IESR
Institute for Essential Services Reform

Flexibility in Power System Development
Sulawesi Case Study

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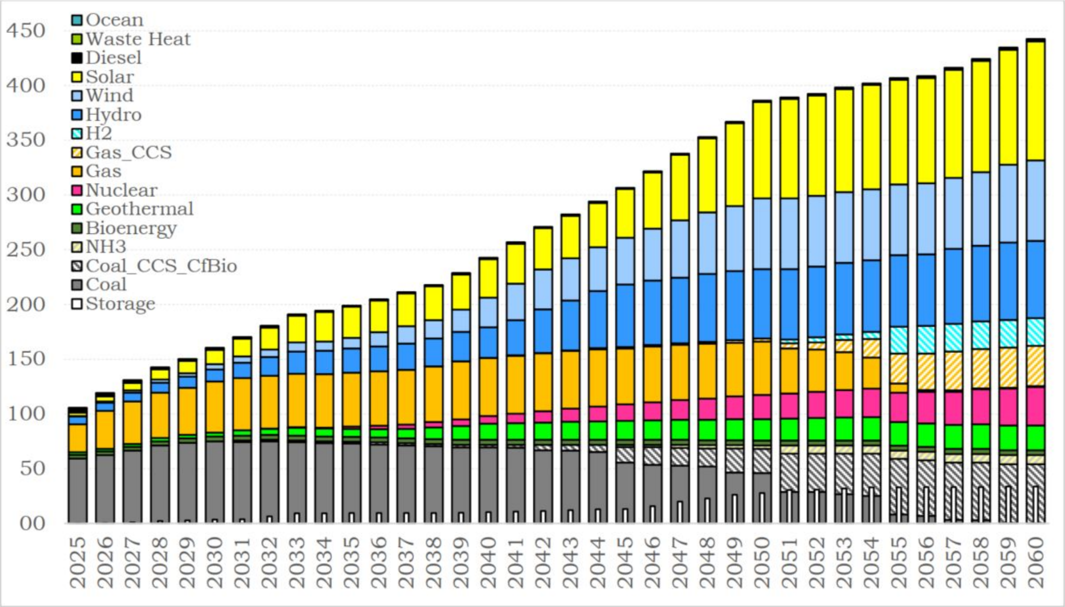
Introduction and Background

Indonesia Decarbonisation Strategy - RUKN

National Capacity Expansion Projection



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

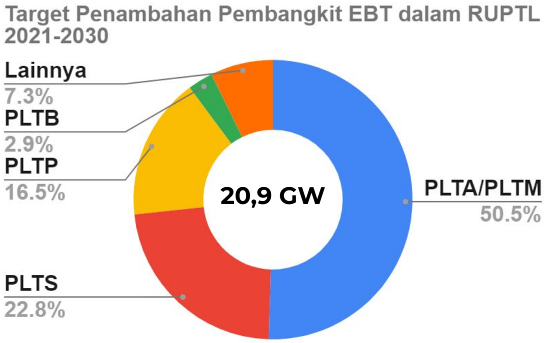
In 2060:

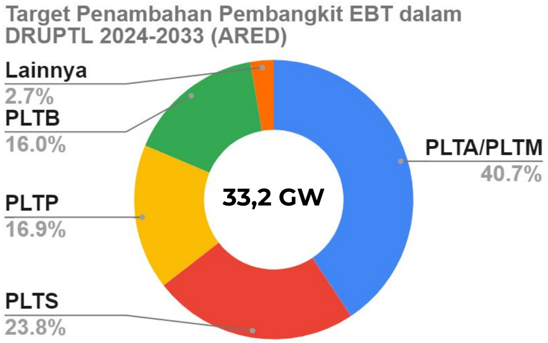
- 58.5% dispatchable capacity
- **41.5% VRE capacity**

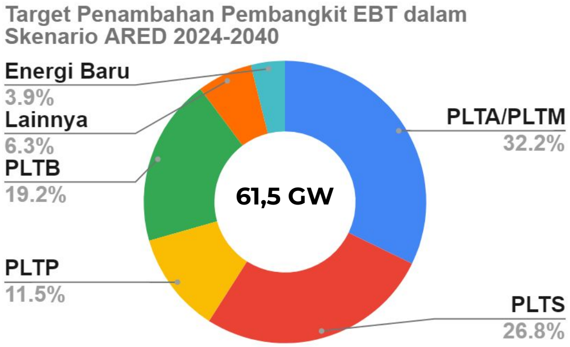
Indonesia Decarbonisation Strategy - RUPTL

"The Greenest RUPTL"

"Beyond the Greenest RUPTL"

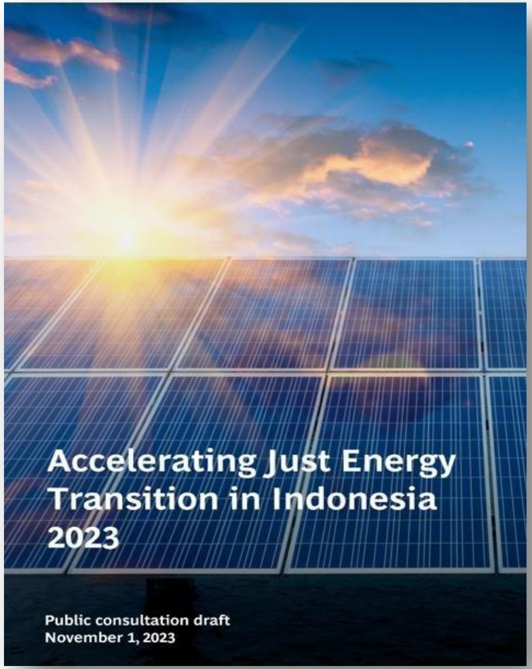






Renewable capacity increases, especially Variable Renewable Energy (VRE) like solar PV and windpower, alongside the development of smart grids and **flexible power system operations**.

Indonesia Decarbonisation Strategy - CIPP



What it takes to implement JETP scenario

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

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

14% VRE in 2030!

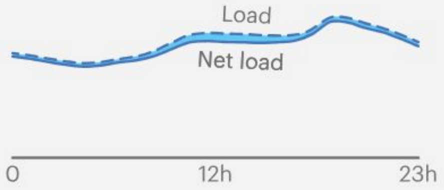
Urgency of a Flexible Power System

IEA’s Phases of VRE Integration

Phase 1

Load versus net load

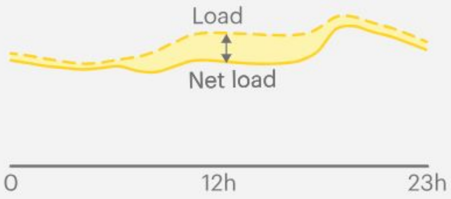
The difference between load and net load is **minimal**



Phase 2

Load versus net load

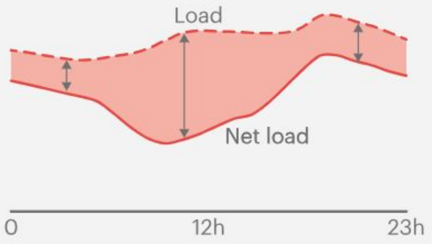
The difference between load and net load is **noticeable**



Phase 3

Load versus net load

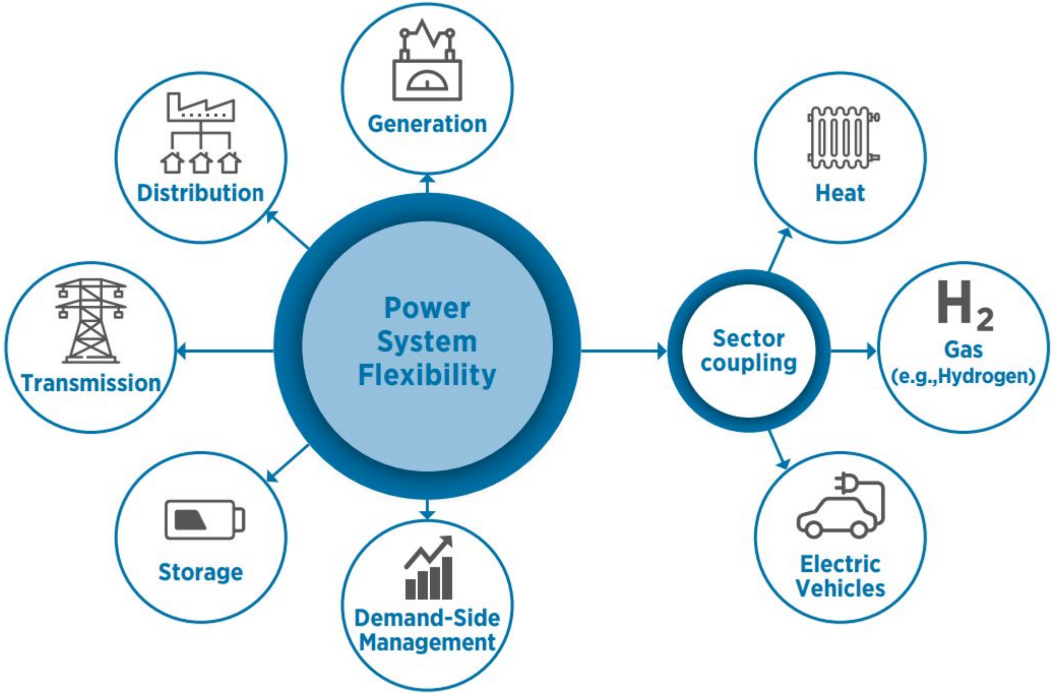
The **"duck"** curve starts emerging, suggesting that more pronounced and longer ramps are required



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

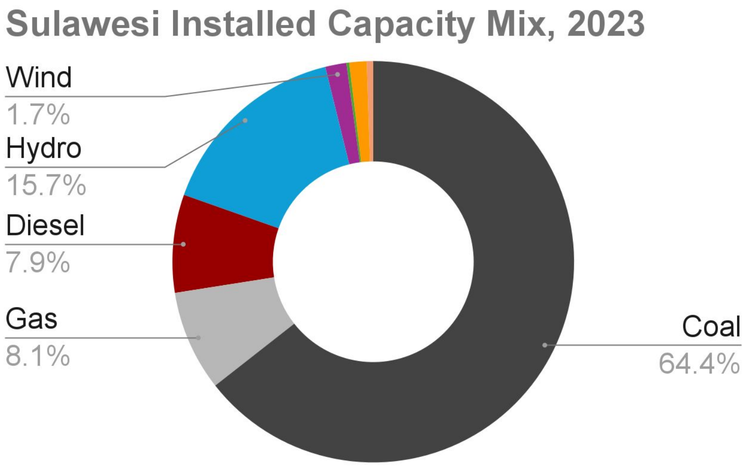


Source: IRENA, 2018

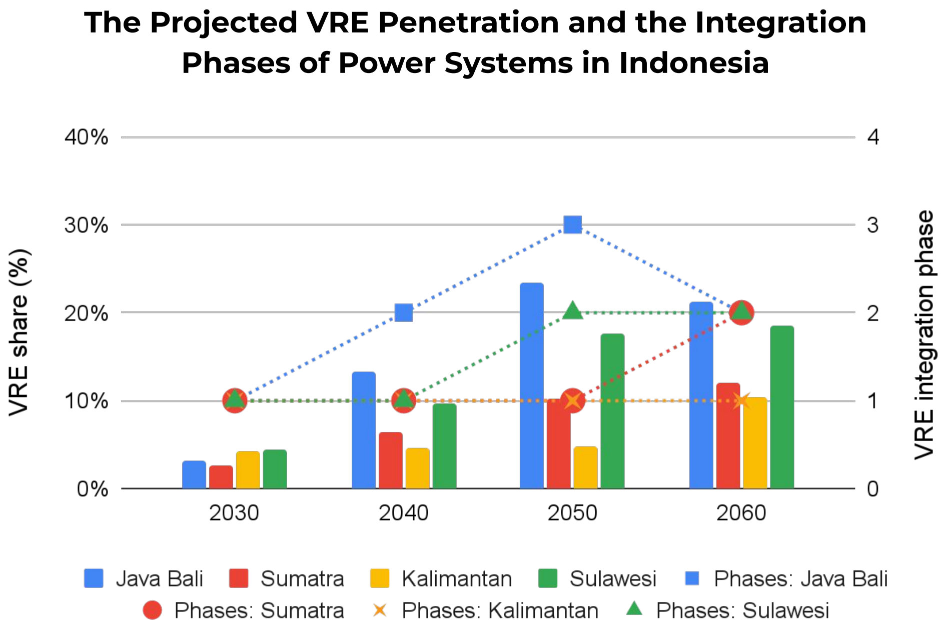
Synergize flexibility source options with current Indonesia planning documents and needs:

- **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

Sulawesi as Case Study: Future Planning



Source: Statistik Ketenagalistrikan 2023 (ESDM, 2023)



Source: IESR analysis from RUKN 2025-2060

Other factors:

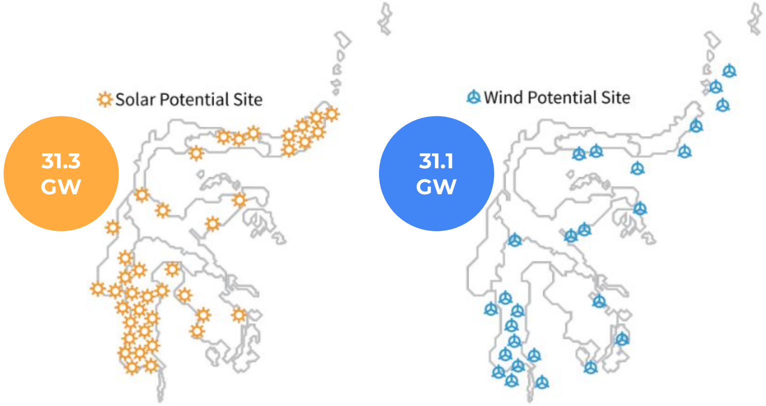
- **Industrial demand growth**
- **35.3% VRE capacity in 2060**

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.

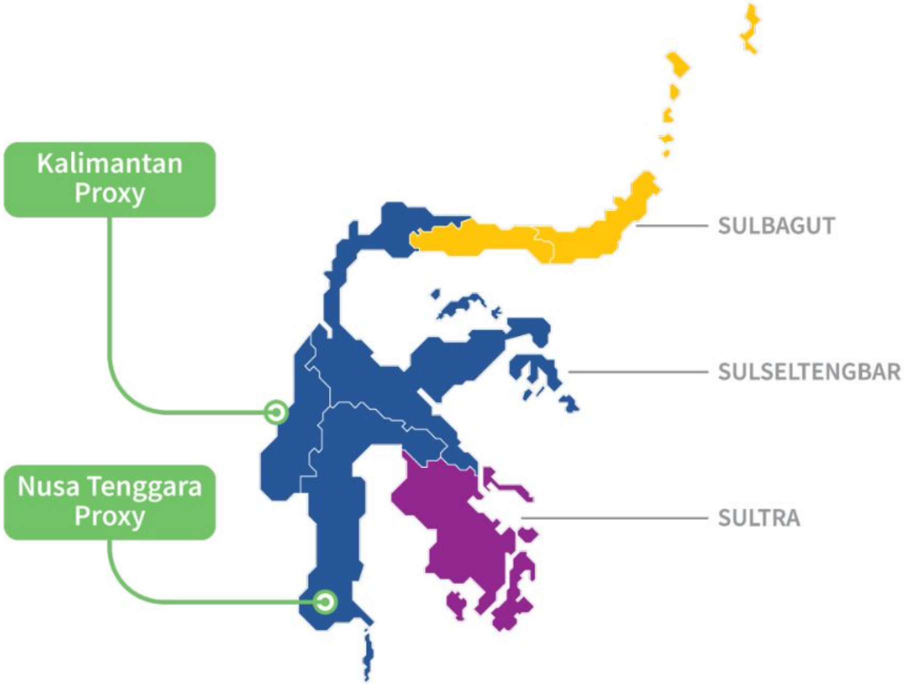
Study Objectives

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:

01	Where flexibility needs arise based on the capacity expansion plan outlined in the RUKN 2025	• Across different timescales: daily, weekly, and seasonal
02	The role of three technical aspects of power system flexibility building blocks	• Power plant flexibility • Interconnections • Energy storage
03	The analysis of a potential alternative pathway to NZE	• Maximizing the use of Sulawesi's large RE potential using a comparison least-cost scenario

Power Supply Model Development and Methodology

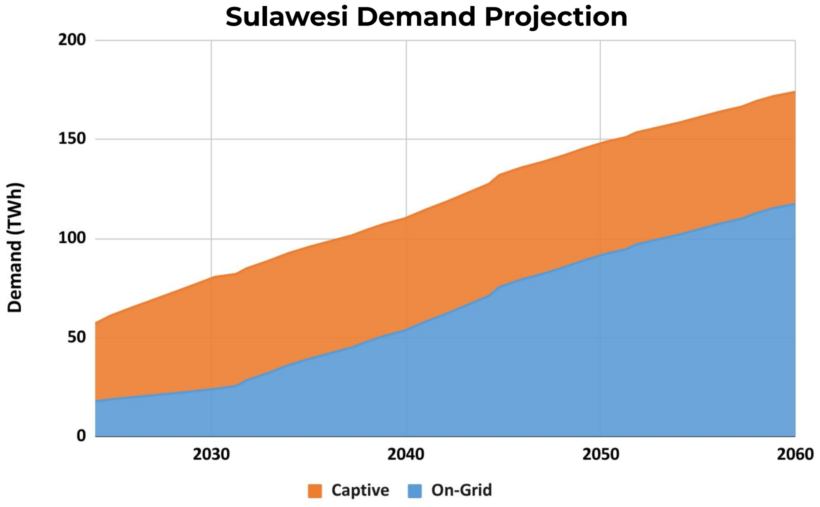
Modelled Region



- 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

Source: KPMG (2023)



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.

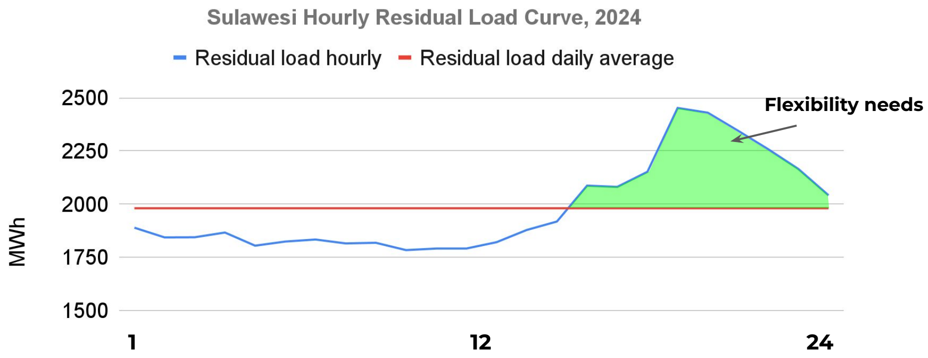
Scenario Design Summary

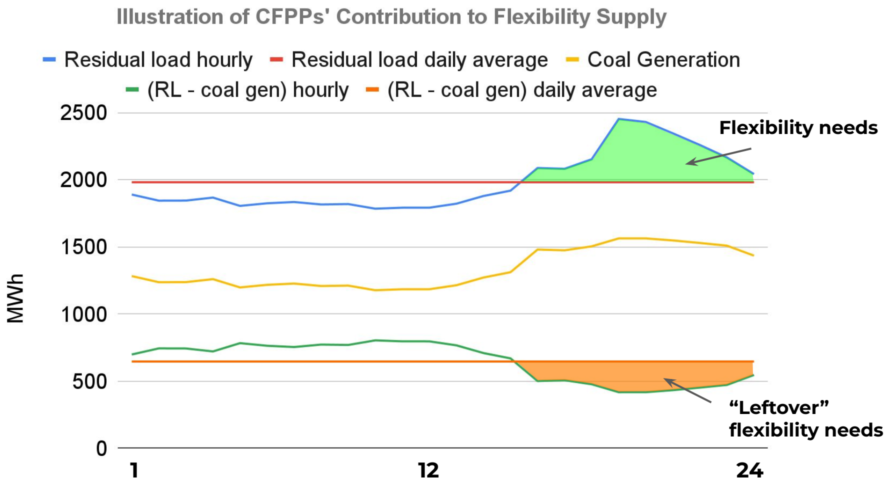
<table>
<tr><th>Scenario</th><th>RUKN Baseline</th><th>RUKN + Battery Duration Variation (BV)</th><th>Least-cost with Imports (LCWI)</th><th>Least-cost + Advanced BESS costs (LCAB)</th><th>Least-cost + Moderate BESS costs (LCMB)</th><th>Least-cost + Conservative BESS costs (LCCB)</th><th>Least-cost + No Storage (LCNS)</th></tr>
<tr><td>Battery Costs</td><td colspan="3">MEMR’s Technology Data Catalogue 2024</td><td>NREL Advanced BESS costs</td><td>NREL Moderate BESS costs</td><td>NREL Conservative BESS costs</td><td>None</td></tr>
<tr><td>Battery Duration Variation</td><td>4-hour BESS only</td><td colspan="6">Optimised mix of 2-hour, 4-hour, and 10-hour BESS</td></tr>
<tr><td>Inter-island Connection</td><td colspan="3">Imports from Kalimantan and Nusra, following RUKN 2025-2060</td><td colspan="4">None</td></tr>
<tr><td>Emission Constraint</td><td colspan="2">None</td><td>Following RUKN Baseline results</td><td colspan="4">None</td></tr>
<tr><td>Fossil Power Plant Scenario</td><td colspan="2">Mandatory:
CFPP & Gas retrofitted following RUKN;
Diesel: shutdown by 2030</td><td colspan="5">Optional:
CFPP & Gas retrofitted by the end of lifetime
Mandatory:
Diesel: shutdown by 2030</td></tr>
<tr><td>Capacity Expansion</td><td colspan="2">Following RUKN 2025-2060</td><td colspan="5">Fully Optimised</td></tr>
<tr><td>Demand</td><td colspan="7">On-grid electricity demand and load profile based on RUKN 2025-2060 (calibrated with RUPTL 2021-2030 and KPMG report on captive power)</td></tr>
<tr><td>Techno-economic Parameters</td><td colspan="7">MEMR’s Technology Data Catalogue 2024</td></tr>
</table>

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:



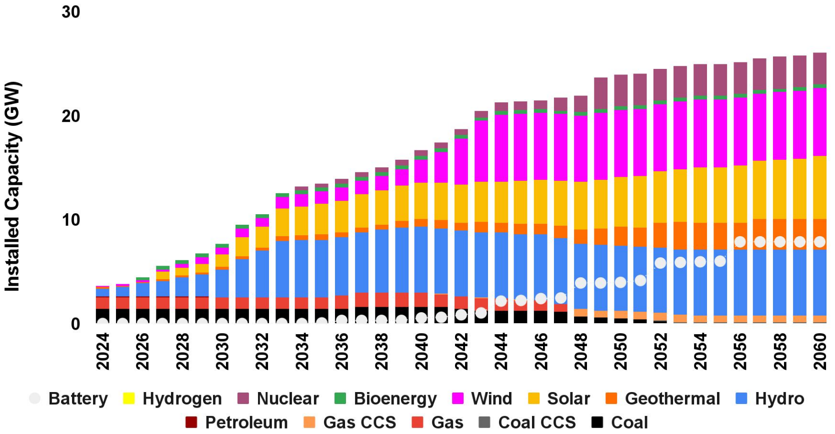


Different factors drive flexibility needs in different timescales (e.g. solar PV fluctuations tend to be on the daily level while wind is more seasonal).

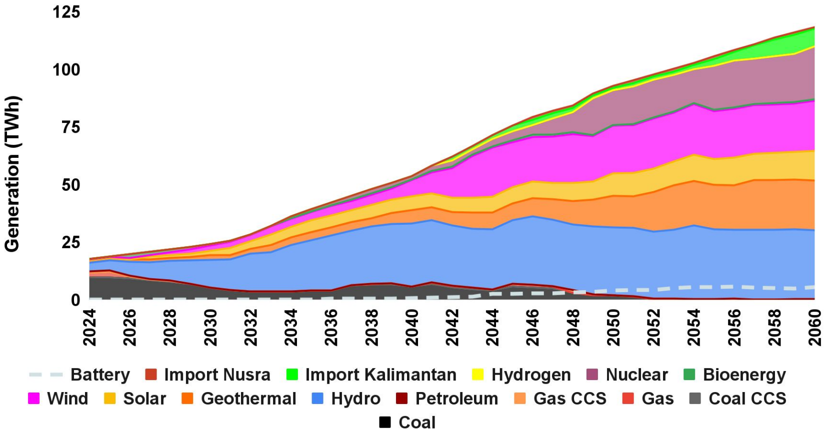
Results and Analysis

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

Installed Capacity in RUKN Scenario

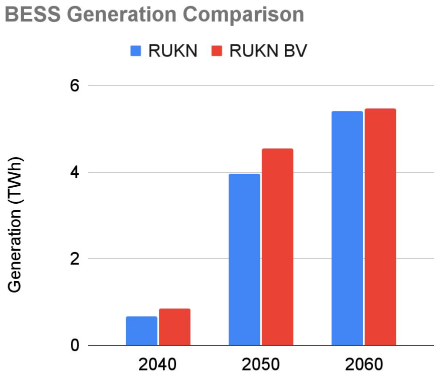


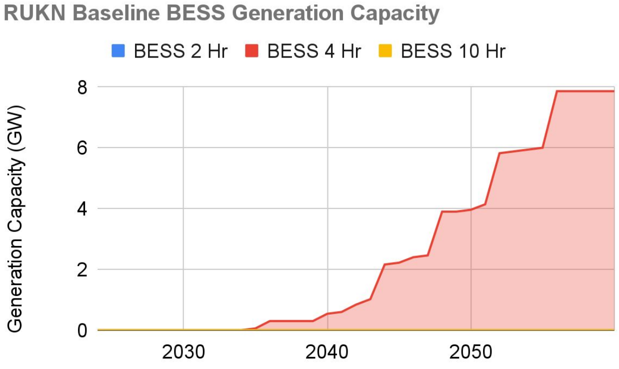
Generation in RUKN Scenario

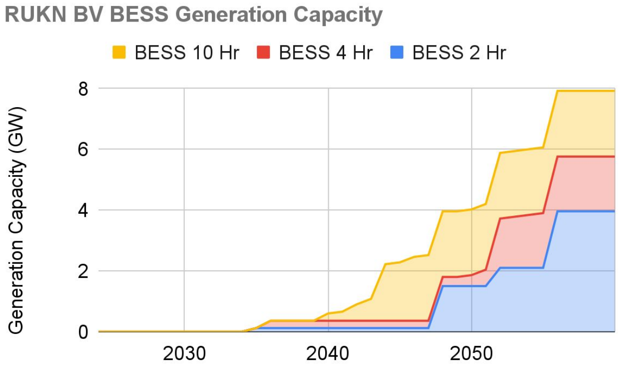


- Generation mix will shift from fossil fuels to renewable energy, with **VRE rising from 2.4% in 2024 to 29% in 2060**.
- All generator types expand their capacities according to RUKN 2025, except BESS, which exceeds the RUKN constraint. Likely due to higher on-grid demand assumptions in this study 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



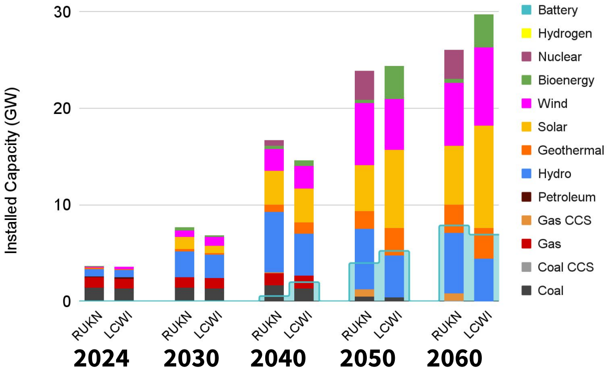




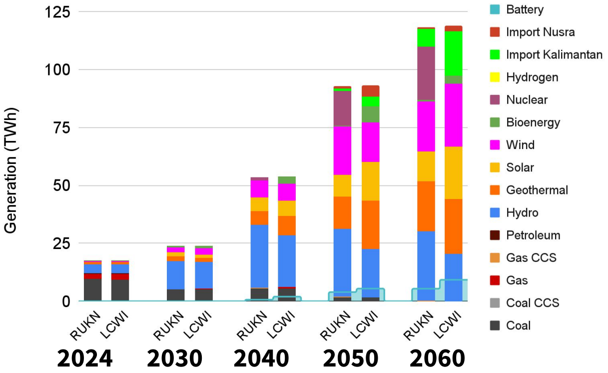
- RUKN BV models BESS in **2-hour, 4-hour, and 10-hour duration** while RUKN Baseline only models **4-hour BESS**.
- **Higher annual electricity discharged from BESS in the RUKN BV scenario**: 27% more in 2040, 15% more in 2050, and 1% more in 2060.
- Over the long term, **2-hour BESS becomes the dominant 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

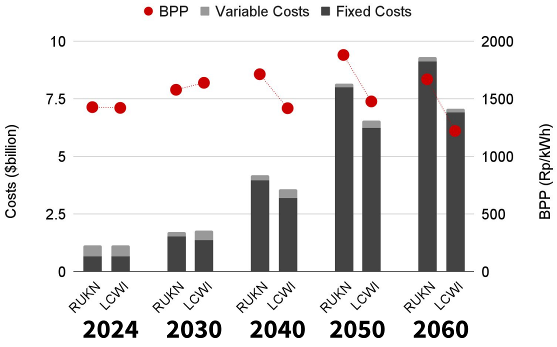
RUKN and LCWI Capacity Expansion Comparison



RUKN and LCWI Generation Comparison



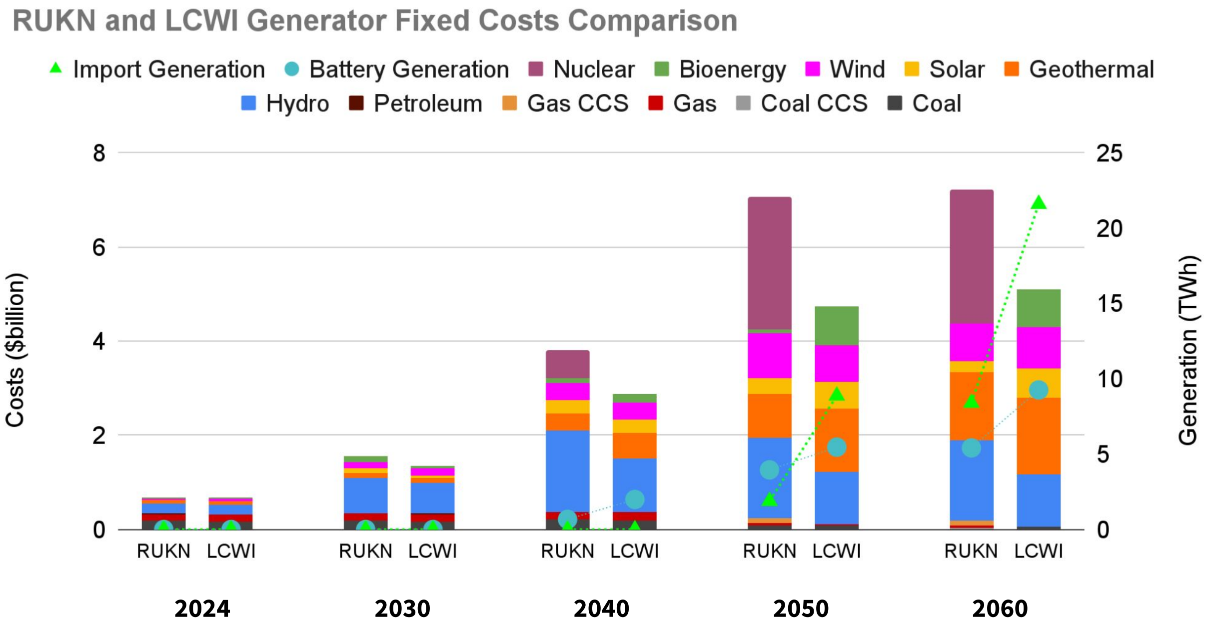
RUKN and LCWI Costs Comparison

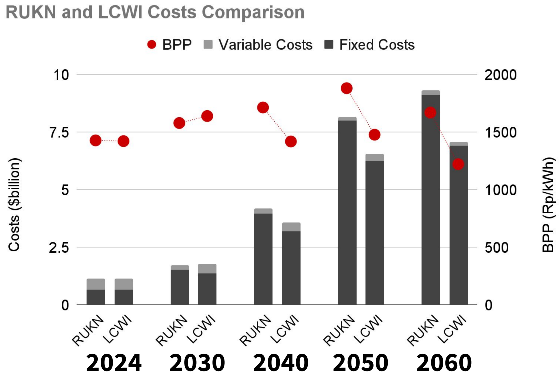


Note: BPP calculation uses 1 USD = 16,000 IDR

- 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 undercurrent policies and planning frameworks.

LCWI Scenario as an Alternative Pathway for Sulawesi



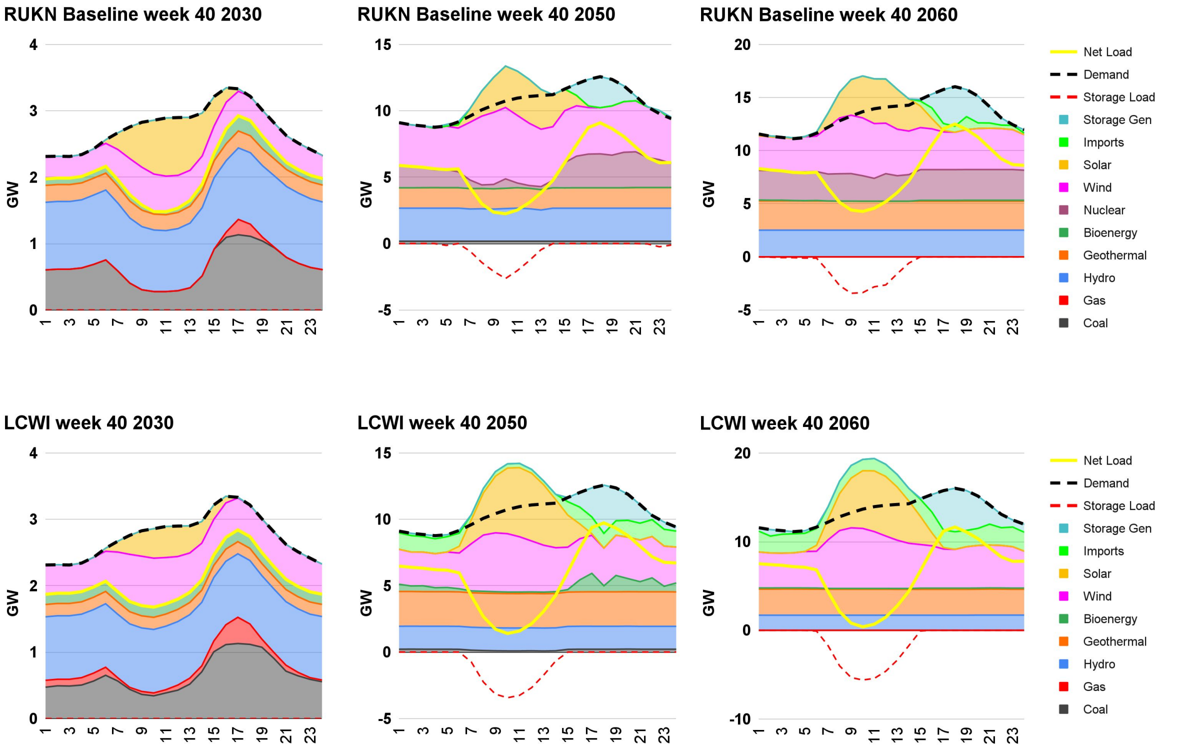


Note: BPP calculation uses 1 USD = 16,000 IDR

- 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

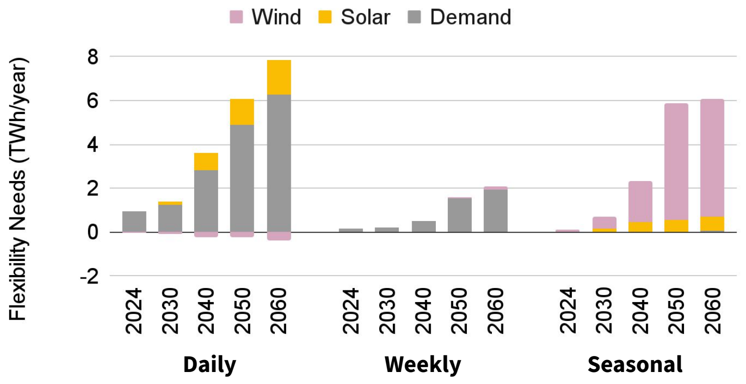
- **Daily net load variability in Sulawesi is projected to increase** in accordance with higher VRE penetration and demand fluctuation.
- Even in 2030, coal and gas power plants still ramps up and down to follow daily net load fluctuations, but phased out in the future as hydro and geothermal operate 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.



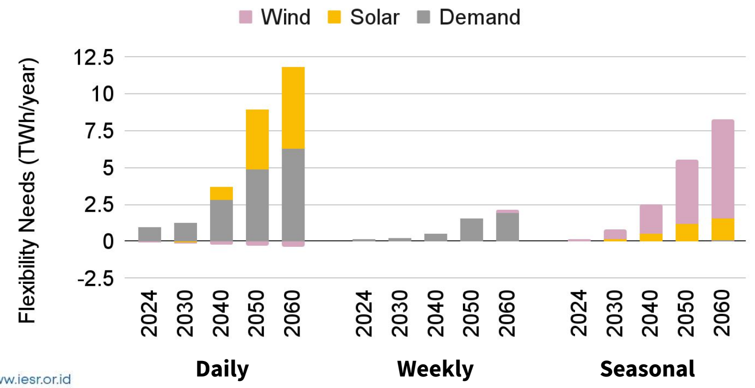
Power System Flexibility Needs in Sulawesi

- 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**.

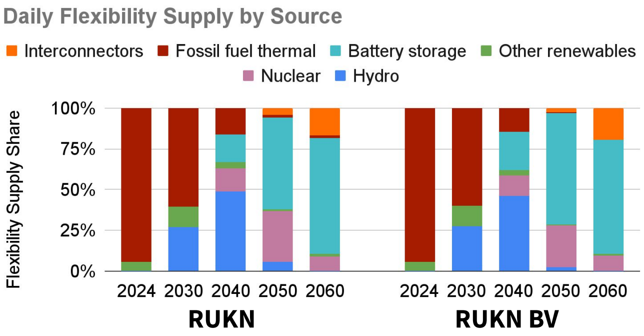
Sulawesi RUKN Flexibility Needs, by Drivers

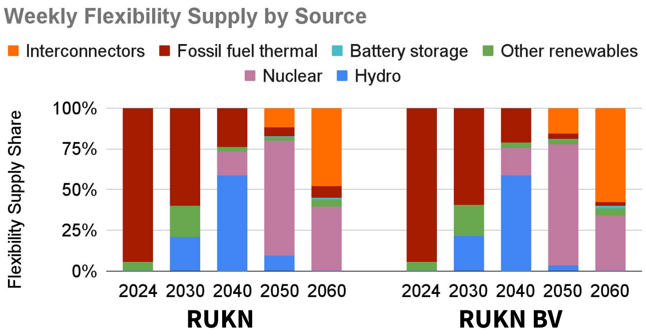


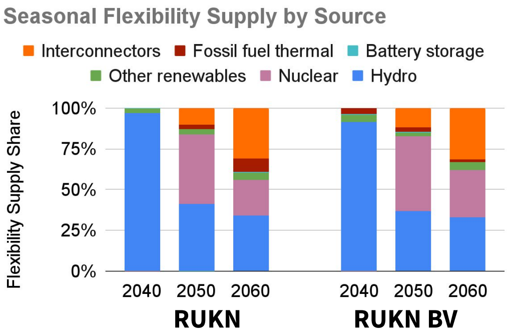
Sulawesi LCWI Flexibility Needs, by Drivers



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

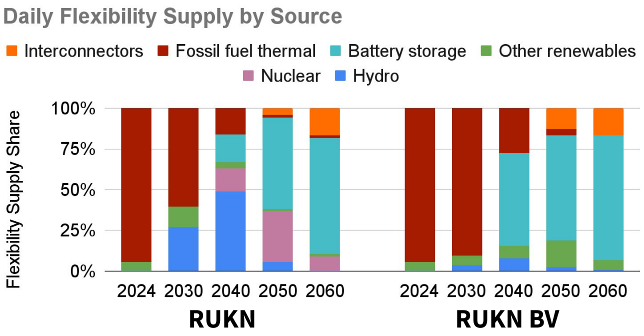


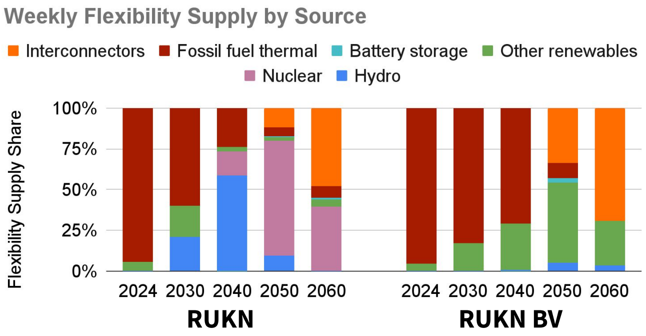


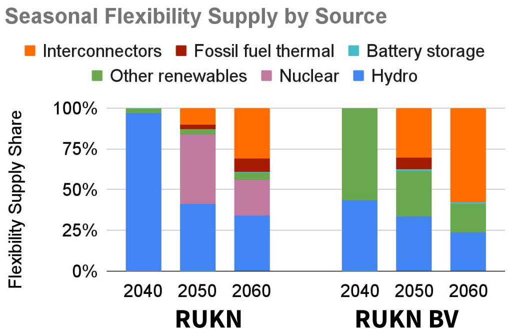


- Currently, **fossil thermal fuel technologies dominate the flexibility supply**. As the power system transitions, the role of fossil fuels is gradually replaced by other technologies, according to the suitability to the timescale.
- **BESS is particularly well-suited to meet daily flexibility needs** 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

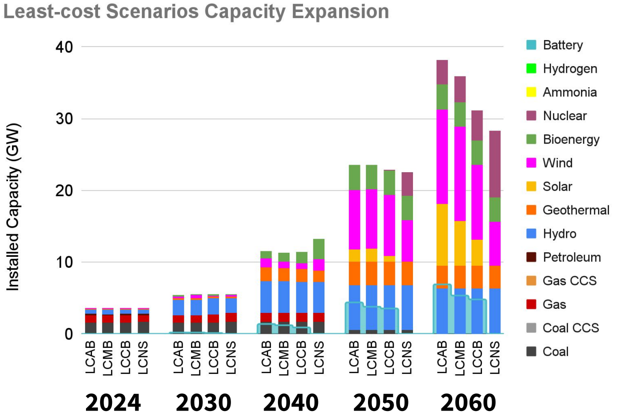


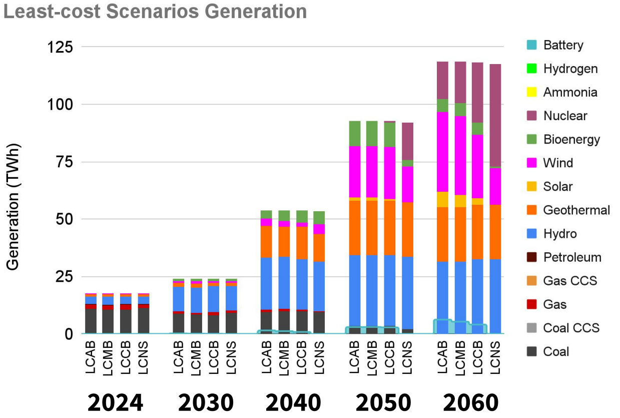


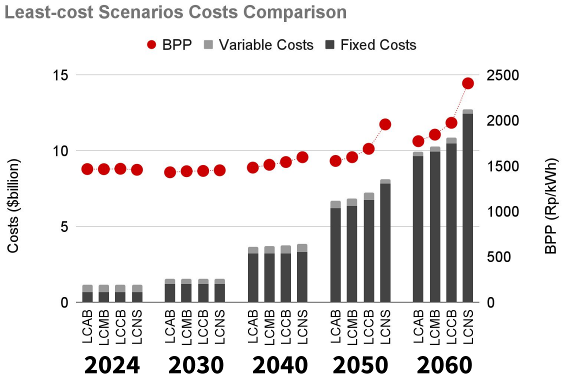


- Overall, **the role of hydropower and nuclear as flexibility sources is reduced in the LCWI scenario**, in line with their lower electricity generation across the modelling time horizon. Conversely, **bioenergy, BESS, and interconnectors contribute more to the flexibility supply.**
- From 2024 to 2050, **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







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

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