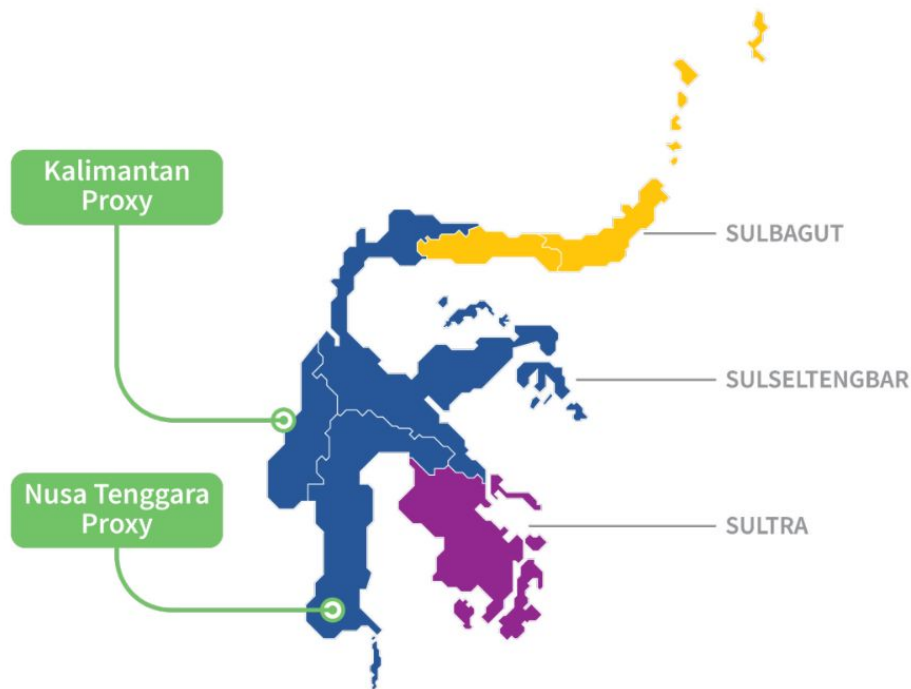
This study was conducted to identify the role of power system flexibility, starting with Sulawesi system, in enabling high levels of VRE penetration. Specifically, it provides insights on:





Power Supply Model Development and Methodology

Modelled Region

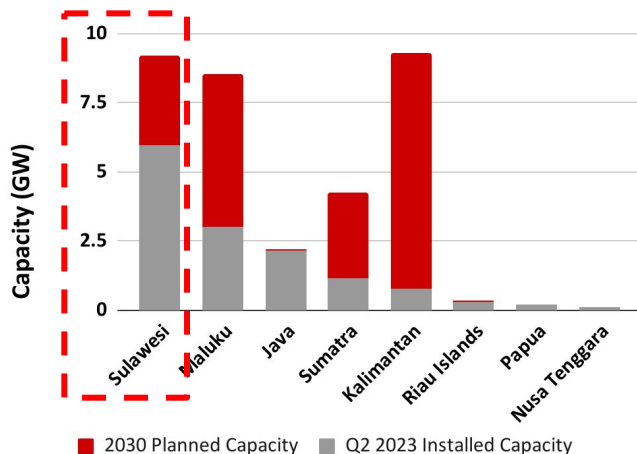


- In the RUPTL 2021-2030, Sulbagut and Sulseltengbar nodes are not connected by transmission lines. Therefore, **only one existing transmission line is modeled**—connecting **Sulseltengbar to Sultra**.
- **Interconnection between all three nodes** are modeled as **candidates** starting from 2031 onwards.
- Sulawesi is projected to **import electricity from Kalimantan and Nusa Tenggara** in the RUKN 2025-2060 (supergrid). **Imports are represented using proxy generators with appropriate cost assumptions.**



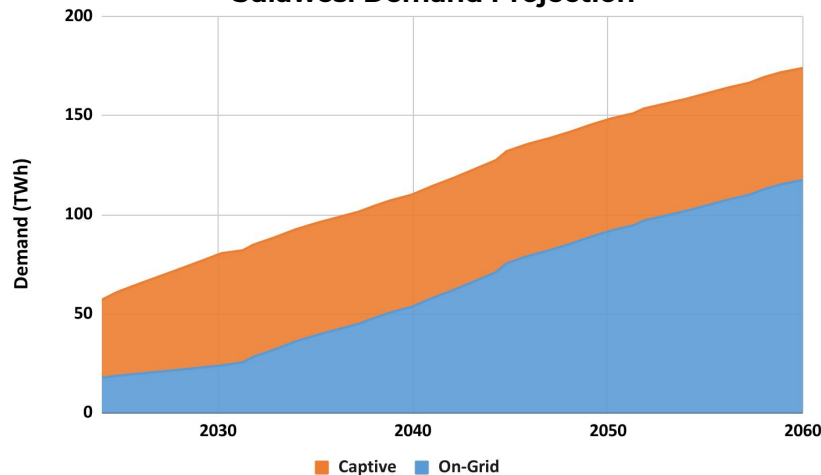
Modelled Demand

Indonesia Captive CFPP Capacity by Province



Source: KPMG (2023)

Sulawesi Demand Projection



Source: IESR analysis from RUKN 2025-2060, RUPTL 2021-2030, and KPMG (2023)

- The on-grid demand projection is developed from **the RUKN 2025, RUPTL 2021-2030, and Captive Power Landscape Assessment for the Energy Transition in Indonesia report by KPMG for ADB (2023).**
- Since the latest RUKN demand also contains the captive demand, the RUPTL's demand projection and indicative captive demand are used to estimate the on-grid demand.
- Captive CFPP CF assumed to be 70%.



Methodology

Techno-economic analysis utilizing PLEXOS least cost optimization

Power System Modelling

Modelling Constraint

Least Net Present Value of Costs

Ensuring Balanced Supply & Demand

Scenarios for Power System Analysis

RUKN Baseline

RUKN with Battery Duration Variation (BV)

Least-cost expansion with imports (LCWI)

Least-cost expansion with advanced battery costs (LCAB)

Least-cost expansion with moderate battery costs (LCMB)

Least-cost expansion with conservative battery costs (LCCB)

Least-cost expansion with no storage (LCNS)

Modelled Output:

Installed capacity projection

Generation projection

Flexibility Parameters

BPP cost

Note: the binding from current regulation and contracts (and potential costs) are not considered.



Scenario Design Summary

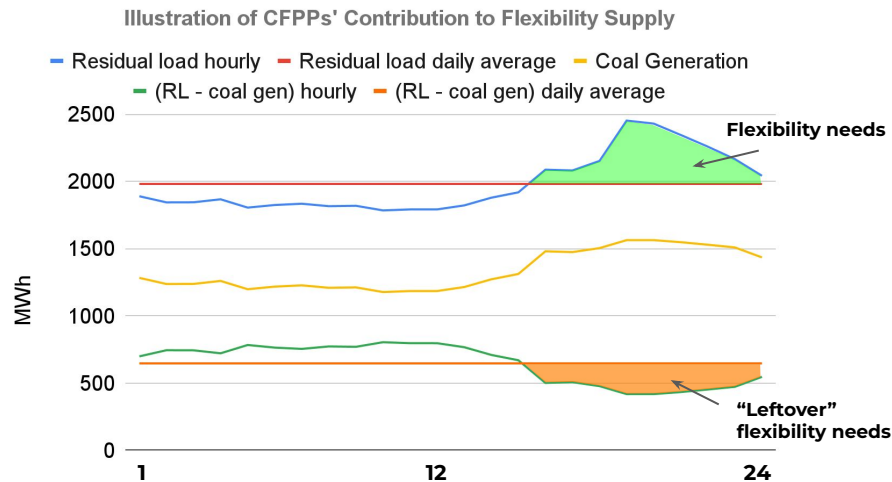
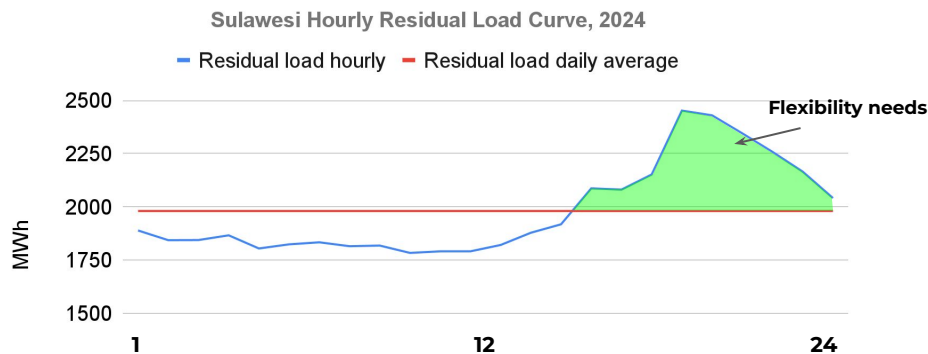
Scenario	RUKN Baseline	RUKN + Battery Duration Variation (BV)	Least-cost with Imports (LCWI)	Least-cost + Advanced BESS costs (LCAB)	Least-cost + Moderate BESS costs (LCMB)	Least-cost + Conservative BESS costs (LCCB)	Least-cost + No Storage (LCNS)
Battery Costs	MEMR's Technology Data Catalogue 2024			NREL Advanced BESS costs	NREL Moderate BESS costs	NREL Conservative BESS costs	None
Battery Duration Variation	4-hour BESS only	Optimised mix of 2-hour, 4-hour, and 10-hour BESS					
Inter-island Connection	Imports from Kalimantan and Nusra, following RUKN 2025-2060			None			
Emission Constraint	None		Following RUKN Baseline results	None			
Fossil Power Plant Scenario	Mandatory: CFPP & Gas retrofitted following RUKN; Diesel: shutdown by 2030		Optional: CFPP & Gas retrofitted by the end of lifetime Mandatory: Diesel: shutdown by 2030				
Capacity Expansion	Following RUKN 2025-2060		Fully Optimised				
Demand	On-grid electricity demand and load profile based on RUKN 2025-2060 (calibrated with RUPTL 2021-2030 and KPMG report on captive power)						
Techno-economic Parameters	MEMR's Technology Data Catalogue 2024						



Technical Flexibility Parameters

Flexibility needs are determined by the **fluctuations in residual load (or net load)** in different timescales: **daily, weekly, and seasonally**.

Daily flexibility example:



Different factors drive flexibility needs in different timescales (e.g. solar PV fluctuations tend to be on the daily level while wind is more seasonal).

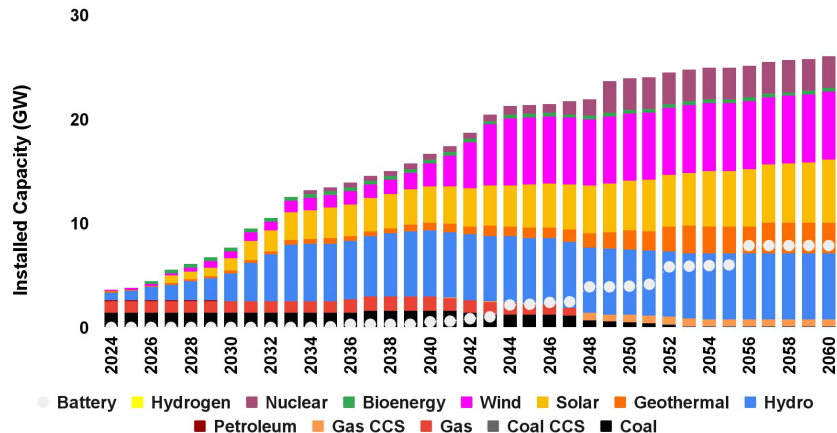


Results and Analysis

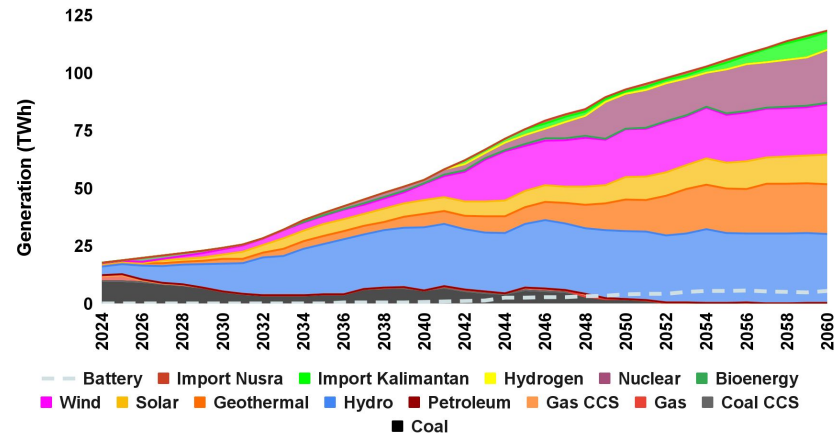


Evolution of the Sulawesi Power System in the RUKN-aligned Scenarios

Installed Capacity in RUKN Scenario



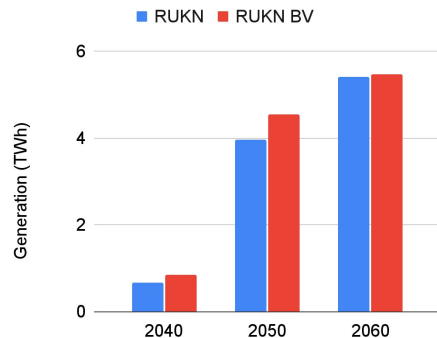
Generation in RUKN Scenario



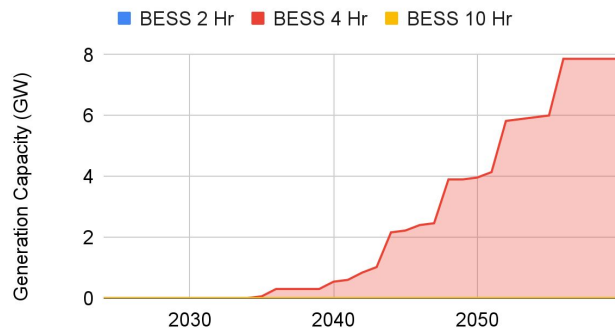
- Generation mix will shift from fossil fuels to renewable energy, with **VRE rising from 2.4% in 2024 to 29% in 2060**.
- All generator types expand their capacities according to RUKN 2025, except BESS, which exceeds the RUKN constraint. Likely due to higher on-grid demand assumptions in this study compared to those used in the RUKN 2025 model.
- Nuclear grows to be the second-largest contributor to the generation mix in 2060, after hydropower. Interconnections also play an important role after their implementation in 2041.

Impact of Duration Variation on BESS Composition and Electricity Generation

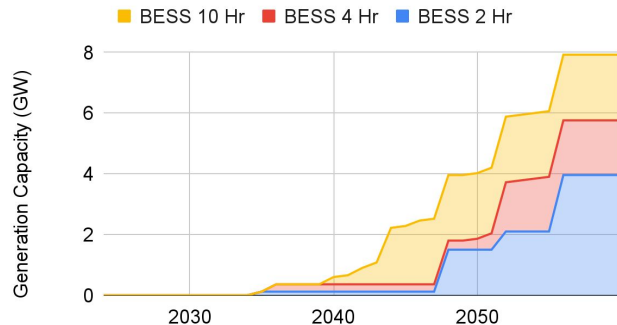
BESS Generation Comparison



RUKN Baseline BESS Generation Capacity



RUKN BV BESS Generation Capacity

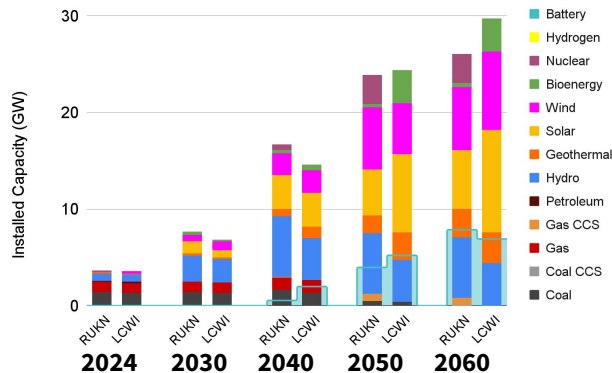


- RUKN BV models BESS in **2-hour, 4-hour, and 10-hour duration** while RUKN Baseline only models **4-hour BESS**.
- **Higher annual electricity discharged from BESS in the RUKN BV scenario:** 27% more in 2040, 15% more in 2050, and 1% more in 2060.
- Over the long term, **2-hour BESS becomes the dominant configuration**, accounting for 50% of total BESS discharge capacity by 2060, with the remainder split between 4-hour (23%) and 10-hour (27%) systems. Preference for shorter duration due to cost-effectiveness for meeting short, sharp demand peaks.
- Overall, BESS duration variation **enables better utilization of stored renewable energy and reduces curtailment**.

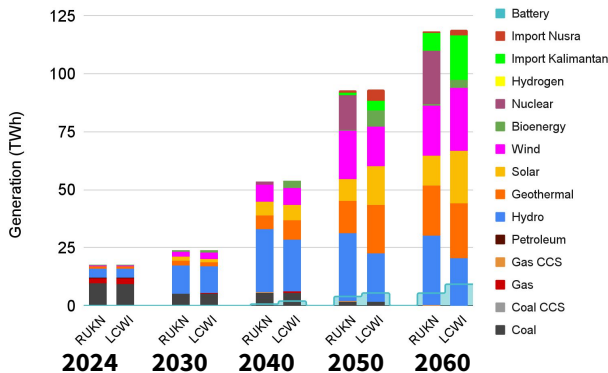


LCWI Scenario as an Alternative Pathway for Sulawesi

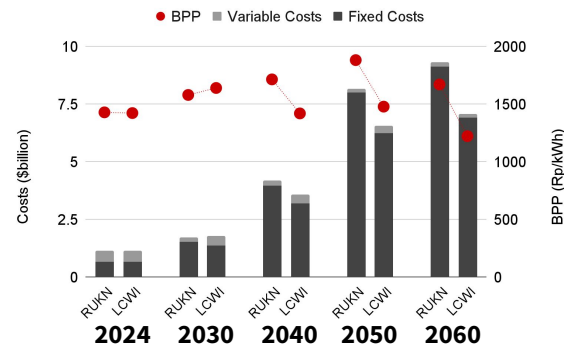
RUKN and LCWI Capacity Expansion Comparison



RUKN and LCWI Generation Comparison



RUKN and LCWI Costs Comparison



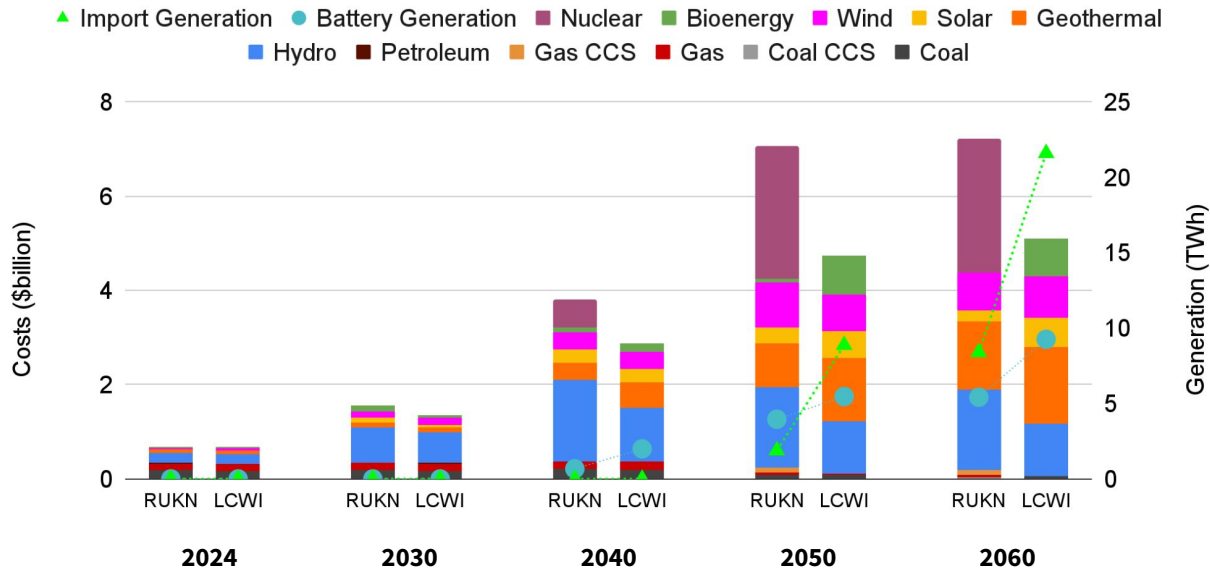
Note: BPP calculation uses 1 USD = 16,000 IDR

- Compared to the RUKN Baseline, the LCWI scenario can achieve **up to 27% lower BPP in 2060** (Rp 1,223/kWh), while keeping emissions at the same level.
- Nuclear is opted out entirely, while the optimisation favours bioenergy, VRE + BESS, and interconnections:
 - Bioenergy peak capacity: **360 MW (RUKN) vs 3.4 GW (LCWI)**
 - By 2060, **75.7% more solar PV generation** and **71% higher from BESS** in the LCWI scenario
 - By 2060, interconnections contribute **2.5-times more electricity generation** in the LCWI scenario
- This outcome highlights a **potential for bioenergy development in Sulawesi**—particularly biomass—that remains largely untapped under current policies and planning frameworks.

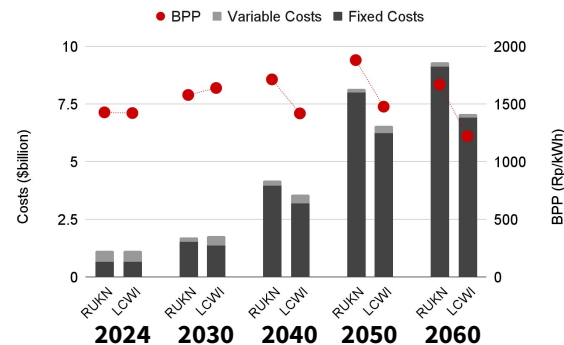


LCWI Scenario as an Alternative Pathway for Sulawesi

RUKN and LCWI Generator Fixed Costs Comparison



RUKN and LCWI Costs Comparison



Note: BPP calculation uses 1 USD = 16,000 IDR

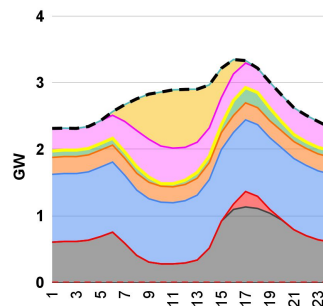
- Gap in fixed costs between LCWI and RUKN Baseline scenarios is mainly due to the **significant CAPEX difference between nuclear power and the technologies favoured in the LCWI scenario.**



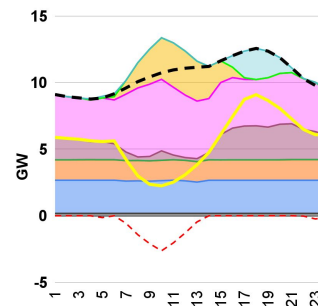
Average Daily Generation Profile in Sulawesi

- **Daily net load variability in Sulawesi is projected to increase** in accordance with higher VRE penetration and demand fluctuation.
- Even in 2030, coal and gas power plants still ramps up and down to follow daily net load fluctuations, but phased out in the future as hydro and geothermal operate as baseload.
- As it becomes available, **BESS smooths out net load variation** by shifting solar PV generation from daytime to the evening.
- Imports from Kalimantan and Nusra will help meet evening peak demand.
- After 2050, the **midday net load dip is deeper in the LCWI scenario**, indicating higher flexibility requirements.
- in the **LCWI** scenario, flexibility needs are met by **BESS, bioenergy, and interconnectors**. In the **RUKN Baseline**, **nuclear power** acts as the main flexible generator.

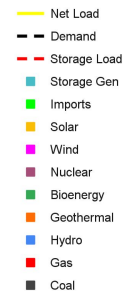
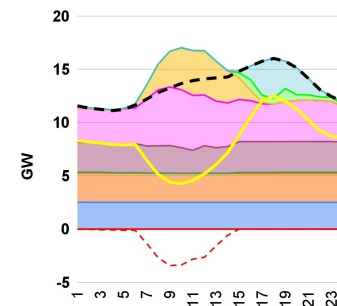
RUKN Baseline week 40 2030



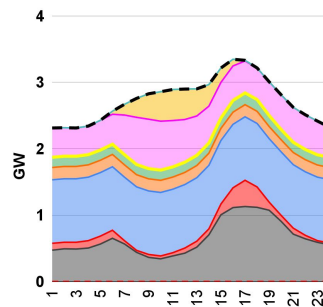
RUKN Baseline week 40 2050



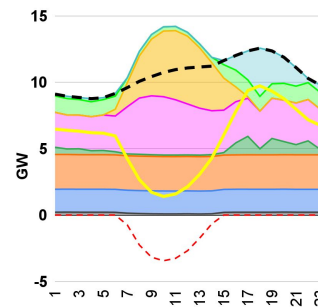
RUKN Baseline week 40 2060



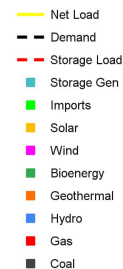
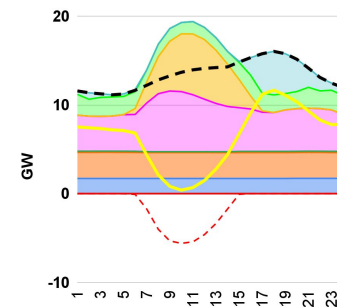
LCWI week 40 2030



LCWI week 40 2050



LCWI week 40 2060

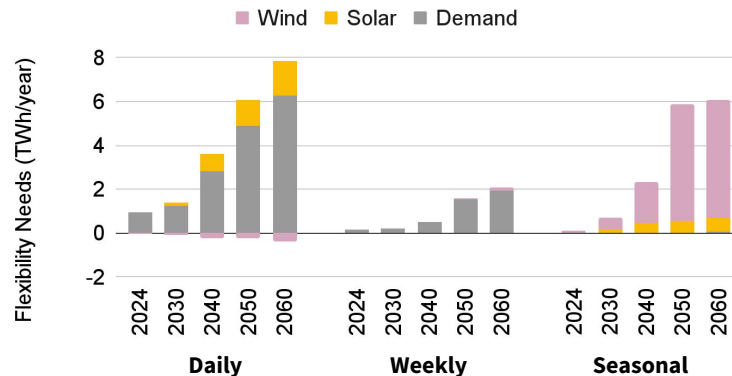




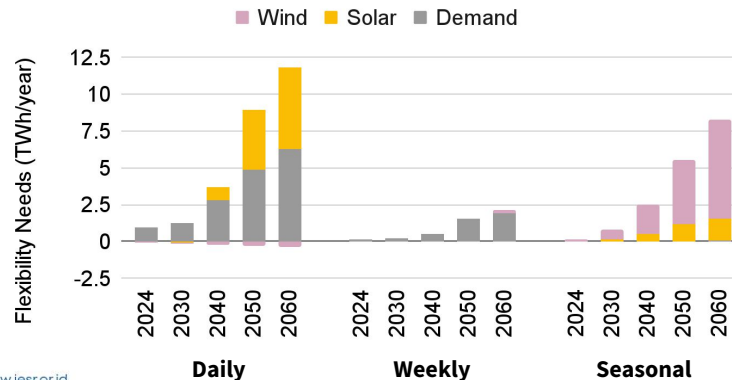
Power System Flexibility Needs in Sulawesi

- In the future, **flexibility needs in Sulawesi will increase significantly across all timescales**. Overall, the flexibility needs in the LCWI scenario are higher than in the RUKN-aligned scenarios.
- The **greatest flexibility need occurs on the daily timescale**, while **weekly flexibility needs are the most modest**. **Seasonal flexibility needs experience the most extreme growth**, from 0.1 TWh/y in 2024 to 6 TWh/y (RUKN) and 8.3 TWh (LCWI) in 2060.
- **Demand fluctuations are the biggest driver of daily flexibility needs**, but solar PV increasingly becomes an **additional contributor**. In LCWI, solar PV accounts for almost half of the flexibility needs.
- **VRE penetration has minimal impact on weekly flexibility needs**.
- The evolution of **seasonal flexibility demand** in this study is primarily driven by VRE penetration, **especially onshore wind**.

Sulawesi RUKN Flexibility Needs, by Drivers

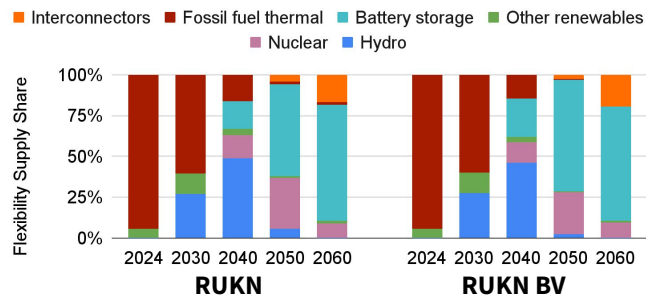


Sulawesi LCWI Flexibility Needs, by Drivers

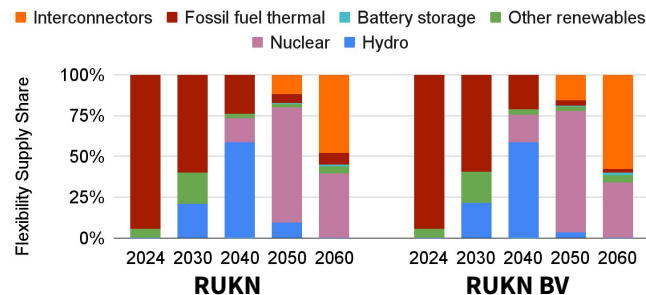


Contribution to Sulawesi's Flexibility Supply in the RUKN-aligned Scenarios

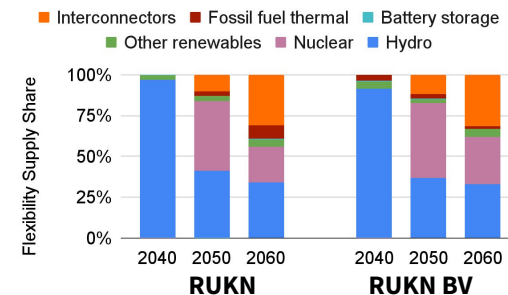
Daily Flexibility Supply by Source



Weekly Flexibility Supply by Source



Seasonal Flexibility Supply by Source

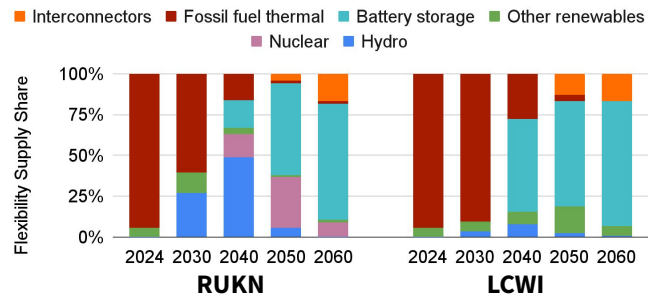


- Currently, **fossil thermal fuel technologies dominate the flexibility supply**. As the power system transitions, the role of fossil fuels is gradually replaced by other technologies, according to the suitability to the timescale.
- BESS is particularly well-suited to meet daily flexibility needs** due to its ability to shift electricity generation from daytime to evening, addressing daily fluctuations in both demand and solar PV generation.
- Interconnections contributes to the flexibility supply across all timescales, **with the highest contribution on the weekly timescale**, followed by seasonal, and then daily.
- Hydropower's role as a flexibility source across all timescales is projected to grow until it peaks in 2040, after which it drops as it shifts to a baseload role in 2060. **Its contribution to the flexibility supply is most prominent on the seasonal timescale.**
- In the transitional period (2030-2050), hydropower and nuclear play important roles in the flexibility supply across all timescales.
- Incorporating battery duration variations into the power system results in a **generally lower share of fossil fuel thermal as a flexibility source** compared to the baseline scenario.

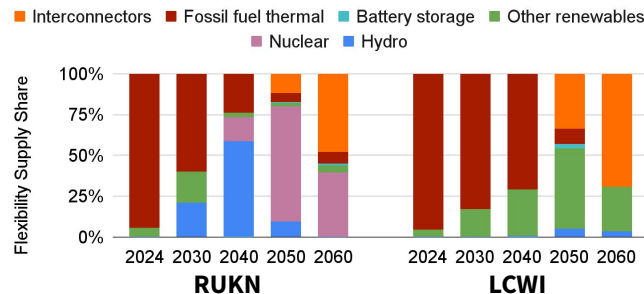


RUKN and LCWI Flexibility Supply Comparison

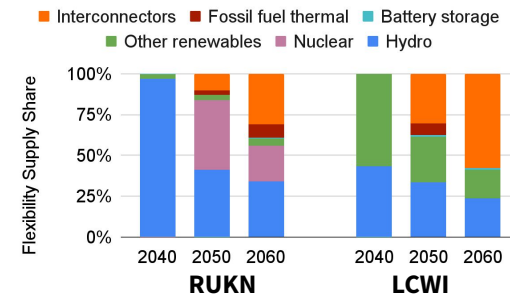
Daily Flexibility Supply by Source



Weekly Flexibility Supply by Source



Seasonal Flexibility Supply by Source

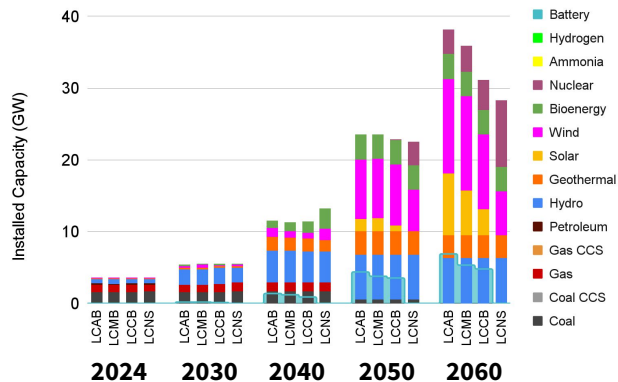


- Overall, **the role of hydropower and nuclear as flexibility sources is reduced in the LCWI scenario**, in line with their lower electricity generation across the modelling time horizon. Conversely, **bioenergy, BESS, and interconnectors contribute more to the flexibility supply**.
- From 2024 to 2050, **fossil fuel thermal technologies also hold a higher share as flexibility sources** in the LCWI scenario compared to the RUKN Baseline.
- In the absence of nuclear in the LCWI scenario, **BESS and other renewables (especially bioenergy) largely replace nuclear's role as daily flexibility sources**. By 2040, BESS contributes 56.5% in LCWI, compared to just 17% in the RUKN Baseline.
- In the 2060 LCWI scenario, **interconnectors dominate both weekly and seasonal flexibility supply, whereas in the RUKN Baseline scenario, their dominance is limited to the weekly timescale**. This highlights the capability of interconnectors to address seasonal flexibility supply when hydropower generation is limited.
- The modeling results suggest that **BESS and interconnectors emerge as crucial sources of flexibility in the power system, helping to contain total system costs**, especially as VRE penetration (and therefore flexibility needs) increase over the long term, as demonstrated in the LCWI scenario.

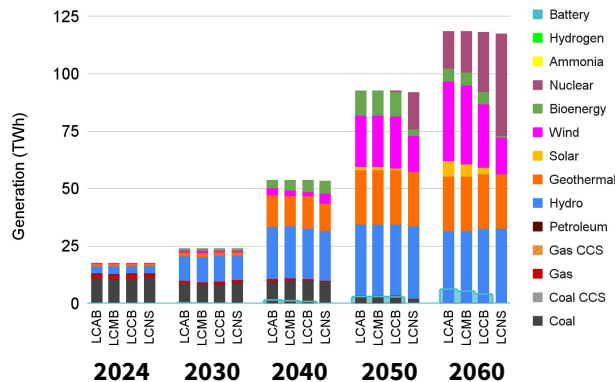


Impact of Battery Costs to Power System Capacity Expansion

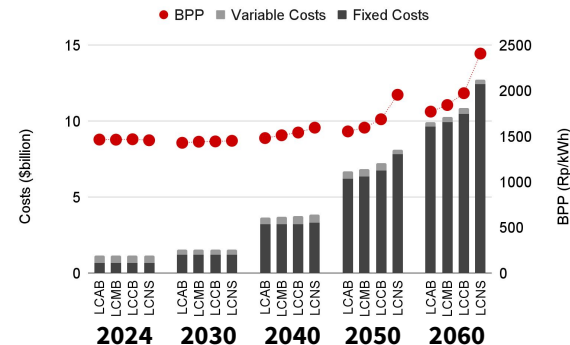
Least-cost Scenarios Capacity Expansion



Least-cost Scenarios Generation



Least-cost Scenarios Costs Comparison



Note: BPP calculation uses 1 USD = 16,000 IDR

- In the least-cost scenarios with no expansion constraints and no import options (sensitivity analysis), **lower BESS costs enable higher VRE penetration.**
- While other technologies remain relatively consistent across all scenarios, **nuclear and VRE emerge as competing options, depending on battery costs.** When battery costs are higher, the model favors nuclear over solar PV + BESS, due to the higher cost of overbuilding solar PV compared to nuclear power plants.
- Despite having lower total installed capacity, the **LCNS scenario is the most expensive compared to the others**, resulting in higher BPP costs than in scenarios where batteries are available.
- As battery costs become more conservative, i.e. less competitive, the power system increasingly relies on nuclear power plants, which have higher capital costs relative to VRE + BESS systems in the other scenarios.



Key Recommendations



Key Recommendations

Integrate

Integrate flexibility analysis into long-term planning and operational forecasting, considering flexibility needs over all timescales and deploying appropriate solutions.

Explore

Explore the untapped potential in utilizing bioenergy, VRE + multi-duration BESS, and interconnections in ways that can achieve lower system costs.

Support

Support BESS and interconnection development as long-term flexibility solutions by using market design, incentives, and enabling regulatory environments.

Reform

Reform contractual frameworks particularly rigid PPAs, that limit the operational flexibility of generators, to allow lower minimum stable generation levels and faster ramping.



Thank You

Accelerating Low Carbon Energy Transition

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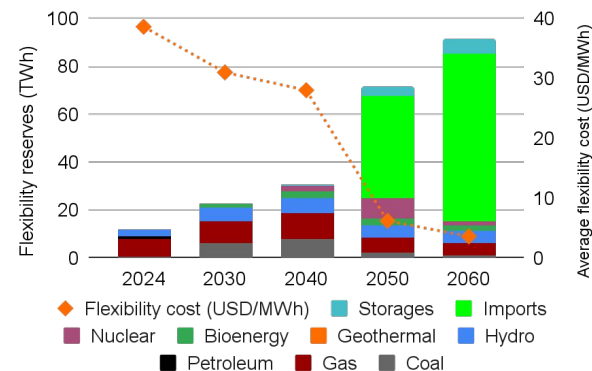
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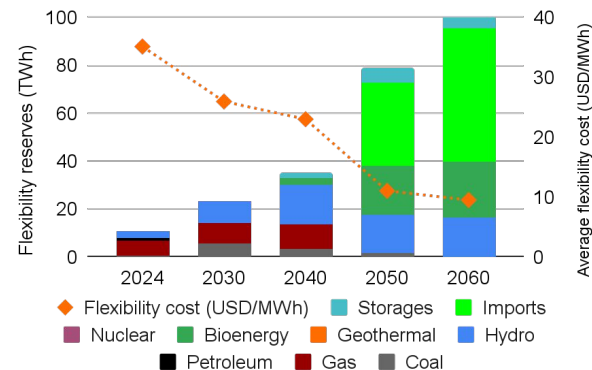
Annual Flexibility Reserves and Related Costs

- Lorem ipsum
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RUKN Baseline Annual Flexibility Reserves and Costs



LCWI Annual Flexibility Reserves and Costs





Key Takeaways and Discussion Points

Study to supplement RUKN in addressing flexibility as an important part of power system operation as VRE integration increases.

Battery duration variation:

- Enables an increased role for BESS as flexibility supplier.
- Minimises curtailment and unserved load.

Lower BESS costs:

- Enables higher VRE integration.
- Lowers overall total costs.
- BESS can act as flexibility supply amidst increased VRE penetration.

Data correction:

- Yearly load profile: represent weekly and monthly flexibility parameters.
- On-grid/captive demand: avoid unserved demand due to data limitation.
- Overall more accurate forecast of flexibility parameters, and therefore more useful recommendations for power system operation and addressing flexibility challenges.



Model development assumption

- Following the National Electricity Plan (RUKN) 2025-2060, the expansions are modeled as below:
 - Power Plant Candidates
 - VRE: Solar PV, Wind
 - RE: Geothermal, Hydro, Biomass, Biogas
 - Non-RE: Gas Power Plant, Nuclear
 - Expansion period:
 - 2025-2030: Gas Power Plant
 - 2025-2060: VRE, RE, Nuclear
 - Fossil power plant when reaches the zero book value:
 - Diesel power plant: shutdown by 2030
 - CFPP: retrofitted to fuel switch NH3 (subcritical) or CCS (supercritical, ultrasupercritical) equipped
 - Gas Power Plant: retrofitted to fuel switch H2



Model development assumption

- Following the National Electricity Plan (RUKN) 2025-2060, the expansions are modeled as below:
 - Reliability and stability criteria
 - Reserve margin is kept to **30%** and declining over the time until **10%** by 2050
 - All power plants except for VRE are contributing to reserve margin
 - Techno-economic parameters based on the Technology Data Catalogue of MEMR 2024



Fuel Price

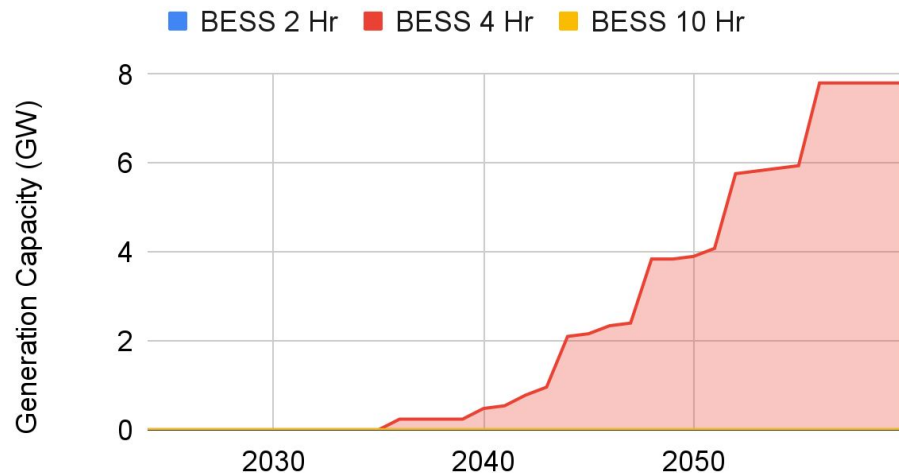
Fuel	Price
Coal	70 USD/tonne
Gas Pipeline	6 USD/MMBTU
LNG	12 USD/MMBTU
Diesel Oil	81 USD/barrel
Biomass	70 USD/tonne
Biogas	4 USD/MMBTU
Ammonia	200 USD/tonne
Hydrogen	15 USD/MMBTU

- The fuel price is based on the National Electricity Plan (RUKN) 2025-2060.
- The current price for domestic coal sales is based on the government's monthly reference export price for high-quality coal—the Harga Batubara Acuan (HBA), which corresponds to a calorific value of 6,322 kcal/kg (gross as received) and is capped at USD 70/tonne.
- Price of gas based on Kepmen ESDM no. 118.K_MG.04-MEM.M-2021, whereby the gas price at the plant gate is limited to 6 USD/mmbtu.
- The biomass price is following PLN's Presidential Instruction, Perdir PLN 04/2022, which quantifies the price based on the ratio to coal calorific value.

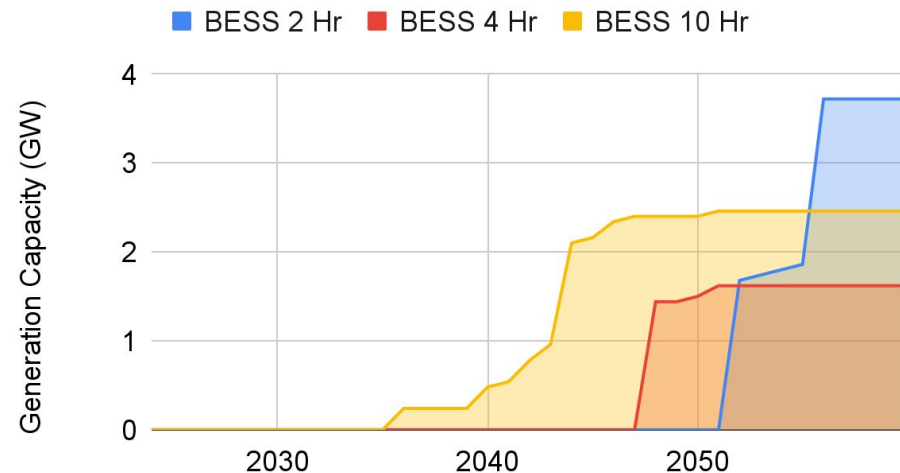


RUKN Scenarios BESS Generation Capacity

RUKN



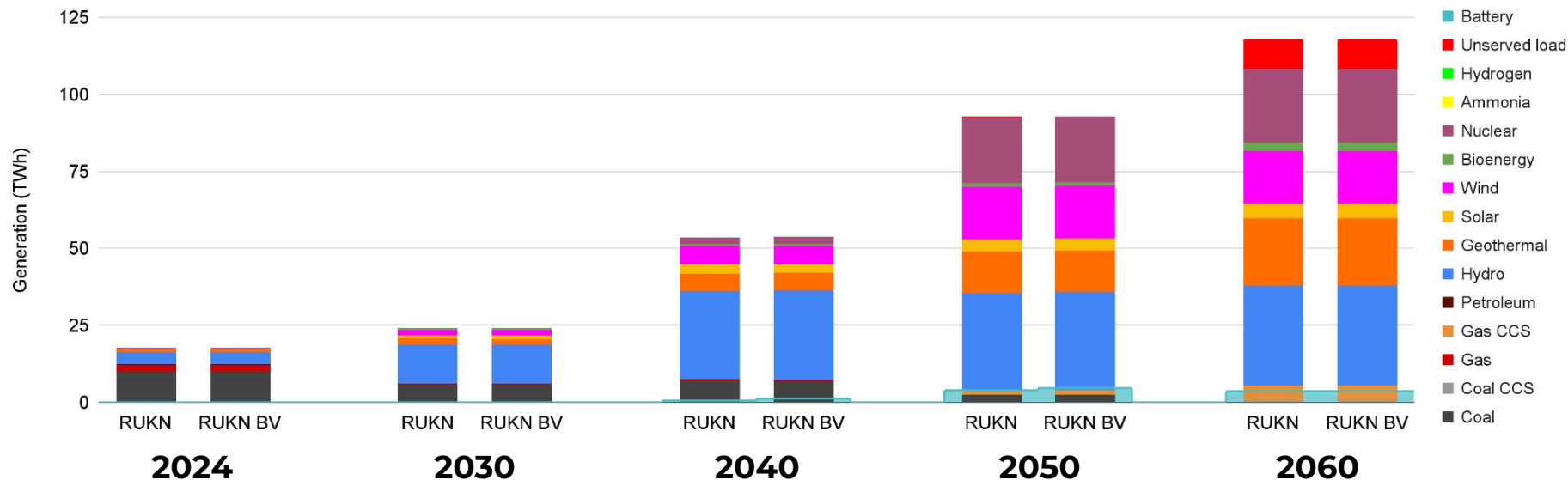
RUKN Battery Var



- In the RUKN BV scenario, the 10-hour BESS is preferred by the optimisation, allowing for more VRE generation to be shifted in a longer timescale.
- Preliminary hypothesis: battery duration variation allows more VRE generation to be stored instead of curtailed, resulting in higher BESS generation and minimised unserved load.



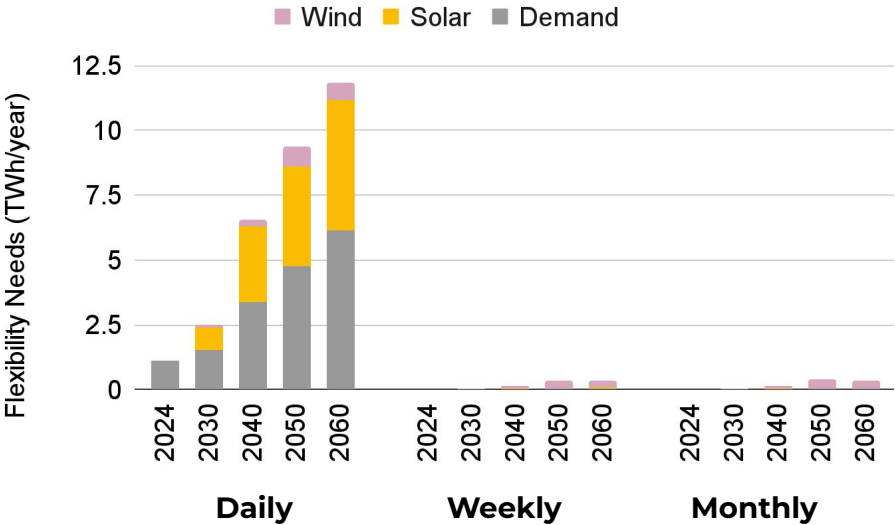
RUKN Scenarios Generation Comparison



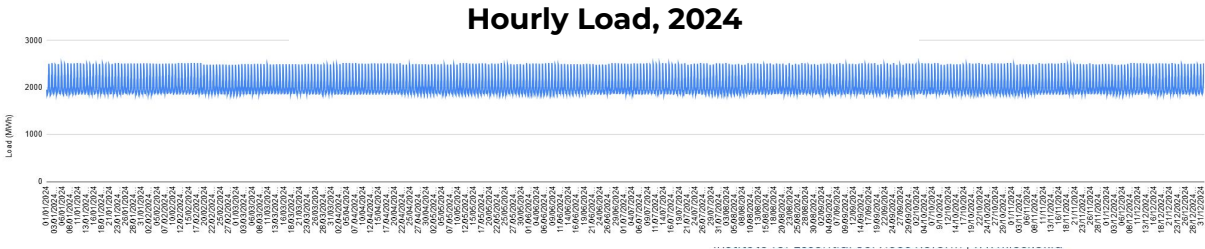
- Generators' electricity production is not affected by battery duration variation and remains the same across the 2 scenarios.
- Despite having the same total BESS installed capacity, the RUKN BV scenario has a larger annual BESS generation, up to a 139% increase relative to the baseline.



RUKN Scenarios Flexibility Needs



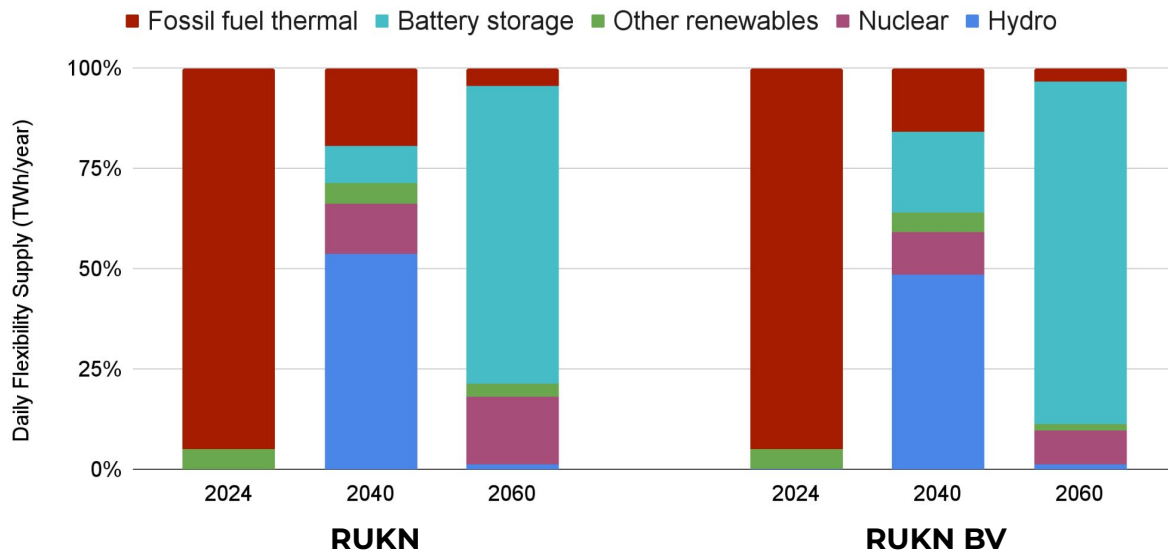
- Flexibility needs in Sulawesi are initially driven by variations in demand.
- After 2030, solar and wind emerges as significant drivers alongside rising demand variation, increasing overall flexibility needs.
- From 2050 onwards, VRE accounts for 50% of the daily flexibility needs.
- Limitation:** weekly and monthly flexibility parameters are not represented well due to the limited weekly and monthly variability of the load profile data.
- Windpower fluctuations are in seasonal timescale, a more representative load profile will support more accurate forecast of flexibility needs as wind penetration increases, especially considering the large wind potential in Sulawesi.



Load profile data does not capture weekly and monthly variability



RUKN Scenarios Daily Flexibility Supply

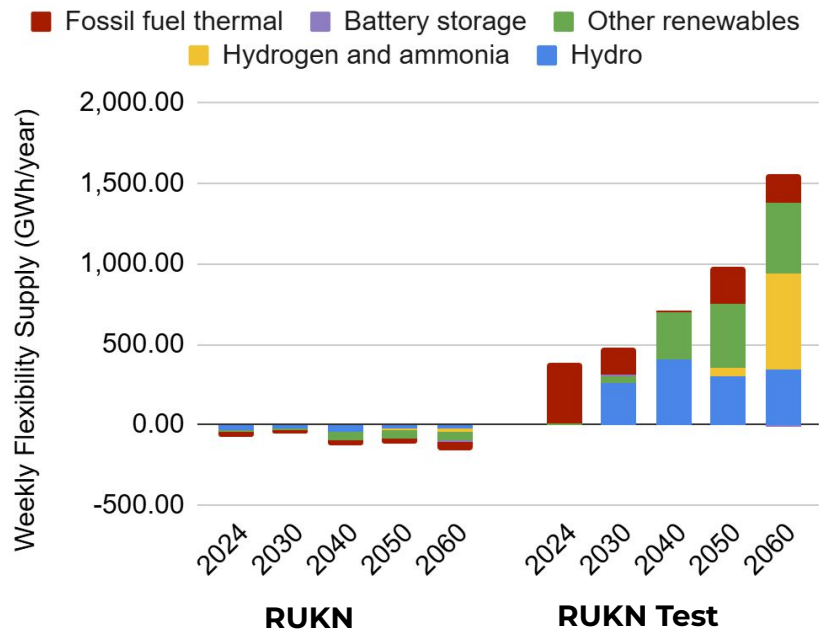
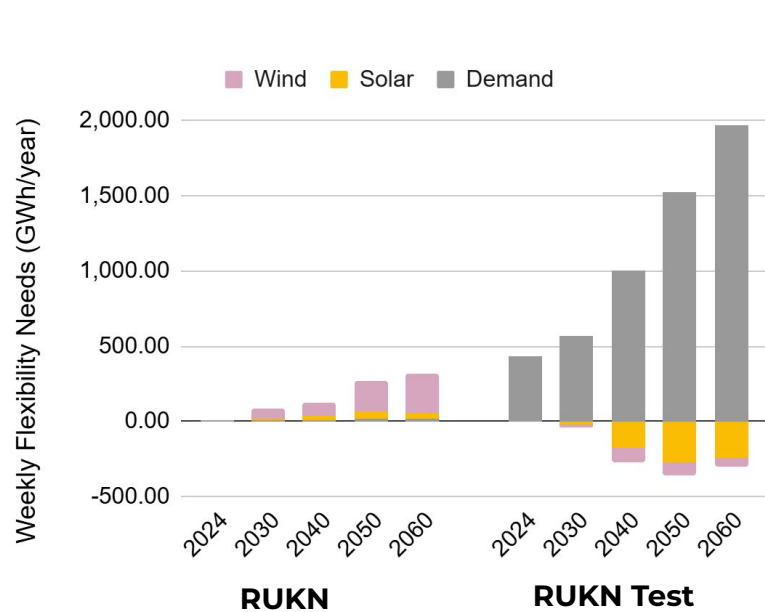


- Daily flexibility supply in Sulawesi are initially supplied by flexible thermal fossil generation.
- As RE penetration increases, hydropower dominates the contribution to flexibility and BESS emerges.
- The role shifts in 2060, when BESS capacity rises to 16-times the 2040 amount, and BESS becomes the main flexibility supplier while hydro takes more of a baseload role.
- BESS duration variation enables higher flexibility supply by BESS.



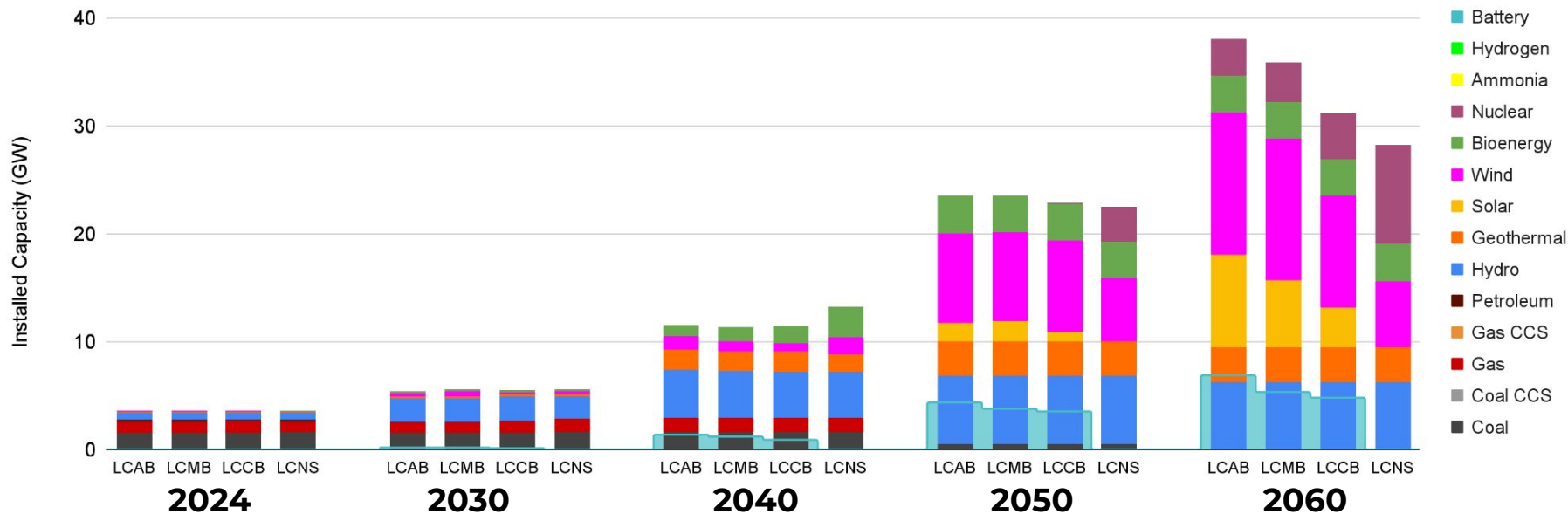
Limitation: Weekly and Monthly Flex Parameters

As a comparison, another scenario (RUKN Test) was made, using a placeholder Jamali load profile that reflects the weekly variability. Results indicate that a more accurate load profile will reflect weekly and monthly flexibility parameters.





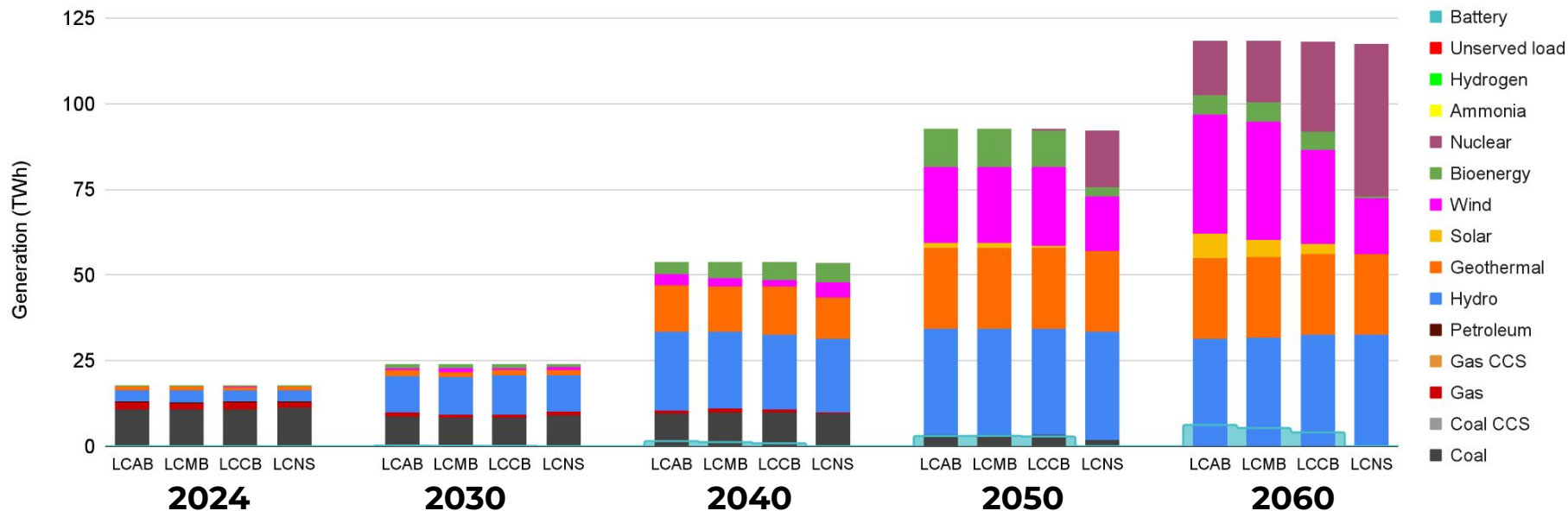
Least-cost Scenarios Capacity Expansion



- Lower BESS costs act as an enabler for higher VRE penetration and capacity expansion, to align with lower emission targets while lowering CAPEX compared to nuclear.
- With lower BESS costs, optimisation prefers VRE + BESS, while as BESS costs increase, nuclear is the alternative.



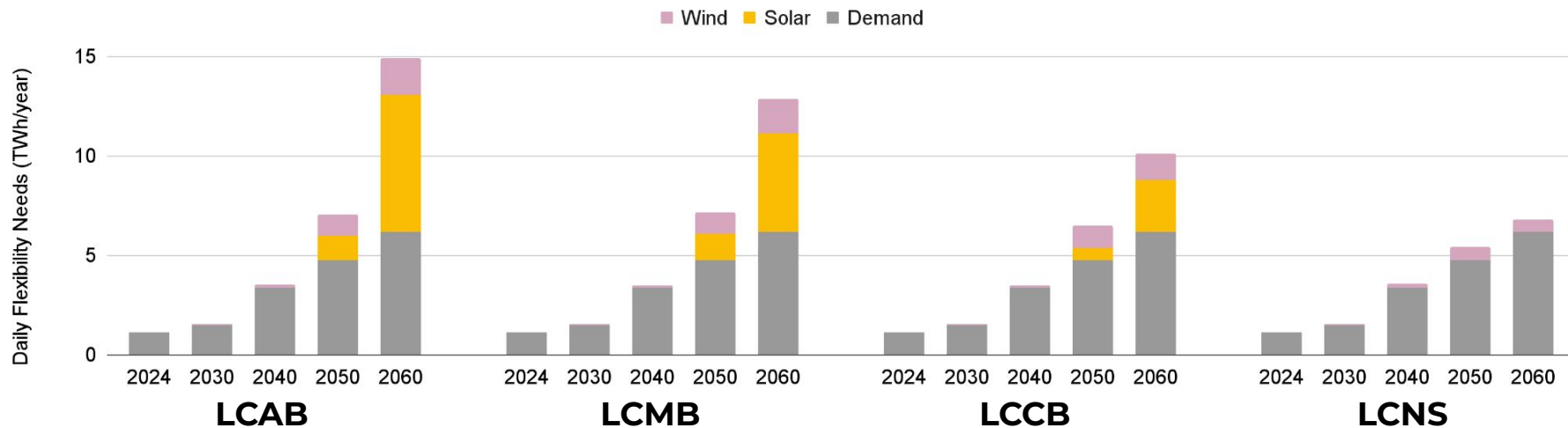
Least-cost Scenarios Generation



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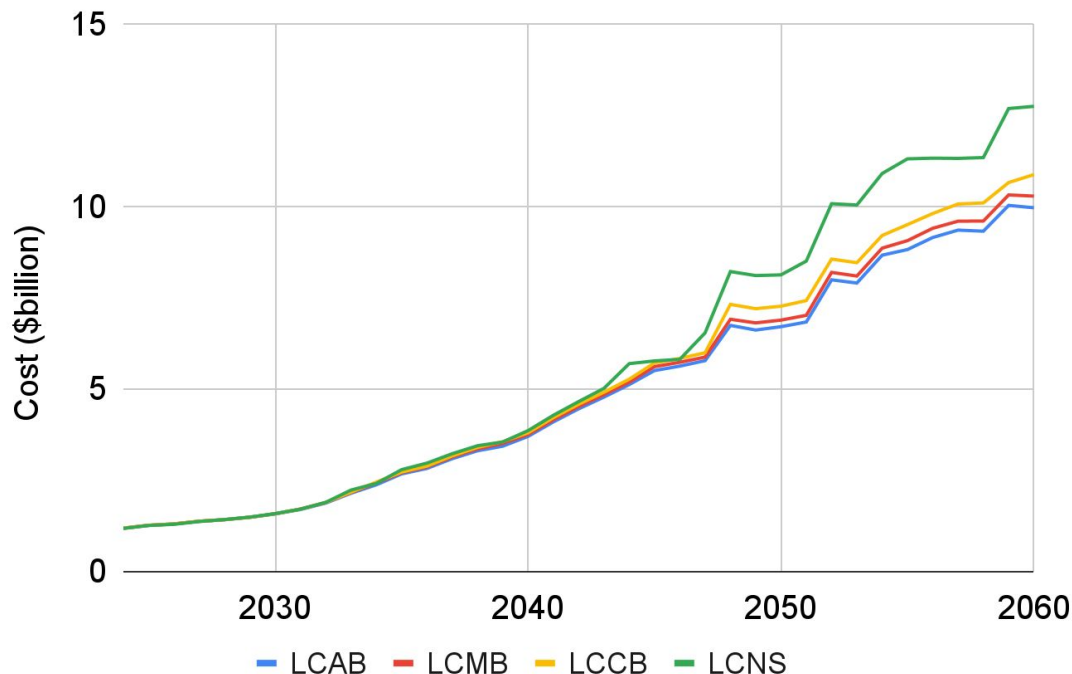
Least-cost Scenarios Daily Flexibility Needs



- Higher VRE penetration enabled by lower battery costs results in higher flexibility needs overall, while the needs from demand variation remains the same across all least-cost scenarios.
- Not necessarily a bad thing, however. Increased BESS capacity leads to higher flexibility needs, but BESS can also fulfill the role as flexibility supplier.



Least-cost Scenarios Total Costs



- In the least-cost scenarios, BESS costs directly affect the capacity mix between VRE + BESS and nuclear.
- In the LCNS scenario, solar PV is not chosen because overbuilding it without BESS would be more expensive than building nuclear power plants.
- However, a mix of VRE + BESS and nuclear would result in lower costs, especially as BESS costs drop and thus enable more VRE integration.
- BESS can also act as flexibility supply in place of nuclear, which lowers the costs of flexibility as well.