Ministry of National
Development Planning/Bappenas
Republic of Indonesia

ENERGY TRANSITION PARTNERSHIP
Powering Prosperity and Enabling Sustainability in South East Asia

SOLAR PV MAPPING AND DEVELOPMENT PLAN (INDONESIA)

GRID INTEGRATION ASSESSMENT

Prepared by : Consortium lead by Trama TecnoAmbiental

tta SOLARGIS ERM QUADRAN SOLUSI ENJINERING INOVASI DINAMIKA PRATAMA

JUNE 2025

UNOPS
AFD AGENCE FRANÇAISE DE DÉVELOPPEMENT
Federal Ministry for Economic Affairs and Climate Action
Department for Energy Security & Net Zero
Environment and Climate Change Canada
Environnement et Changement climatique Canada
Australian Government
Department of Climate Change, Energy, the Environment and Water
CIFF CHILDREN'S INVESTMENT FUND FOUNDATION
SEQUOIA CLIMATE FOUNDATION

GRID INTEGRATION ASSESSMENT

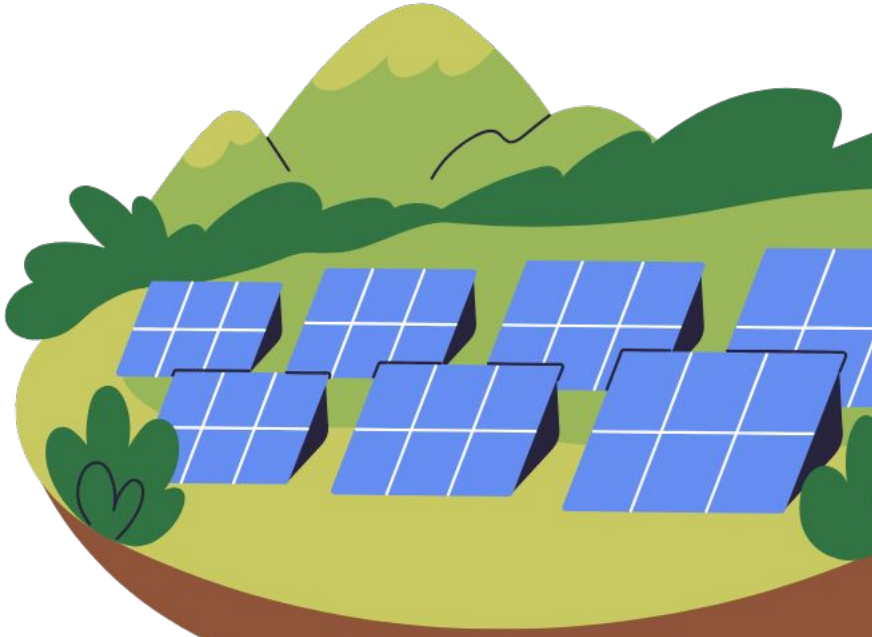
CONSULTATION MEETING WITH PLN

June 25th, 2025

Prepared by:

Consortium lead by Trama TecnoAmbiental, S.L. (TTA)

TABLE OF CONTENTS



INTRODUCTION

1.1 BACKGROUND

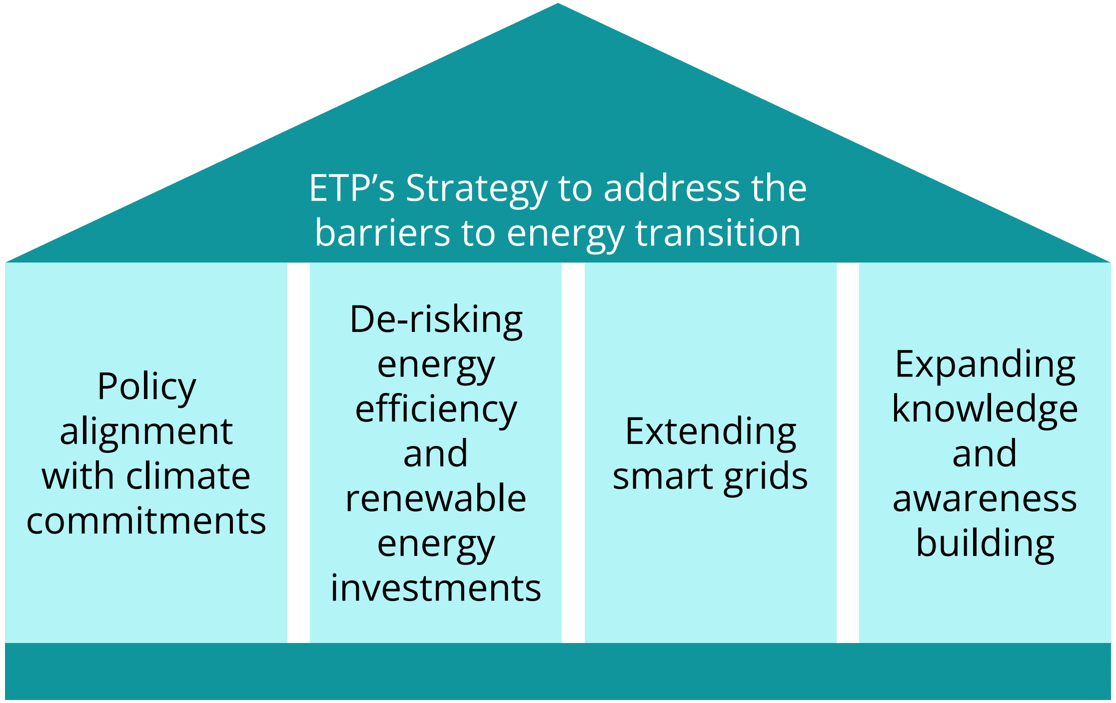
The Southeast Asia Energy Transition Partnership brings together governments and philanthropies to work with partner countries in the region. ETP supports the transition towards modern energy systems that can simultaneously ensure economic growth, energy security, and environmental sustainability.

ETP priority countries:


Indonesia


The Philippines


Vietnam



For this project, **ETP is working with the Ministry of National Development Planning (BAPPENAS) to support Indonesia's renewable energy transition planning**.

Project Objectives:

- Strengthen the enabling environment for renewable energy (RE) policies
- Increase the flow of public and private investments to RE projects
- Improve the development and accessibility of RE knowledge

1.2 PROJECT OBJECTIVES

14.11%	Current Renewable Energy shared
8.8 GW	New additional RE installed capacity by 2030
$8 B	Annual investment in RE required

This project aims to increase the use of solar photovoltaic (PV) technology in Indonesia to reduce emissions and meet the country's goal of achieving net-zero emissions in the power sector by 2050.

Key Project Outputs:

a. Solar Irradiance Data Mapping and accessible database

b. **Grid assessment and Impact evaluation**

c. Environmental and Social Impact Assessment

d. A solar PV development and investment plan for 1 GW of the JAMALI power grid

e. Pre-feasibility document of the 1GW Solar PV mapping and development in JAMALI systems

1.3 THE CONSULTANT TEAM

Trama TecnoAmbiental (TTA)

CONSORTIUM CO-LEAD

PT Inovasi Dinamika Pratama (Inovasi)

CO-LEAD AND ENGAGEMENT

SolarGIS

SOLAR RESOURCE & GIS LEAD

PT Quadran Solusi Enjinering (QSE)

GRID MODELLING LEAD

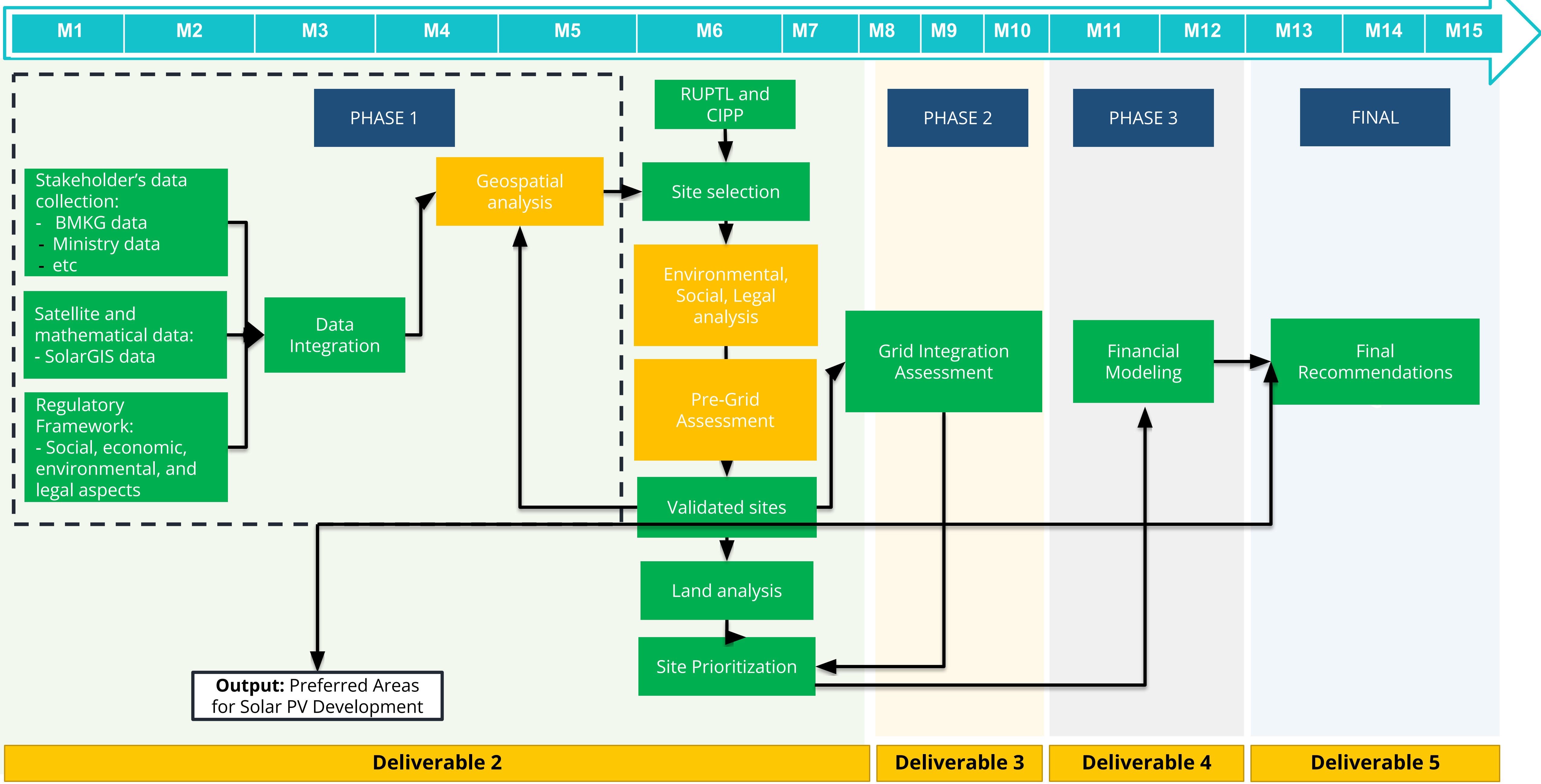
PwC Indonesia (PwC)

REGULATORY AND FINANCIAL LEAD

Environmental Resources Management (ERM)

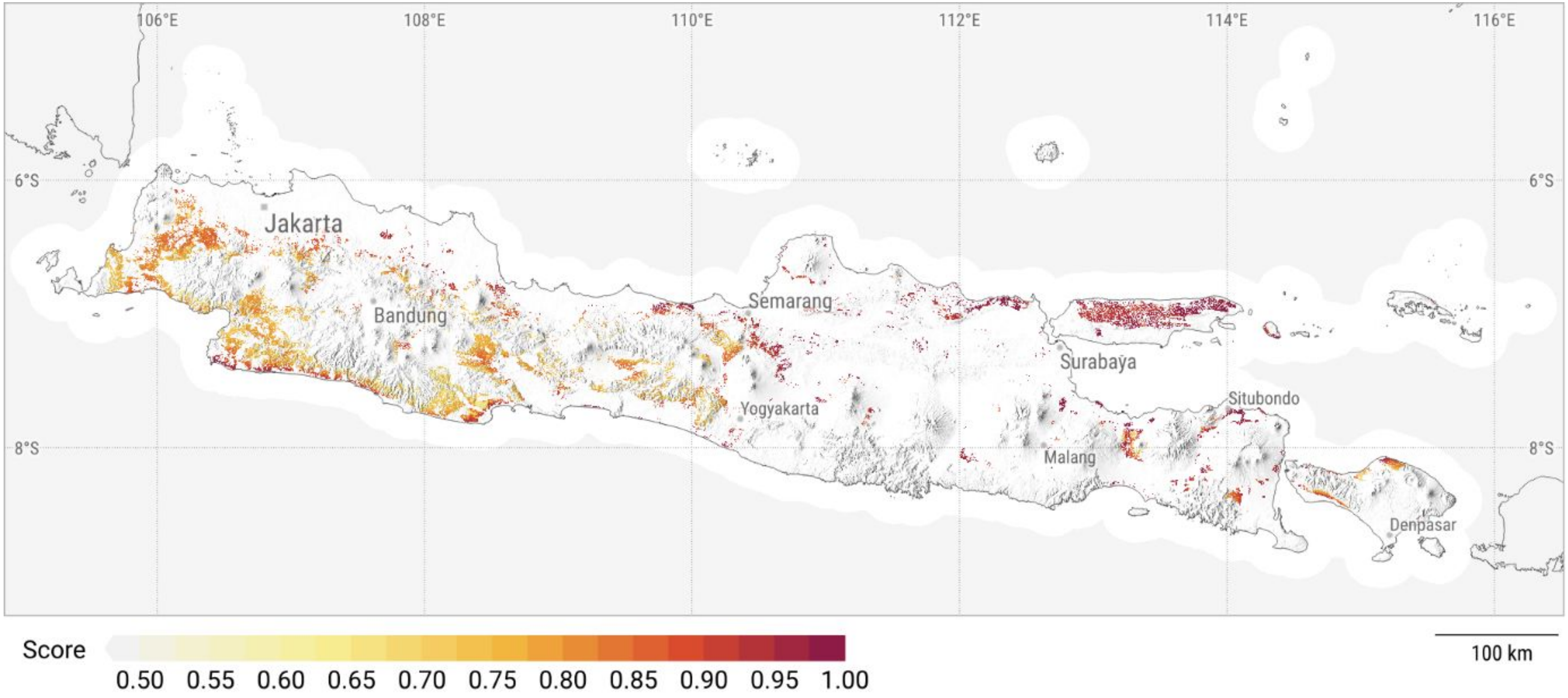
SOCIAL AND ENVIRONMENTAL LEAD

1.5 METHODOLOGY OF THE PROJECT



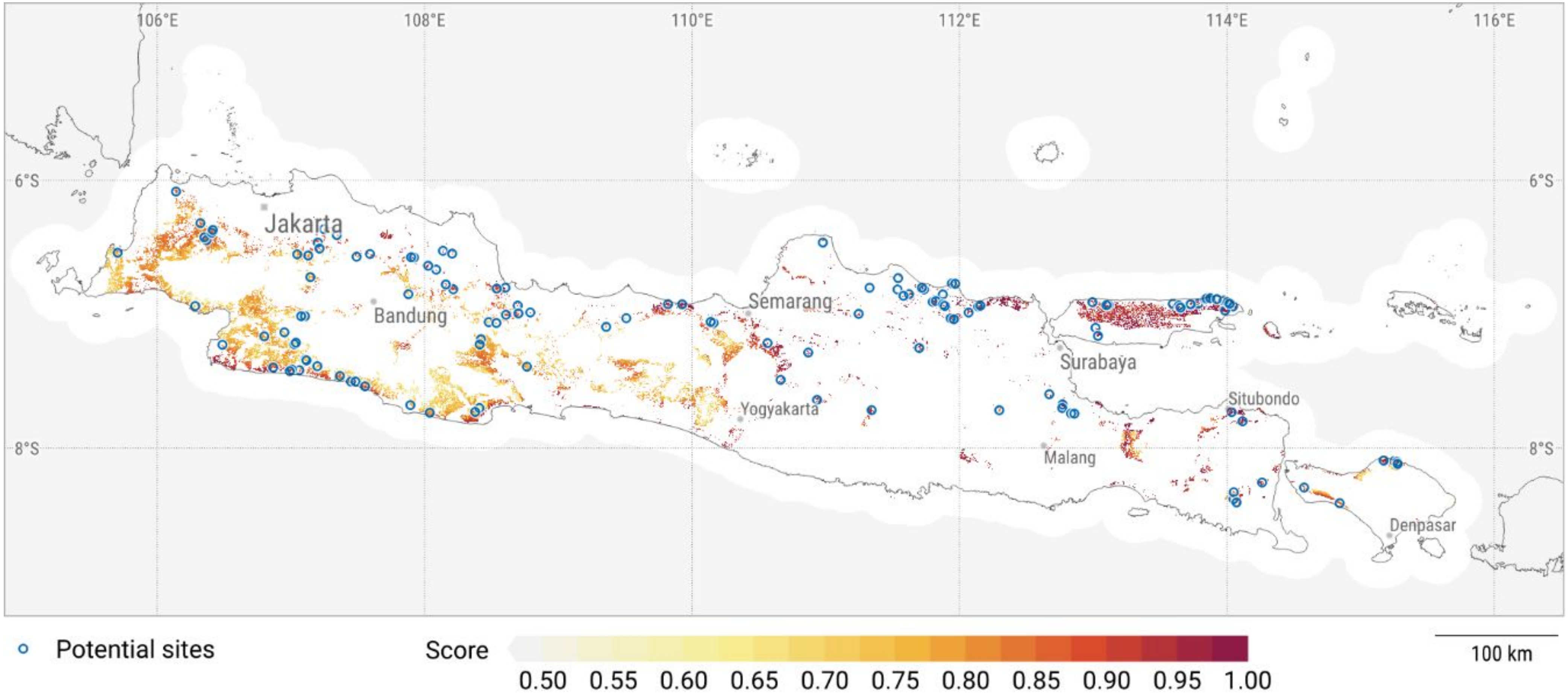
GEOSPATIAL ANALYSIS RESULT

Geospatial analysis result, the composite of binary and range layers



GEOSPATIAL ANALYSIS RESULT

140 Pre-selected Sites



Calculated score for the classified areas and 140 pre-selected potential locations for utility-scale PV development. Higher scores present more favorable areas

Phase 1: Solar Irradiance Mapping Methods

A Multi-Criteria Decision Matrix (MCDM) assessment was built collaboratively to identify the preferred locations for PV development in JAMALI. The process consisted of:

Geospatial analysis
- Preferred areas for Solar PV Development Map
- List Preferred sites selected

Environmental and Social analysis
- Assesment of the E&S risks on the selected sites
- List of excluded sites and qualified sites

Preliminary grid impact analysis
- Distance to the grid
- Maximum hosting capacity

Financial analysis (in later stage)
- IRR
- Project viability

140 sites were selected

3 were excluded due to E&S evaluation

137 sites with the total 11.2 GW potential were ranked

Phase 1: Solar Irradiance Mapping Result

GEOSPATIAL ANALYSIS

- 140 sites

E&S ANALYSIS

- 137 sites qualified
- 41 high-risk
- 96 medium risk
- 3 excluded

PRE-GRID ASSESSMENT

- Maximum Hosting Capacity for relevant substations
- Potential Solar PV Capacity

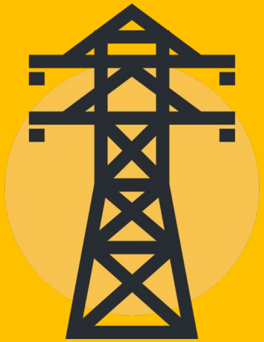
SITE PRIORITIZATION

- Final list of sites: 137 sites with 11.2 GW capacity

Potential Capacity Calculation :

Land Availability

+



Maximum hosting capacity per substation

→ **Potential capacity**

OBJECTIVES OF THE REPORT

2.1 OBJECTIVES OF THE REPORT

M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15

Deliverable 3
Report on Grid Integration Assessment

The grid assessment aims to address/identify the existing power systems' technical, economic, and environmental challenges. It also aims to estimate the integration of renewable energy and assess whether any of the sites initially selected would negatively affect it.

As part of the 1 GW Solar Development and Mapping Project in Indonesia, and specifically its Phase 1 Report: Solar Irradiance Mapping, a total of 137 potential sites have been identified as suitable for ground-mounted, utility-scale solar PV projects in the JAMALI region. D2 employed a multi-criteria decision-making (MCDM) process incorporating geospatial, environmental, and social assessments and a preliminary grid integration analysis. Initially aimed at integrating 1 GW of renewable energy into the existing JAMALI grid, the project's scope was expanded to 2.2 GW in agreement with the ETP.

This report seeks to validate whether these sites can be technically integrated into the JAMALI system. The 137 potential sites collectively represent a total capacity of 11.22 GW. This report will conduct a grid integration assessment focusing on top-ranked sites based on MCDM scoring from previous deliverables and additional financial and economic factors. The overall deliverable´s output is identifying a selection of technically viable sites to achieve the 2.2 GW target.

- **How much solar PV can be integrated into the JAMALI system?**
- **What are the technical consequences of integrating PV plants into the JAMALI system?**
- **What could be the economic impact of PV integration on the JAMALI system?**

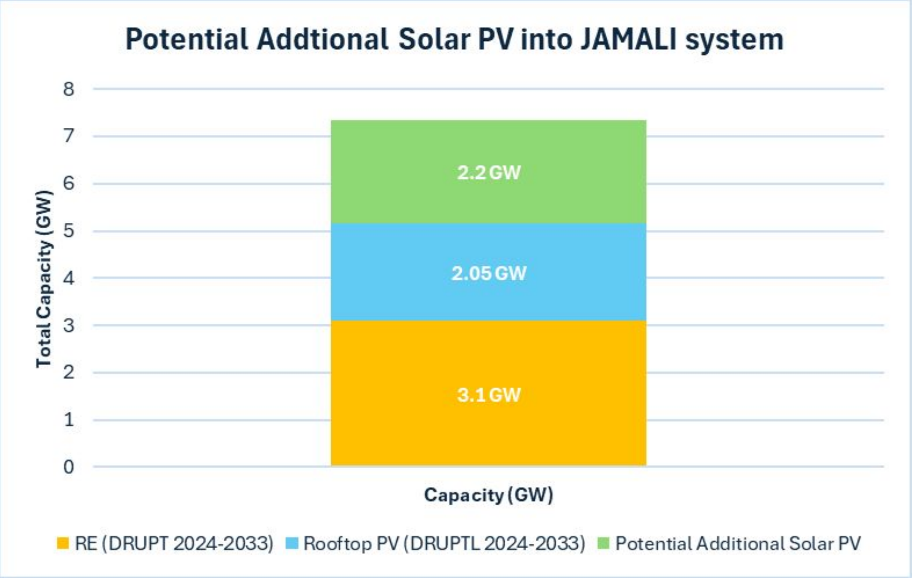
The outputs of this report are:

1. Hosting capacity analysis
2. Grid impact assessment
3. Production simulation analysis
4. List of technically viable sites to achieve the 2.2GW target
5. Technical insights to key stakeholders, including the Ministry of National Development Planning (BAPPENAS), the Ministry of Energy and Mineral Resources (MEMR), and the state-owned electricity company (PLN).

2.2 KEY INSIGHTS

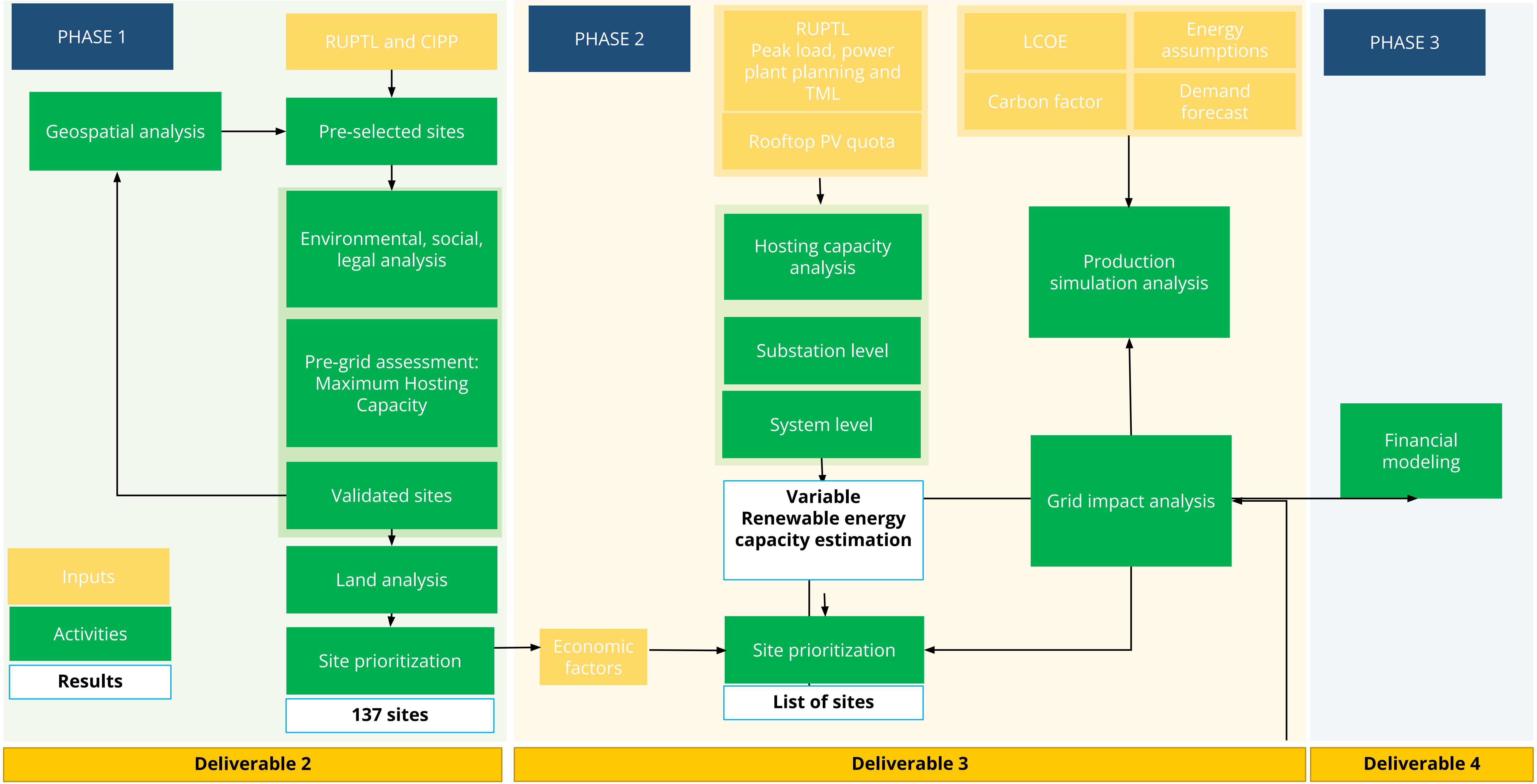
The key insights of the report are:

1. The JAMALI grid can absorb up to **2.2 GW** of Solar PV by 2030, on top of the **3.1 GW** Renewable Energy Plan in the PLN Electricity Plan (2024).
2. **25 sites** have been selected from the Phase 1 site list, with each province assigned a site. These sites are technically viable and will be re-evaluated during the financial analysis stage.
3. In the business-as-usual scenario, adding **2.2 GW of Solar PV increases the system's LCOE** due to the replacement of coal, the cheapest option when excluding social and environmental costs and carbon tax.
4. To further balance the cost increases associated with PV integration, implementing a carbon tax could be a strategic option to disincentivize fossil fuels or Carbon Credits or Renewable Energy Certificate to incentivize RE.
5. Optimal integration of **1.66 GW PV** can replace more expensive gas generation, helping **reduce overall system costs**. However, coal power production will not be replaced with Solar PV.
6. Aligning with the government's coal reduction plan, Solar PV will lower system costs by replacing gas, especially as coal is phased down.



METHODOLOGY

3.0 METHODOLOGY OF THE PHASE 2

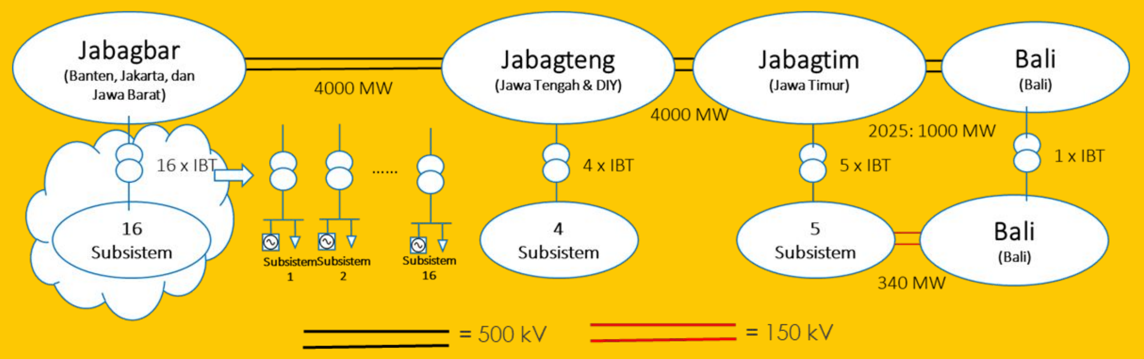


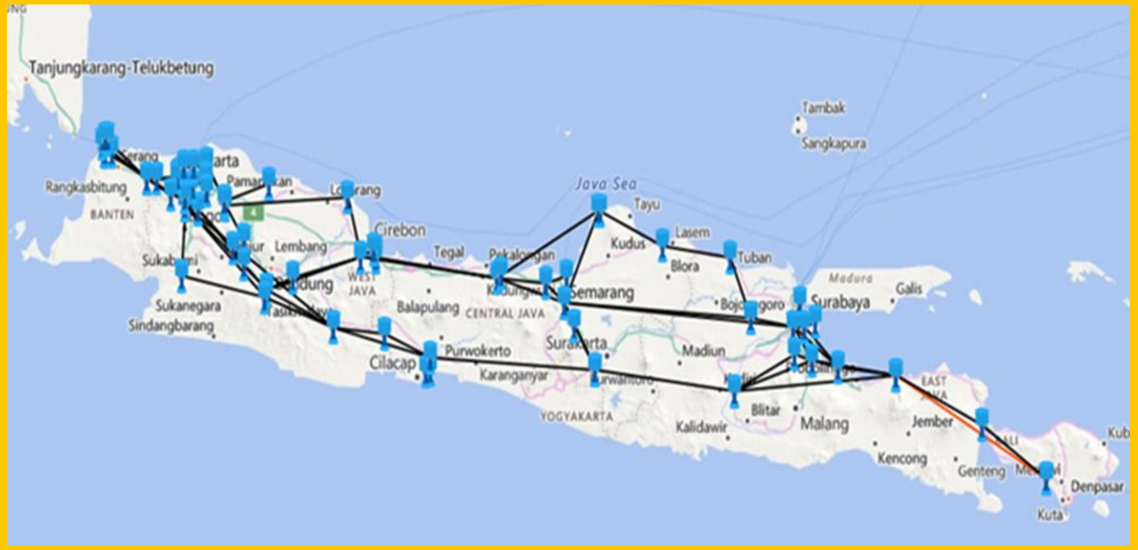
3.1 SCENARIOS AND ASSUMPTIONS

To run the hosting capacity analysis and the grid impact study, assumptions are defined before system modeling. Assumptions are taken on:

3.1 SYSTEM MODELLING: TOPOLOGY

- ❑ The JAMALI Grid modelling uses a 500 kV transmission backbone.
- ❑ Power plant planning refers to the power balance for 2024-2030.
- ❑ Utility-scale solar PV power plants will be added in this study
- ❑ PLEXOS will be used for this simulation





3.1 SYSTEM MODELLING: DEMAND FORECAST UP TO 2030

Data Input:

- Existing load profile per subsystem
- Forecast demand up to 2030

Results :

Load profile per subsystem (2024-2030)

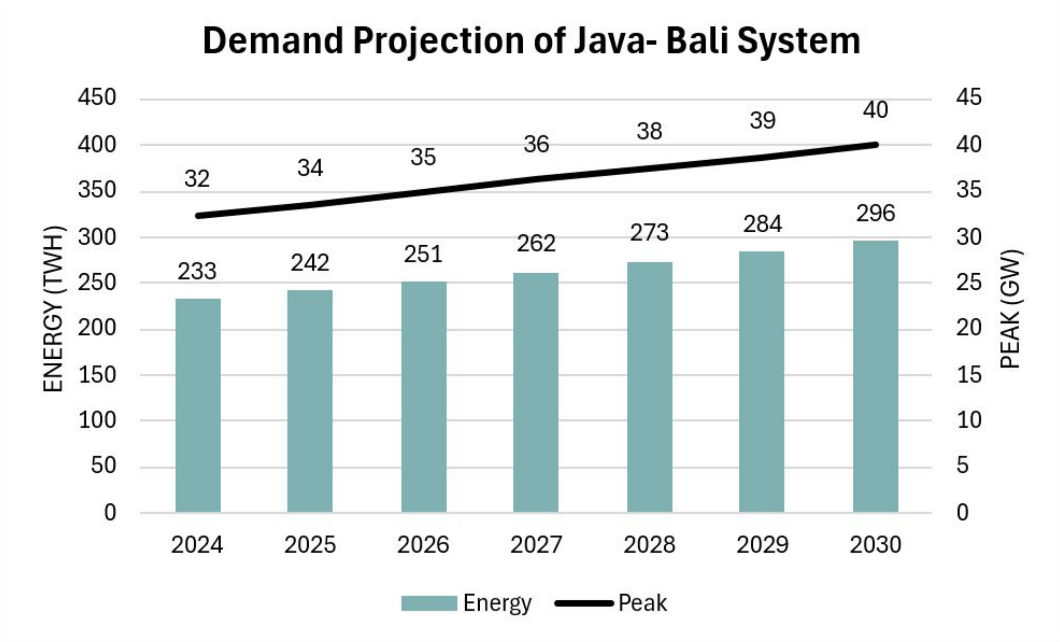
Existing demand profile per subsystem

Proportional to total system demand

Energy & peak demand forecast of JAMALI System

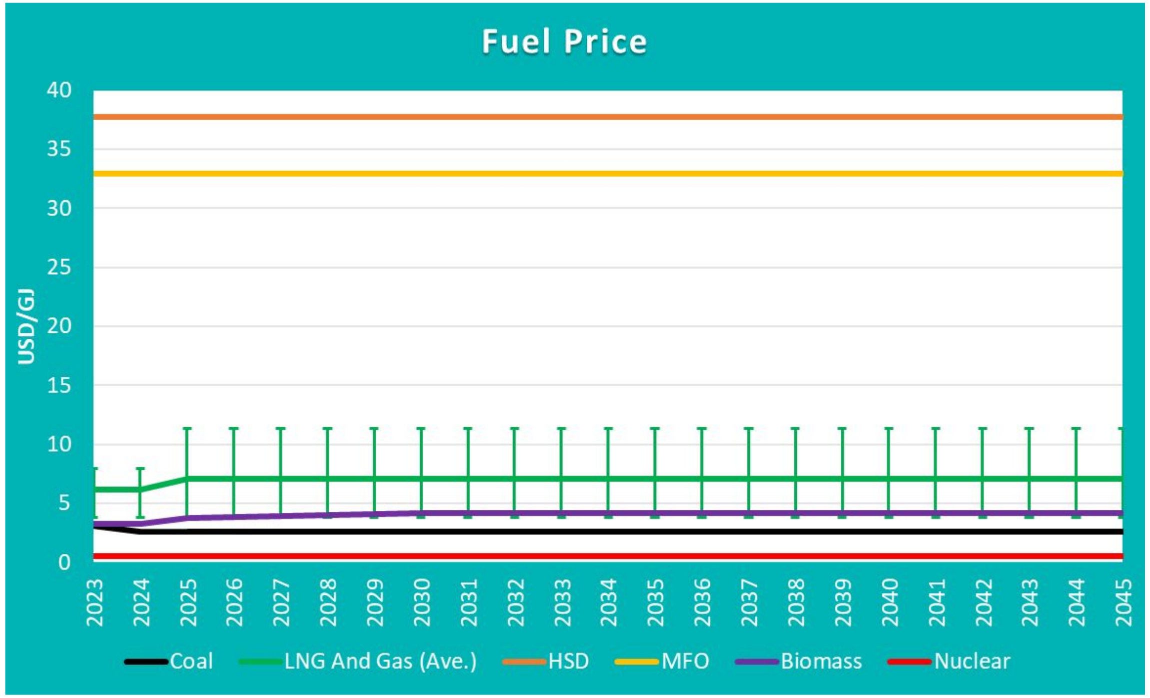
Load curve of each subsystem (2024-2030)

Study horizon 2024-2030



- **Demand growth from 2024 – 2030 refers to the demand forecast in PLN Electricity Plan study as of July 2024.**

3.1 SYSTEM MODELLING: PRIMARY ENERGY



Assumptions:

- The price of coal is subject to the Domestic Market Obligation (DMO) regulations.
- The price of gas and LNG refers to Ministerial Decree No. 135.K/HK.02 MEM.M/2021.
- The price of gas pipelines is extended until 2045, while the price of LNG is set at $12/MMBtu starting in 2025. Additional LNG can be utilized at $12/MMBtu starting from 2033.
- The price of biomass is based on PLN data until 2032 and is then extended until 2045.
- The price of nuclear fuel is $1978/kg, including processing costs, assuming a uranium price of $75.5/kg.

Fuel		Unit	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal		USD/ton	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
LNG and Gas Pipe	Ave.	USD/MMBtu	6.5	6.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
	Min	USD/MMBtu	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	Max	USD/MMBtu	8.4	8.4	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	Buffer	USD/MMBtu	-	-	-	-	-	-	-	-	-	-	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
HSD		USD/liter	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
MFO		USD/liter	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Biomass		USD/ton	52.7	53.7	60.8	62.3	63.8	65.4	67.1	68.7	70.5	72.2	72.2	72.2	72.2	72.2	72.2	72.2	72.2	72.2
Nuclear		USD/kg	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978

Reference :

[1]https://solarindustri.com/berita/harga-solar-industri-01-14-juni-2023/

3.1 SYSTEM MODELLING: CARBON FACTOR

Fuel	Carbon Factor (kg/GJ)
Sub Bituminous	96.1
Lignite	101
Peat	106
Gas	56.1
Oil	74.1
Biomass	0

- ❑ The carbon factor refers to the conversion calculation in APPLE-GATRIK (Appendix 3)[1].
- ❑ Biomass is assumed to be a fuel with net zero emissions.
- ❑ Coal-fired power plants (CFPP) are modelled in detail, incorporating carbon intensity for each plant based on data provided by PLN.

Coal-Fired Power Plant	Carbon Intensity (ton/MWh)
CFPP SURALAYA #1	1.06
CFPP SURALAYA #2	1.03
CFPP SURALAYA #3	1.04
CFPP SURALAYA #4	1.09
CFPP PAITON #01	1.04
CFPP SURALAYA #5	0.99
CFPP SURALAYA #6	0.98
CFPP SURALAYA #7	1
CFPP LABUAN #01	1.04
CFPP INDRAMAYU #1	1.04
CFPP INDRAMAYU #2	1.06
CFPP INDRAMAYU #3	1.05
CFPP LABUAN #02	1.08
CFPP REMBANG #1	1.09
CFPP REMBANG #2	1.09
CFPP SURALAYA #08	1.14
CFPP PAITON #09	1.04
CFPP PACITAN #1	1.11
CFPP PACITAN #2	1.13
CFPP PALABUAN RATU #01	1.15
CFPP PALABUAN RATU #02	1.09
CFPP PALABUAN RATU #03	1.1
CFPP TANJUNG AWAR-AWAR #1	1.1
CFPP TANJUNG AWAR-AWAR #2	1.09
CFPP ADIPALA	1.35
CFPP BUKIT ASAM #01	1.38
CFPP BUKIT ASAM #02	1.5
CFPP BUKIT ASAM #03	1.61
CFPP OMBILIN #01	1.27
CFPP LABUHAN ANGIN #01	2.04
CFPP LABUHAN ANGIN #02	1.75
CFPP NAGAN RAYA #01	1.71

Reference:
[1]DJK (2018), "Pedoman Penghitungan dan Pelaporan Inventarisasi Gas Rumah Kaca Bidang Energi - Sub Bidang Ketenagalistrikan", Direktorat Jendral Ketenagalistrikan, Jakarta
[2]PLN Data (2023)

3.1 SYSTEM MODELLING: VRE TOTAL CAPACITY

- The total capacity of VRE power plants is estimated to be scheduled for implementation by 2030 as part of the PLN Electricity Plan study.
- PV power plants are categorized into utility-scale and PV rooftop systems.

Table of VRE total capacity in DRUPTL 2024-2033 and rooftop PV quota until 2030

JAMALI		Unit	2024	2025	2026	2027	2028	2029	2030
Maximum Penetration	VRE Utility Scale	MW	375	800	2290	2680	2820	2960	3100
	Rooftop PV	MW	825	900	910	1010	1400	1500	2050
	VRE Total	MW	1200	1700	3200	3690	4220	4460	5150

3.2 HOSTING CAPACITY ANALYSIS

Purpose: To evaluate the grid's capacity to handle additional renewable energy by considering factors such as peak load, existing power generation capacity, and planned renewable energy projects using **DIgSILENT Power Factory**.

Substation Level Analysis

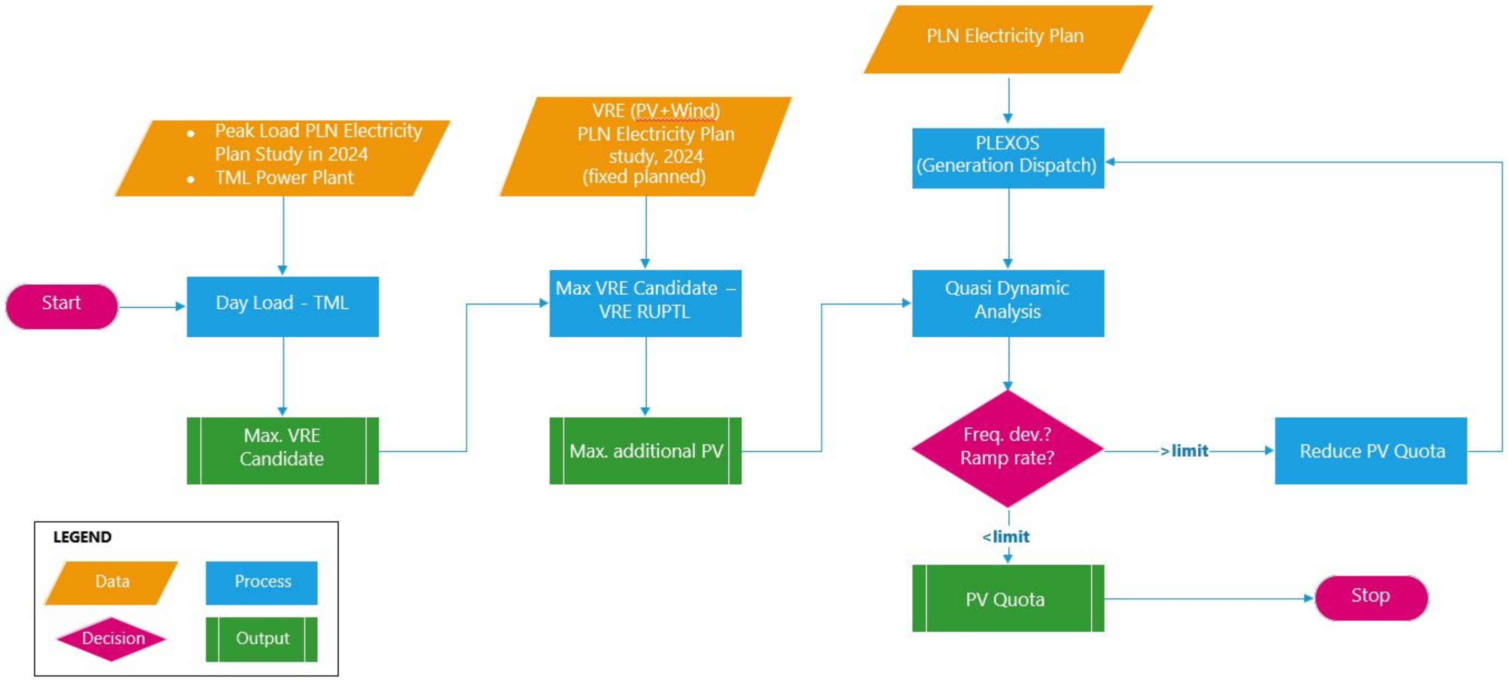
- This analysis focuses on evaluating the integration of photovoltaic (PV) systems at the substation level, aim to determine how much PV capacity can be connected to a substation before operational limits are reached.

System Level Analysis

- At the system level, the hosting capacity analysis aims to determine the maximum amount of VRE specifically solar PV that the JAMALI grid can accommodate while maintaining overall system stability.

At the substation level: Phase 1: Solar Irradiance Mapping report assessment identified the maximum hosting capacity for each substation to which the proposed solar PV systems (across 137 sites) can be connected. This analysis establishes the maximum solar PV capacity that can be integrated into each substation, ensuring that the substation can accommodate the additional generation without exceeding operational limits.

3.2 HOSTING CAPACITY ANALYSIS : JAMALI SYSTEM LEVEL



Initial Data Collection	Peak load from RUPTL 2023–2032 and Thermal Minimum Loading (TML) of existing power plants are assessed.
Day Load Profile Calculation	Using peak load and TML, the grid's daily load profile is calculated, indicating how much renewable energy can be integrated.
Maximum PV Capacity Estimation	The day load profile helps estimate the technical maximum PV capacity.
Fixed VRE Capacity Consideration	The fixed VRE capacity from RUPTL and Rooftop PV quotas are factored in.
Additional PV Capacity	The difference between maximum potential PV capacity and fixed VRE capacity is calculated.
Simulation & Stability Assessment	The maximum PV capacity is simulated using PLEXOS, and a quasi-dynamic analysis checks frequency deviation and ramp rates. Iterative adjustments ensure that the grid remains stable, concluding with the final PV quota.

3.3 GRID IMPACT STUDY: SITE PRIORITIZATION

RANKING OF 137 SITES

- The site ranking among the 137 is adjusted, mainly to include the economic parameters of land prices and distance to the grid.

UPDATED LIST OF TOP-RANKED SITES

- A new list of sites will be generated based on the updated top-ranked sites and provincial diversification

VALIDATION OF THE UPDATED LIST WITH GRID IMPACT ANALYSIS

- This list of 25 sites will be validated in the next step, which involves grid impact analysis. The capacity assigned for the selected sites is divided into four : 25 MW, 50 MW, 75 MW, and 100 MW.

3.3 GRID IMPACT STUDY: POWER SYSTEM ANALYSIS

The analysis below is performed:

Load Flow Study	•Minimum and maximum voltage levels at each Substation (GI) across five areas are tracked to ensure they stay within safe limits.
Short-Circuit Levels	•Short-circuit levels at GIs connected to PV are calculated to ensure protection systems can manage potential faults.
Transient Stability	•The system's response to disturbances like faults or outages is analyzed to confirm the grid remains stable and recovers smoothly.

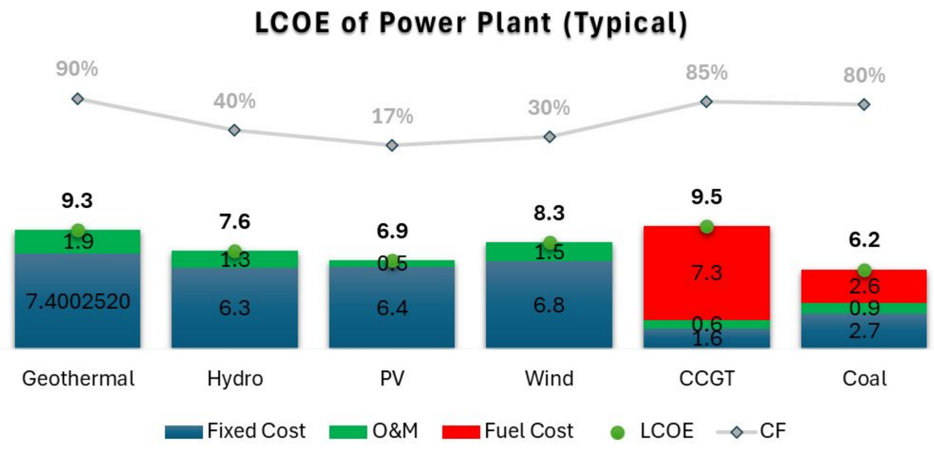
The JAMALI grid is divided into five areas, which are:

Areas	**Sub-systems**
AREA 1	The subsystems include Bekasi24-Cawang1, Cibinong12-Depok2, Cilegon12, Kembangan2-Balaraja34, Gandul13-Kembangan2, Balaraja12, Bekasi13-Cibinong3, Cawang23-Depok1, Gandul24, and Suralaya-Cilegon3
AREA 2	The subsystems includes Bandung S, Cibatu12, Cibatu34-Mandirancan, Cirata, and Tasikmalaya.
AREA 3	The subsystems includes the Pedan12, Tanjungiati-Ungaran3, Ungaran12-Kesugihan, and Pedan34 subsystems.
AREA 4	The subsystems includes Krian12-Gresik, Ngimbang, Paiton-Grati, Kediri, and Krian34. Lastly
AREA 5	The subsystems includes Bali subsystem.

3.3 GRID IMPACT STUDY: PRODUCTION SIMULATION

GENERATION MIX	**Purpose:** Evaluates contributions of different energy sources (coal, gas, renewables) to electricity supply.	
	Data input: Power generation production from 2024-2030, including multi-unit outputs.	
EMISSION REDUCTION CALCULATION	**Purpose:** Quantifies reductions in greenhouse gas emissions.	
	Data input: carbon emission factor	
ECONOMIC IMPACT ANALYSIS	**Purpose:** Assesses financial impact of energy projects on the economy.	
	Data Input: LCOEs of different power plants.	
	Three scenarios are analyzed:	**Scenario 1:** The base case scenario, which includes PV plants as planned under RUPTL.
		Scenario 2: An additional 2.2 GW of PV capacity is integrated.
		Scenario 3: A carbon tax of $2/ton is applied.

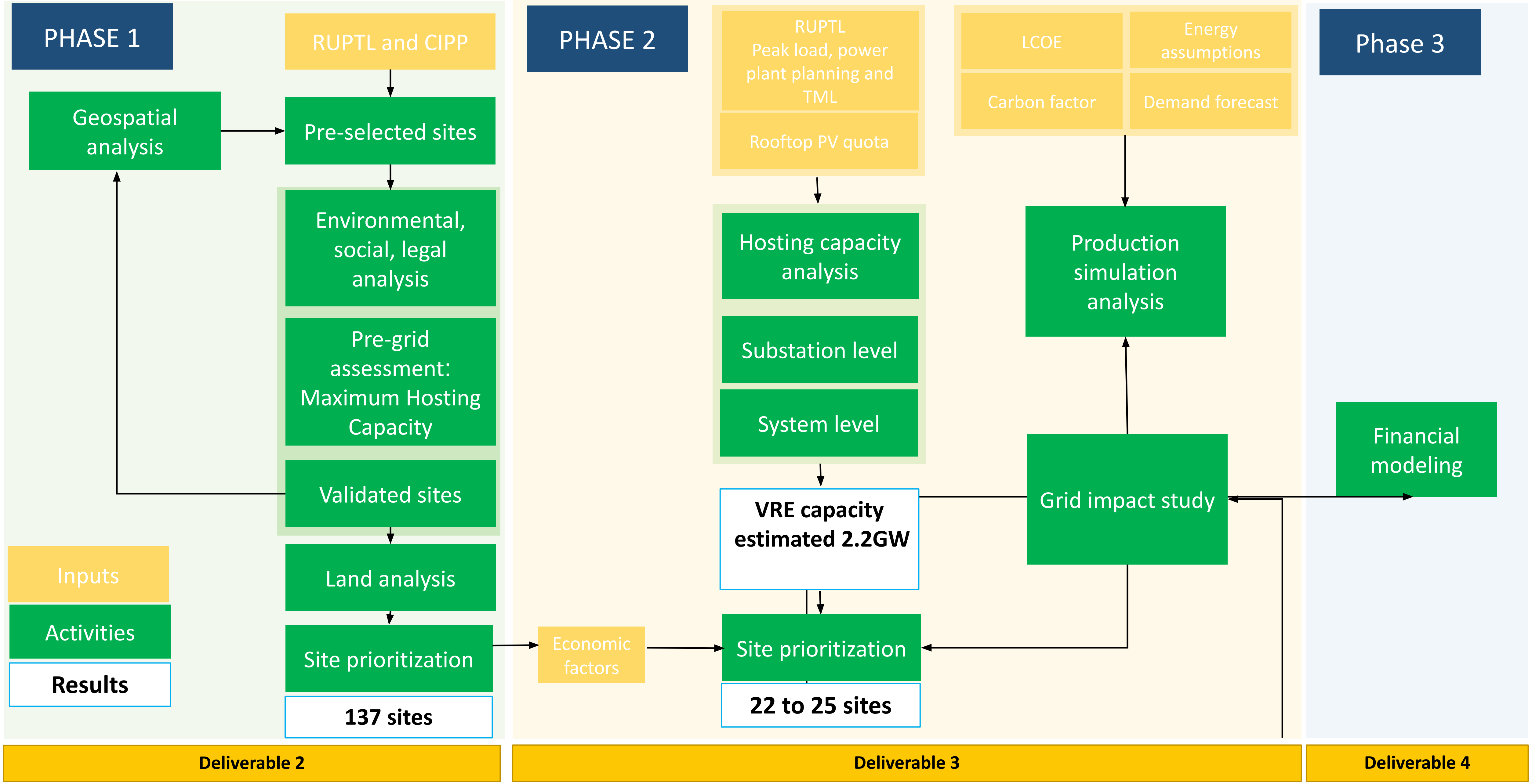
Economic Assumption:



- For Solar PV: The ceiling price of **6.95 c$/kWh** applies, as the Solar PV plants are expected to be built and operational within this timeframe. (according to Presidential Regulation Number 112 of 2022)
- The sensitivity analysis is performed to analyze on how changes in coal and PV prices affect the LCOE

RESULT AND ANALYSIS

4.0 RESULTS


PHASE 1
RUPTL and CIPP
Geospatial analysis
Pre-selected sites
Environmental, social, legal analysis
Pre-grid assessment: Maximum Hosting Capacity
Validated sites
Land analysis
Site prioritization
137 sites
Inputs
Activities
Results
PHASE 2
RUPTL Peak load, power plant planning and TML
Rooftop PV quota
LCOE
Energy assumptions
Carbon factor
Demand forecast
Hosting capacity analysis
Substation level
System level
Production simulation analysis
VRE capacity estimated 2.2GW
Grid impact study
Economic factors
Site prioritization
22 to 25 sites
Phase 3
Financial modeling
Deliverable 2
Deliverable 3
Deliverable 4

4.1 HOSTING CAPACITY ANALYSIS: JAMALI MAXIMUM RE PENETRATION

The table below presents the forecasted VRE capacity in the JAMALI region from 2024 to 2030. It provides three key sections:

JAMALI			2024	2025	2026	2027	2028	2029	2030
Maximum Penetration	PV Rooftop (DRUPTL 2024-2033)	MW	825	900	910	1010	1400	1500	2050
	VRE Utility Scale (DRUPTL 2024-2033)	MW	375	800	2090	2680	2820	2960	3100
	PV Utility (Quota for additional PV)	MW	1100	1100	1100	1100	1200	1900	2200
	VRE Total	MW	2300	2800	4040	4530	5420	6360	7350

Description:

- VRE Scale Utility shows VRE's utility-scale contribution - **cumulative**
- PV Rooftop displays the projected capacity of rooftop solar installations - **cumulative**
- **PV Utility refers to utility-scale PV capacity, which will start at 1100 MW in 2024 and reach 2200 MW by 2030** - **cumulative**
- The final row, VRE Total, sums the total VRE capacity, starting at 2300 MW in 2024 and rising to 7350 MW by 2030 - **cumulative**

4.1 HOSTING CAPACITY ANALYSIS: JAMALI MAXIMUM RE PENETRATION

- As a result, by 2030, the system will absorb up to **2,200 MW, or 2.2 GW**.
- Therefore, this study prioritizes site selection based on the strategic importance and geographical diversity within the JAMALI regions, ensuring top sites are chosen from each province. The total capacity of the selected sites in the site prioritization, amounting to 2.2 GW, must align with the system's capacity availability.
- The table below presents the maximum PV that can be integrated into the JAMALI grid is shown cumulatively for each year until 2030 and the recommendation for additional PV to be integrated to the system each year.

PLTS		Unit	2023	2024	2025	2026	2027	2028	2029	2030
PV Utility (Quota for additional PV)		MW		**1100**	**1100**	**1100**	**1100**	**1200**	**1900**	**2200**
Additional PV Utility Capacity per Year		MW	**-**	**-**	**300**	**300**	**300**	**300**	**500**	**500**

4.2 GRID IMPACT STUDY : LIST OF PRIORITIZED SITES

Based on the updated top-ranked sites and the provincial diversification, meaning that each province has assigned sites, the following table constitutes the list of 25 sites prioritized to achieve 2.2 GW.

No.	ADM1	ADM2	ADM3	ADM4	Hub Name	Capacity (MW)
1	Jawa Tengah	Pati	Dukuhseti	Wedusan	GITET 500 kV Tanjung Jati	100
2	Jawa Tengah	Rembang	Sale	Tengger	GI 150 kV Semen Indonesia	100
3	Jawa Timur	Tuban	Bancar	Siding	GI 150 kV Mliwang	100
4	Jawa Timur	Sumenep	Dasuk	Dasuk Timur	GI 150 kV Sumenep	100
5	Jawa Tengah	Sukoharjo	Polokarto	Genengsari	GI 150 kV Palur	100
6	Jawa Timur	Bojonegoro	Tambakrejo	Dolokgede	GI 150 kV Cepu	100
7	Jawa Timur	Situbondo	Arjasa	Bayeman	GI 150 kV Situbondo	75
8	Jawa Barat	Cianjur	Sindangbarang	Kertasari	GI 150 kV Patuha	75
9	Jawa Tengah	Kendal	Patean	Sidodadi	GI 150 kV Weleri	100
10	Jawa Timur	Sumenep	Ambunten	Tambaagung Barat	GI 150 kV Sumenep	75
11	Jawa Tengah	Brebes	Banjarharjo	Cikakak	GI 70 kV Babakan	75
12	Jawa Tengah	Rembang	Sale	Joho	GI 150 kV Semen Indonesia	75
13	Jawa Timur	Tuban	Kerek	Trantang	GI 150 kV Sementuban	75
14	Jawa Tengah	Rembang	Sedan	Sambong	GI 150 kV PLTU Rembang	100
15	Banten	Pandeglang	Panimbang	Citeureup	GI 150 kV Tanjung Lesung	100
16	Jawa Timur	Banyuwangi	Glenmore	Karangharjo	GI 150 kV Genteng	100
17	Jawa Barat	Indramayu	Terisi	Cikawung	GI 70 kV Parakan	50
18	Jawa Barat	Karawang	Telukjambe Barat	Wanasari	GI 150 kV Mekarsari	100
19	Jawa Barat	Ciamis	Jatinagara	Cintanagara	GI 150 kV Ciamis	100
20	Jawa Barat	Indramayu	Gantar	Bantarwaru	GI 150 kV Haurgeulis	75
21	Jawa Barat	Tasikmalaya	Cipatujah	Cipatujah	GI 150 kV Karangnunggal	100
22	Banten	Lebak	Maja	Pasir Kecapi	GI 150 kV Tigaraksa	100
23	Banten	Lebak	Curugbitung	Sekarwangi	GI 150 kV Rangkasbitung	100
24	Bali	Buleleng	Tejakula	Sembiran	GI 150 kV Baturiti	100
25	Bali	Buleleng	Kubutambahan	Bukti	GI 150 kV Baturiti	25

4.2 GRID IMPACT STUDY : LOAD FLOW ANALYSIS

Before connecting 2200 MW PV

After connecting 2200 MW PV

Detailed load flow simulation result can be found in ANNEX

4.2 GRID IMPACT STUDY : SHORT CIRCUIT ANALYSIS

Before connecting 2200 MW PV

After connecting 2200 MW PV

Detailed load flow simulation result can be found in ANNEX

4.2 GRID IMPACT STUDY : DYNAMIC/TRANSIENT ANALYSIS

- Dynamic or transient stability analysis studies a power system's ability to maintain synchronism and recover after a disturbance, such as the loss of a major generation unit or a sudden decrease in renewable energy output.

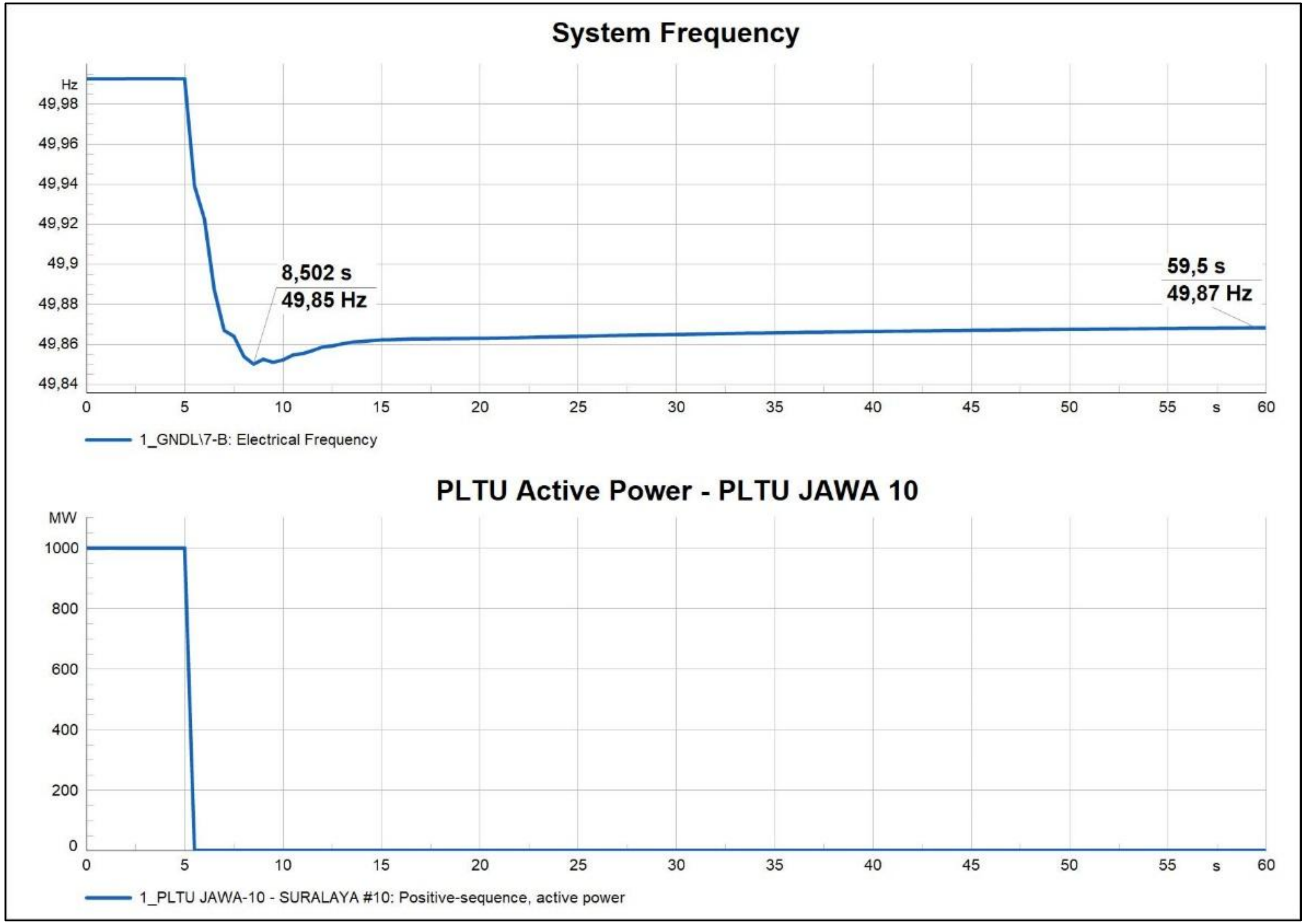
- It examines how the system reacts to these disturbances regarding voltage, frequency, and overall stability over a short time frame (seconds to minutes) to ensure the system can return to a stable operating condition without collapsing.

For phase 2, three events were analyzed:

1. **Event 1:** The impact of removing the largest generation unit from the grid.
2. **Event 2:** The effect of a 50% reduction in PV Power output in Area 3.
3. **Event 3:** The effect of a 20% reduction in PV power output on the system.

Each event is evaluated to assess the grid's stability under varying conditions.

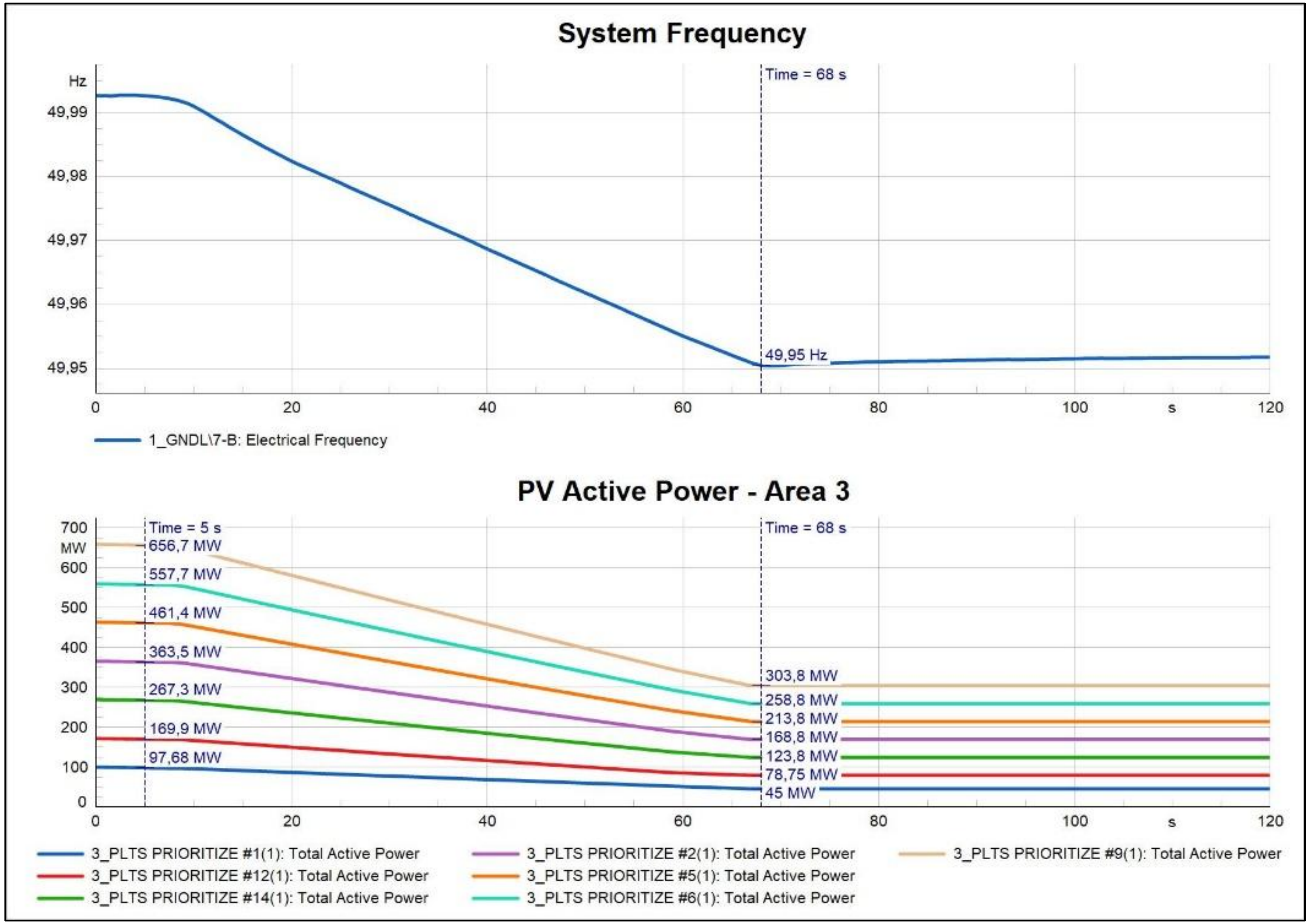
4.2 GRID IMPACT STUDY : DYNAMIC/TRANSIENT ANALYSIS



Event 1

In the first event, when the largest generation unit, PLTU JAWA-10, was removed from the grid, the frequency dropped to 49.85 Hz. Although this was a significant decrease, it remained within the safe frequency deviation limit.

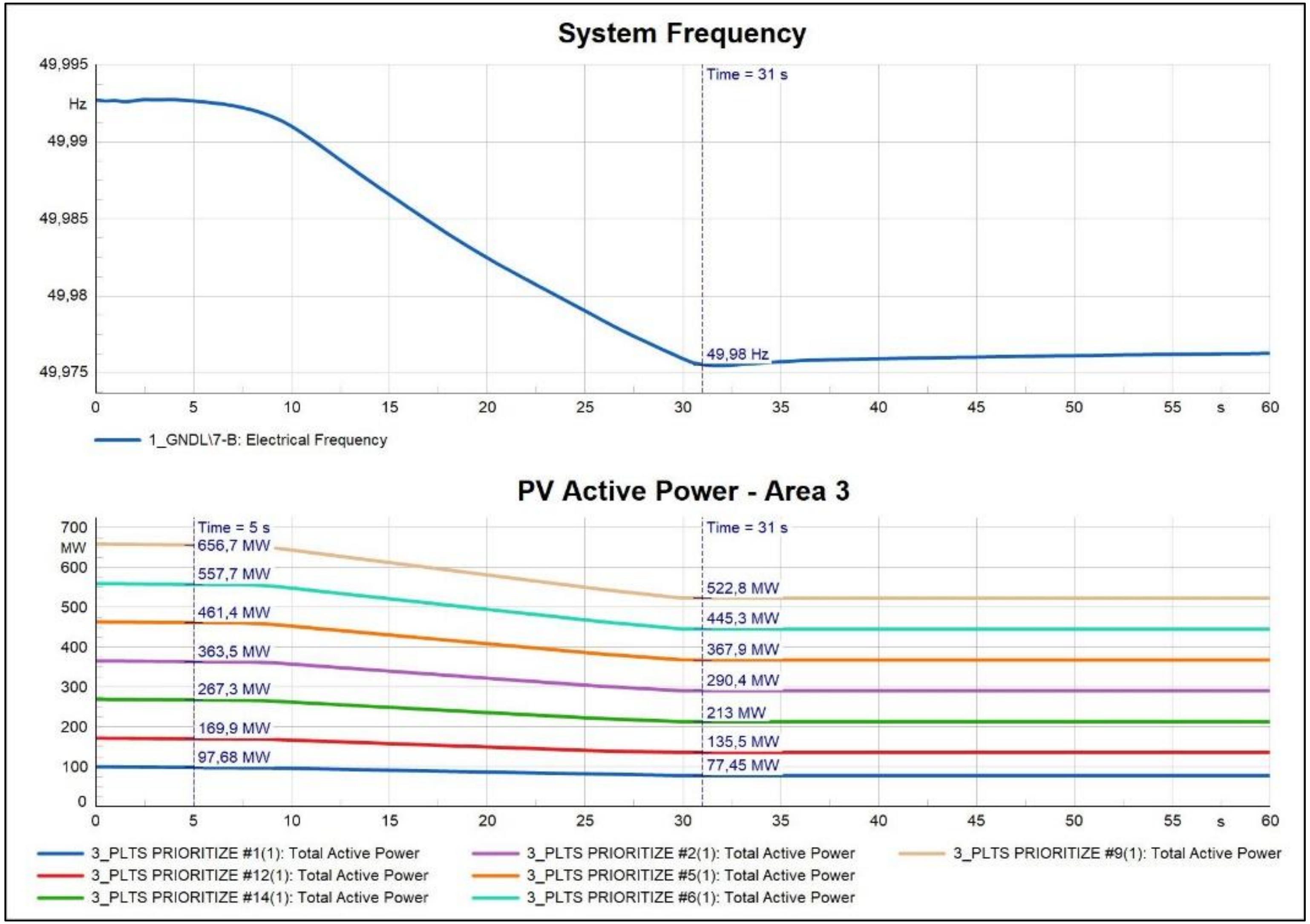
4.2 GRID IMPACT STUDY : DYNAMIC/TRANSIENT ANALYSIS



Event 2

In the second event, when the power output of PV plants in Area 3 was reduced by 50%, dropping from 655 MW to 300 MW over 68 seconds, the frequency decreased to 49.95 Hz, and it remained within the safe frequency deviation limit.

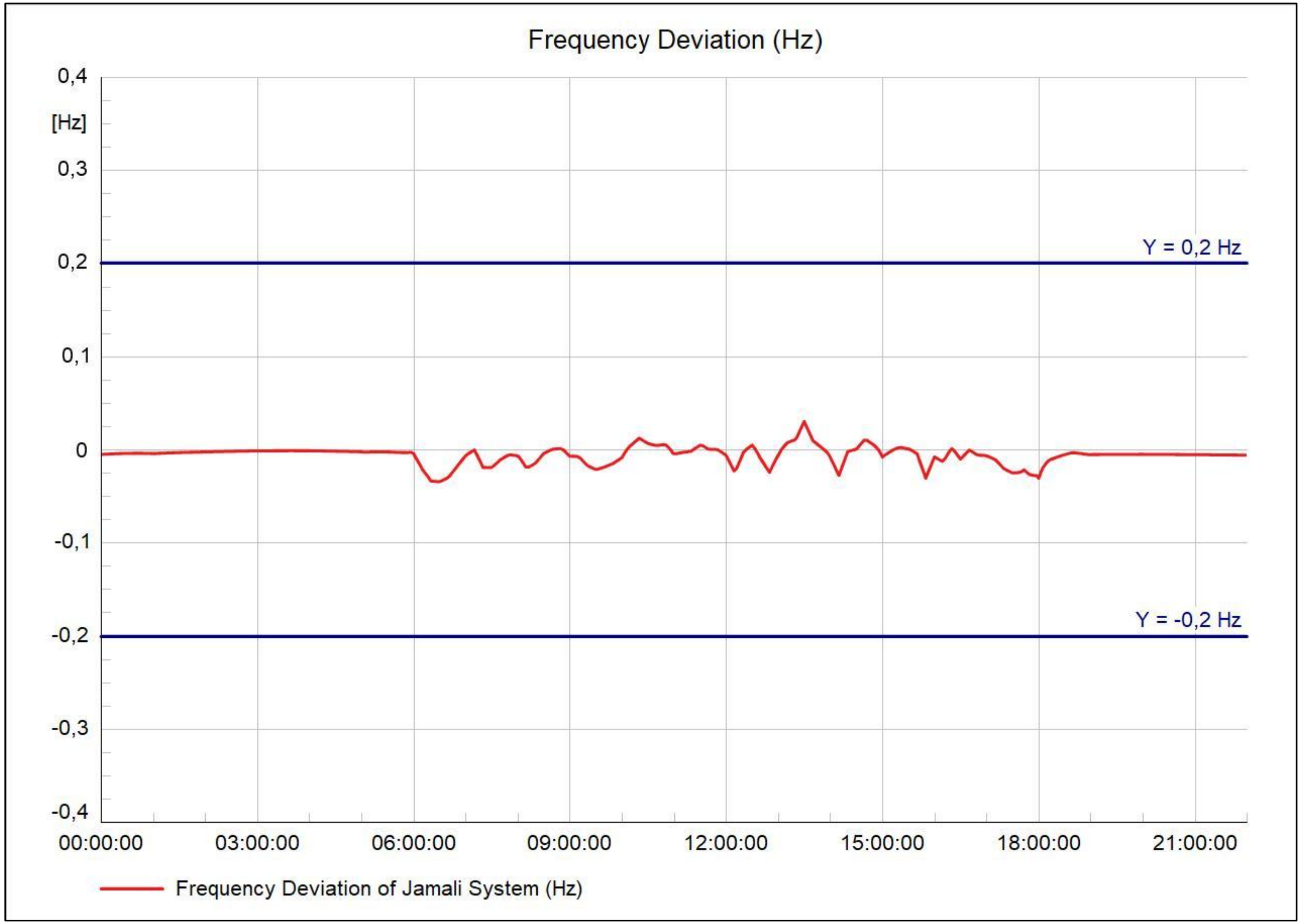
4.2 GRID IMPACT STUDY : DYNAMIC/TRANSIENT ANALYSIS



Event 3

In the third event, a 20% reduction in PV power output, from 655 MW to 520 MW over 31 seconds, caused the frequency to drop slightly to 49.98 Hz. Despite the reduction, the frequency remained within the acceptable range, indicating stable grid performance.

4.2 GRID IMPACT STUDY : QUASI DYNAMIC ANALYSIS



In this case, the analysis monitored the JAMALI system's frequency deviation over a day to assess how it responded to changes in power generation or load.

The frequency stayed within the safe range of ±0.2 Hz, This result confirms **that the grid can manage demand and renewable energy fluctuations without significant issues**, maintaining reliable frequency stability, which is vital for supporting the integration of renewable sources like solar power.

4.2 GRID IMPACT STUDY: GENERATION MIX

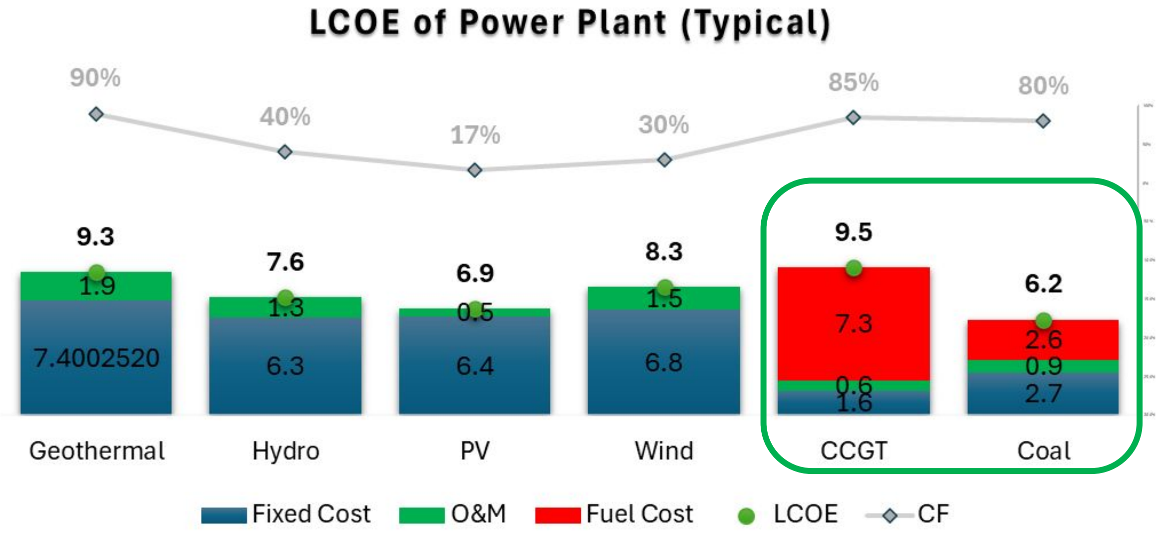
Capacity Factor of Scenario 1: Base Case Scenario

Category	Property	2024	2025	2026	2027	2028	2029	2030
CFPP	Capacity Factor	69%	72%	75%	75%	78%	78%	79%
CCGT	Capacity Factor	29%	28%	29%	30%	33%	33%	31%
GT	Capacity Factor	13%	19%	15%	24%	1%	2%	1%
Gas Engine	Capacity Factor	74%	60%	36%	37%	8%	10%	7%
Hydro	Capacity Factor	26%	26%	26%	26%	26%	27%	27%
Mini Hydro	Capacity Factor	63%	63%	63%	64%	64%	64%	64%
Wind	Capacity Factor	-	-	30%	30%	30%	29%	30%
PV	Capacity Factor	18%	18%	18%	18%	18%	18%	18%
Geothermal	Capacity Factor	90%	90%	89%	90%	90%	90%	90%
PS	Capacity Factor	-	-	-	-	0%	0%	0%

- ❖ The addition of 2200 MW of solar PV in 2030 does not have a significant impact on the change in the average capacity factor (CF) by type of power plant in the JAMALI System.
- ❖ The average CCGT CF (red border) decreases, especially in 2029 and 2030, because it has a higher fuel cost compared to CFPP (green border).

Capacity Factor of Scenario 2: Additional Solar Power Plants

Category	Property	2024	2025	2026	2027	2028	2029	2030
CFPP	Capacity Factor	69%	72%	74%	75%	77%	78%	79%
CCGT	Capacity Factor	29%	28%	28%	30%	33%	32%	29%
GT	Capacity Factor	13%	19%	15%	24%	1%	1%	1%
Gas Engine	Capacity Factor	74%	60%	36%	37%	9%	11%	8%
Hydro	Capacity Factor	26%	26%	26%	26%	26%	27%	27%
Mini Hydro	Capacity Factor	63%	63%	63%	64%	64%	64%	64%
Wind	Capacity Factor	-	-	30%	30%	30%	29%	30%
PV	Capacity Factor	18%	18%	18%	18%	18%	18%	18%
Geothermal	Capacity Factor	90%	90%	89%	90%	90%	90%	90%
PS	Capacity Factor	-	-	-	-	0%	0%	0%



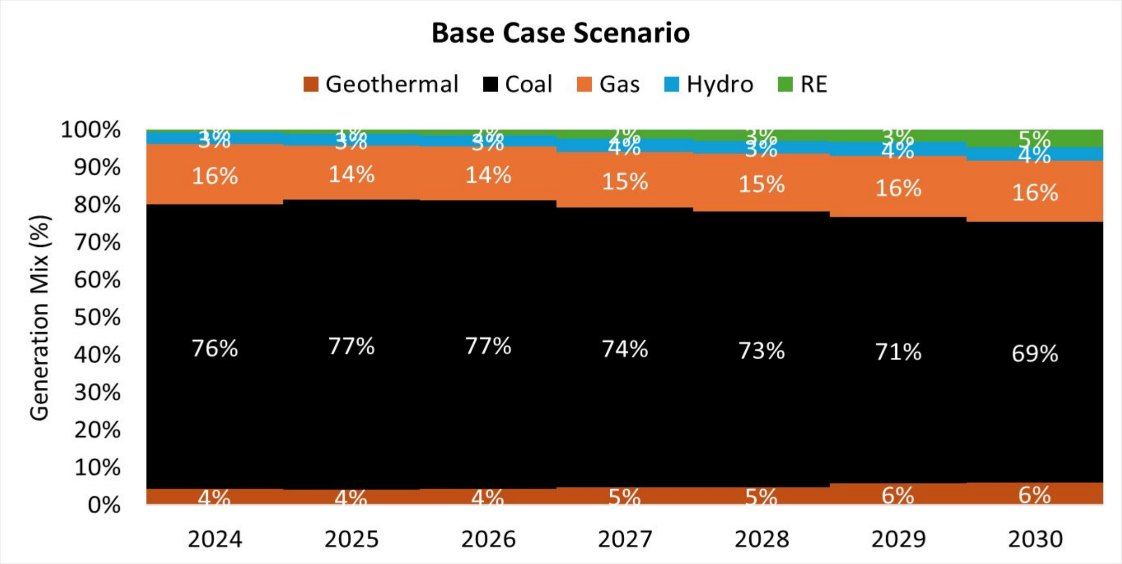
Notes:

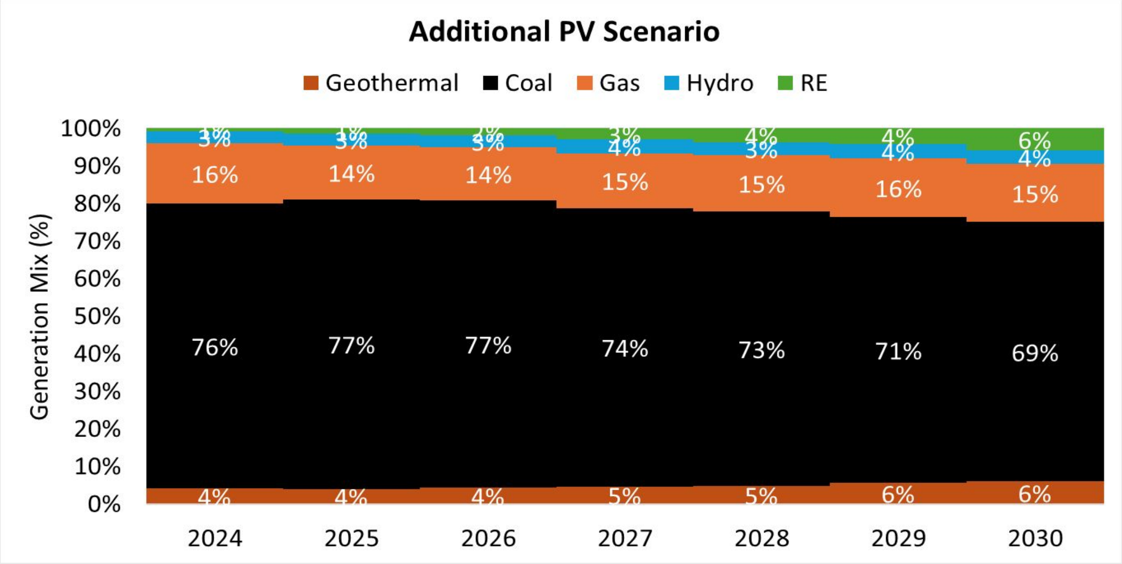
CFPP: coal-fired power plant

CCGT: Combined Cycle Gas Turbines

GT: Gas Turbine

4.2 GRID IMPACT STUDY: GENERATION MIX



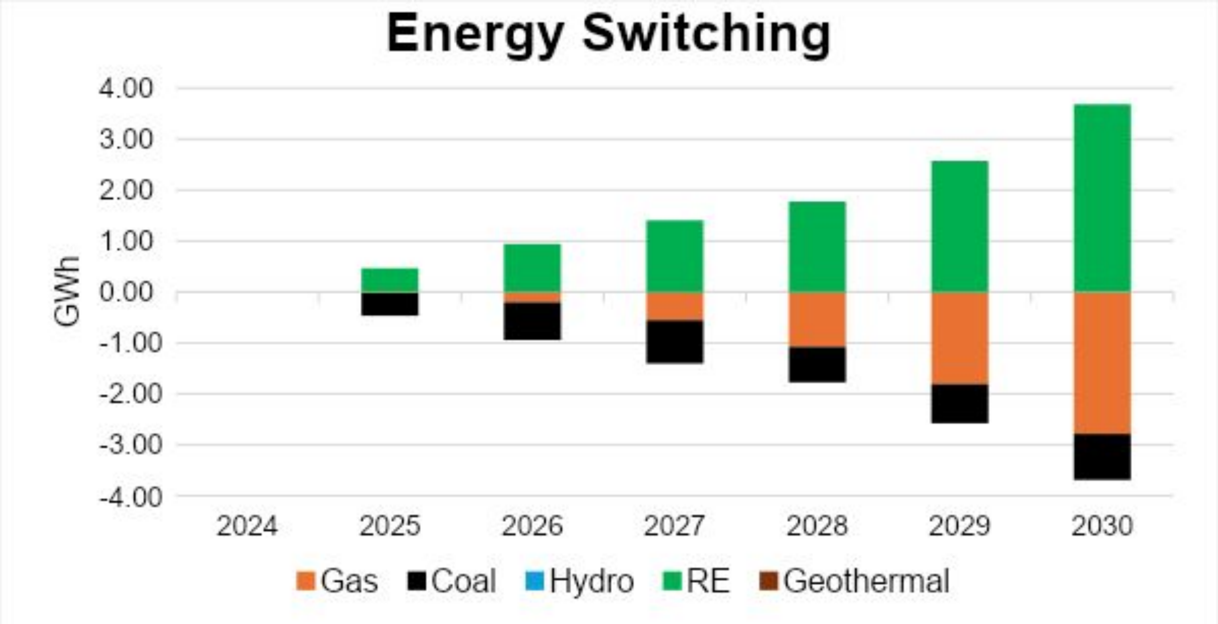


- ❑ By 2030, coal-based generation decreases by 0.9%, and gas generation falls by 1.2%, while the VRE mix increases from 4.6% to 5.9%, representing 26.5% increase compared to the baseline scenario

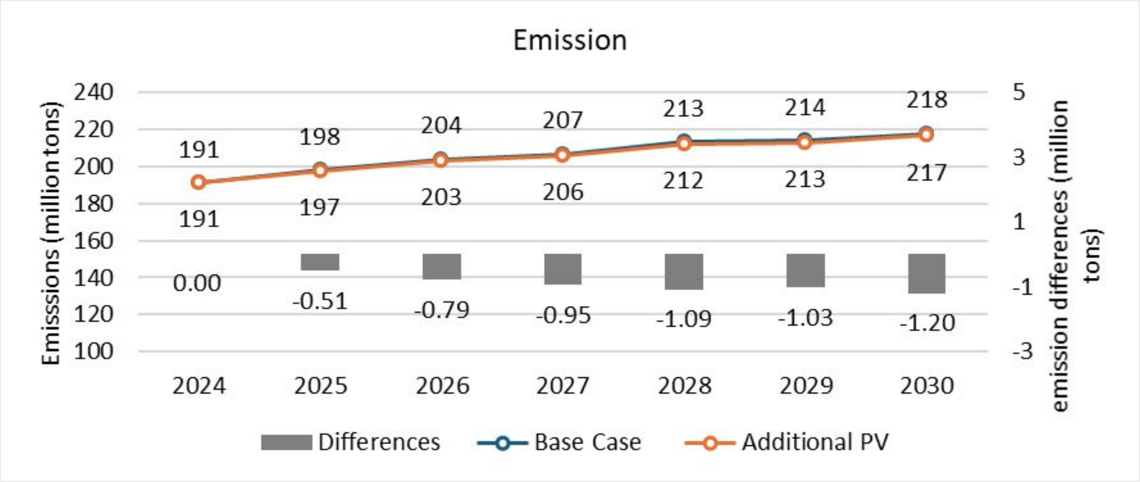
- ❑ From 2028 to 2030, gas power plants respond to growing demand, allowing gas to take on a larger role as they adjust to load conditions. This shift creates an opportunity for PV energy to replace more gas generation than in previous years, as it is often associated with lower variable costs.

4.2 GRID IMPACT STUDY: GENERATION MIX

- The additional renewable energy from the extra solar PV since 2025 replaces energy from gas and coal-fired power plants (CFPP).
- In 2030, the increased use of gas in the base case scenario has the potential to be replaced by additional RE. This is reflected in the graph, which shows energy switching between RE and gas that year.
- Reducing gas, which is notably more expensive than coal, has a positive impact when replaced by RE, in this case, utility-scale solar PV.
- The maximum benefit of additional solar PV by only reducing gas. The simulation result shows that in 2030, gas will be reduced by 2.79 TWh. With a 18% capacity factor gas can be replaced by 1663 MWp Solar PV.

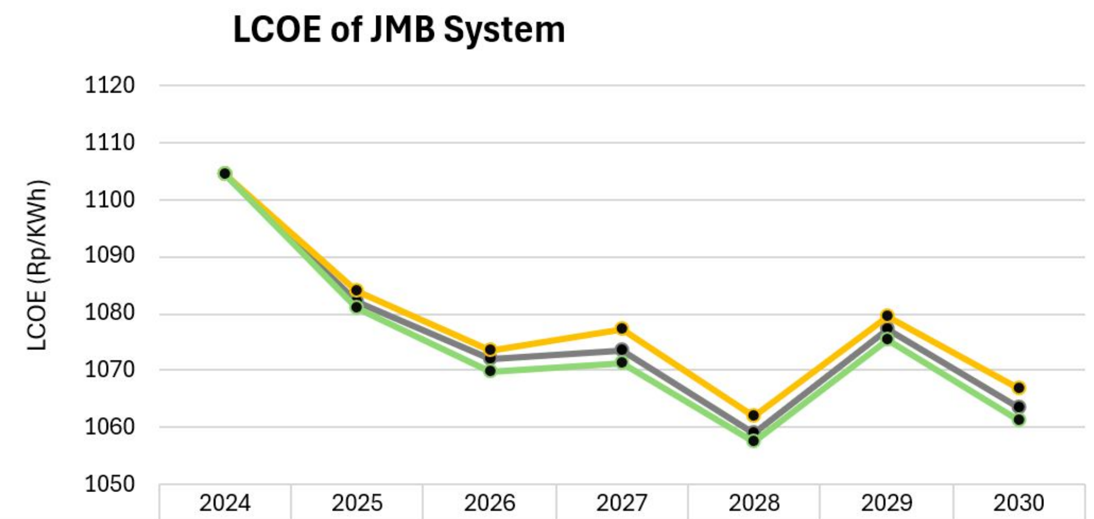


4.2 GRID IMPACT STUDY: CARBON EMISSION



- ❑ The replacement of coal and gas energy with solar PV energy also leads to a decrease in the average emissions value by approximately 0.93 million tons annually.
- ❑ The total reduction in emissions from 2025 to 2030 is 5.6 million tons.

4.2 GRID IMPACT STUDY: JAMALI SYSTEM LCOE



	2024	2025	2026	2027	2028	2029	2030
Base Case	1104.5	1082.3	1071.9	1073.6	1058.8	1077.2	1063.3
Additional PV	1104.5	1083.9	1073.7	1077.2	1062.0	1079.4	1066.8
New Solar PV Capacity (1663 MWp)	1104.5	1081.0	1070.0	1071.4	1057.4	1075.5	1061.3

Rationale behind the graph

- 2027: Addition of a 170 MW geothermal power plant (PLTP) as a baseload generator, causing a slight increase in Levelized Cost of Electricity (LCOE).
- 2028: No significant new power plants added. Rising demand increases the capacity factor (CF) of coal-fired power plants (PLTU), lowering Generation Cost (BPP).
- 2029: Significant new power plants added, including a 400 MW geothermal power plant (PLTP) with high BPP, leading to an increase in LCOE.
- 2030: Addition of 200 MW geothermal power plant (PLTP), but demand growth outpaces the increase, resulting in a similar impact as in 2028.

RESULT

- By adding PV, LCOE **increases by 2.7 Rp/kWh** or the total of 4.3 Trillion Rupiah due to high upfront PV investment costs. Initial costs outweigh energy savings, but **after ten years, PV costs will significantly drop** (Perpres no. 112 year 2022), **which is not reflected in this yearly system**
- To prevent increases in LCOE when integrating new PV capacity, implementing a carbon tax on thermal power plants, particularly coal-fired power plants (CFPPs) or implementing REC for additional PV integrated to incentivize Solar PV are recommended.
- **A carbon tax** on coal-fired power plants leads to potential cost savings of **over 100 billion Rupiah savings**.
- If the solar PV capacity is reduced with **the sole purpose of replacing gas energy with only 1.66 GW** instead of 2.2 GW, the system LCOE will **decrease by an average of 1.7 Rp/kWh**, resulting in a total savings of 2.8 trillion rupiah over 5 years.

*1 USD = 16.000 IDR

4.2 GRID IMPACT STUDY: SENSITIVITY ANALYSIS

Sensitivity analysis scenarios

Sensitivity	Fuel Price		PV Price	
	Regulated Price (DMO)	Market Price	Ceiling Price (6.95 cUSD/kWh)	Lower PV price (5.5 cUSD/kWh)
Scenario 1	✓		✓	
Scenario 2	✓			✓
Scenario 3		✓	✓	
Scenario 4		✓		✓

World Bank Market Outlook, April 2024

	PRICES (in nominal US Dollars)					
COMMODITY	Unit	2021	2022	2023	2024f	2025f
Coal, Australia	$/mt	138.1	344.9	172.8	125.0	110.0
Crude Oil, Brent	$/bbl	70.4	99.8	82.8	84.0	79.0
Natural gas, Europe	$/mmbtu	16.1	40.3	13.1	9.5	10.5
Natural gas, U.S	$/mmbtu	3.9	6.4	2.5	2.4	3.5
Liquefied natural gas, Japan	$/mmbtu	10.8	18.4	14.4	12.5	13.5

RESULT

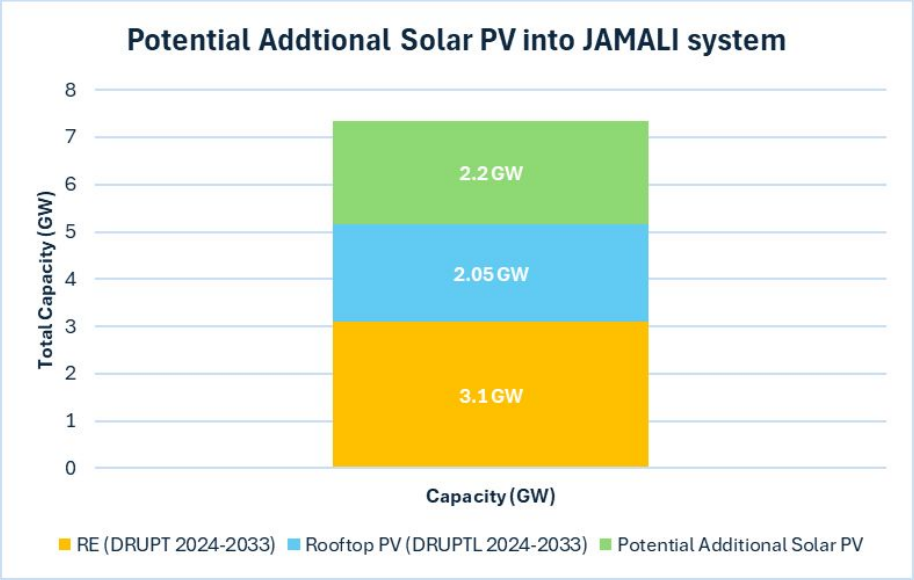
Delta LCOE (Additional PV - Base Case)									
Number	Scenario	Unit	2024	2025	2026	2027	2028	2029	2030
1	DMO + PV (Perpres) Price	Rp/KWh	0.0	1.6	1.8	3.6	3.2	2.2	3.6
2	DMO + PV (Anon. Private Project)	Rp/KWh	0.0	1.2	0.9	2.3	1.6	0.1	0.6
3	Market Coal Price + PV (Perpres) Price	Rp/KWh	0.0	1.1	1.1	2.4	2.5	1.5	2.9
4	Market Coal Price + PV (Anon. Private Project)	Rp/KWh	0.0	0.7	0.2	1.1	0.9	-0.7	-0.1

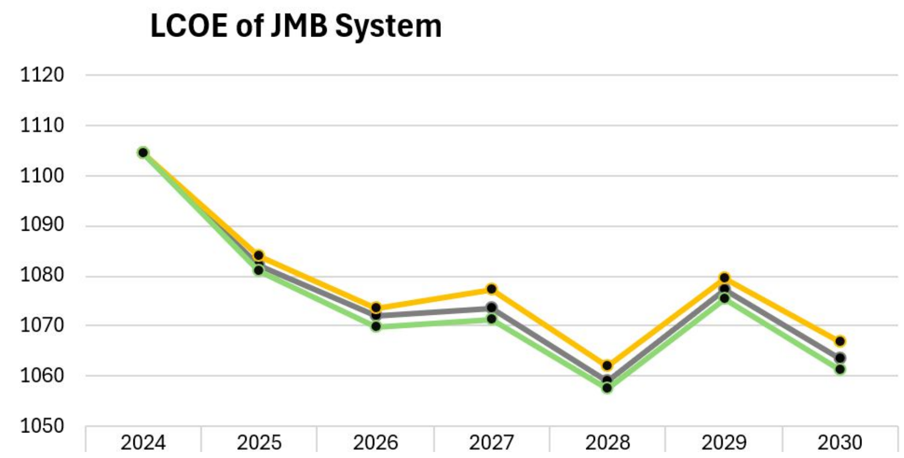
Delta Total Cost (Additional PV - Base Case)										
Number	Scenario	Unit	2024	2025	2026	2027	2028	2029	2030	Total
1	DMO + PV (Perpres) Price	Triliyun Rupiah	0.0	0.4	0.5	0.9	0.9	0.6	1.1	4.3
2	DMO + PV (Anon. Private Project)	Triliyun Rupiah	0.0	0.3	0.2	0.6	0.4	0.0	0.2	1.8
3	Market Coal Price + PV (Perpres) Price	Triliyun Rupiah	0.0	0.3	0.3	0.6	0.7	0.4	0.9	3.1
4	Market Coal Price + PV (Anon. Private Project)	Triliyun Rupiah	0.0	0.2	0.0	0.3	0.2	-0.2	0.0	0.5

- In Scenario 1, where coal prices follow the DMO, and Scenario 3, which uses market coal prices ($40/ton higher), the impact on LCOE varies. Market coal prices in Scenario 3 lead to higher LCOE but allow for greater PV penetration, resulting in more significant cost savings compared to the DMO scenario.
- Lowering PV prices in both DMO and market coal scenarios has a more significant positive effect on reducing delta LCOE and total system costs. The incremental LCOE increase is smaller when lower PV prices are applied, regardless of the coal price scenario.
- In Scenario 4 year 2029-2030, the addition of PV energy generates negative delta values, meaning that LCOE decreases. This is due to PV displacing gas generation, as coal-fired plants are already operating at maximum capacity.

CONCLUSION

1. The JAMALI grid can absorb up to **2.2 GW** of Solar PV by 2030, on top of the **3.1 GW** Renewable Energy Plan in the PLN Electricity Plan 2024-2033 (as of July 2024).
2. **25 sites** have been selected from the Phase 1 site list, the grid assessment for assigned capacity shows that the integration for these 25 sites is within the safe range.
3. In the business-as-usual scenario, an additional **2.2 GW of Solar PV increases the system's LCOE by 2.7 Rp/kWH** due to the replacement of coal, the cheapest option when excluding social and environmental costs and carbon tax.
4. To further balance the cost increases associated with PV integration, implementing a carbon tax could be a strategic option to disincentivize fossil fuels or Carbon Credits or Renewable Energy Certificate to incentivize RE.
5. Optimal integration of **1.66 GW PV** can replace more expensive gas generation, helping **reduce overall system costs by 1.7 Rp/kWH**. However, coal power production will not be replaced with Solar PV.
6. Aligning with the government's coal reduction plan, Solar PV will lower system costs by replacing gas, especially as coal is phased down.





ENERGY TRANSITION PARTNERSHIP

Powering Prosperity and Enabling Sustainability in South East Asia

THANK YOU

Prepared by : Consortium lead by Trama TecnoAmbiental

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ANNEX

4.1 HOSTING CAPACITY ANALYSIS: JAMALI MAXIMUM RE PENETRATION

The table below presents the forecasted VRE capacity in the JAMALI region from 2024 to 2030. It provides three key sections:

JAMALI			2024	2025	2026	2027	2028	2029	2030
PV Maximum Candidate		MW	1325	1636	2354	2983	3878	4913	6340
Candidate	VRE RUPTL	MW	375	800	2090	2680	2820	2960	3100
	PV Utility	MW	264	264	264	303	1058	1953	3240
Maximum Penetration	**VRE Utility Scale - RUPTL**	**MW**	**375**	**800**	**2090**	**2680**	**2820**	**2960**	**3100**
	PV Rooftop	**MW**	**825**	**900**	**910**	**1010**	**1400**	**1500**	**2050**
	PV Utility (Quota for additional PV)	**MW**	**1100**	**1100**	**1100**	**1100**	**1200**	**1900**	**2200**
	VRE Total	**MW**	**2300**	**2800**	**4040**	**4530**	**5420**	**6360**	**7350**

1. **PV Maximum Candidate**
   - The maximum potential PV capacity to be integrated into the grid each year - cumulative

2. Candidate
- VRE RUPTL, which shows the projected VRE capacity based on the National Electricity Plan (DRUPTL) – cumulative
- PV Utility, which reflects the expected utility-scale PV capacity for each year

3. Maximum Penetration:
- VRE Scale Utility shows VRE's utility-scale contribution - cumulative
- PV Rooftop displays the projected capacity of rooftop solar installations - cumulative
- **PV Utility refers to utility-scale PV capacity, which will start at 1100 MW in 2024 and reach 2200 MW by 2030** - cumulative
- The final row, VRE Total, sums the total VRE capacity, starting at 2300 MW in 2024 and rising to 7350 MW by 2030 - cumulative

4.2 GRID IMPACT STUDY : LOAD FLOW ANALYSIS BEFORE CONNECTION

AREA	GI Min	Voltage (kV)	Voltage (pu)	GI Max	Voltage (kV)	Voltage (pu)	IBT	Loading (%)	Line	Loading (%)
AREA 1	1_CIKANDE7	487,2	0,97	1_SURALAYA7	494,6	0,99	1_IBT75_IDMY #1	94,7	1_DKSB - 1_KBJR #4	89,8
	1_TELUK NAGA5	144,9	0,97	1_GIS GANDARIA5	157,3	1,05				
AREA 2	2_CIBINONG1-7	492,0	0,98	2_MATENGGENG/PLTA PS7	501,2	1,00	2_IBT75_CBNG #3	75,7	2_CWBR - 2_SLLM #1	77,5
	2_KIARAPAYUNG5	146,0	0,97	2_CIRATA FPV5	158,2	1,05				
AREA 3	PEDAN-TSKBR 1	497,5	1,00	3_SWITCHING GRINDULU7	507,5	1,02	3_IBT75_PDAN #4	80,6	3_PWDD - 3_KDMB #1	72,6
	3_PUDAKPAYUNG5	144,6	0,96	3_BATANG2/LIMPUNG5	157,0	1,05				
AREA 4	4_GRESIK BARU7	503,6	1,01	4_WATUDODOL/KALIPURO7	518,1	1,04	4_IBT54_DRYO #1	98,3	4_SWHN - 4_UDAN #1	89,9
	4_BULUKANDANG5	146,3	0,98	4_SURABAYA BARAT/KRIAN5	156,1	1,04				
AREA 5	5_ANTOSARI7	517,9	1,04	5_ANTOSARI7	518,1	1,04	5_IBT75_ASRI #1	27,5	5_PBWG - 5_PMRN #1b	66,3
	5_PAYANGAN5	150,6	1,00	5_ANTOSARI5	155,1	1,03				

Before Connection of 2200 MW PV: The system was operating within normal limits, with voltage levels and loadings on transmission lines and transformers all within acceptable ranges. There were no signs of instability or overloading in any part of the grid.

4.2 GRID IMPACT STUDY : LOAD FLOW ANALYSIS AFTER CONNECTION

AREA	GI Min	Voltage (kV)	Voltage (pu)	GI Max	Voltage (kV)	Voltage (pu)	IBT	Loading (%)	Line	Loading (%)
AREA 1	1_CIKANDE7	487,1	0,97	1_SURALAYA7	494,5	0,99	1_IBT75_IDMY #1	93,3	1_DKSB - 1_KBJR #4	91,8
	1_TELUK NAGA5	144,9	0,97	1_GIS GANDARIA5	157,3	1,05				
AREA 2	2_CIBINONG1-7	491,9	0,98	2_MATENGGENG/PLTA PS7	501,0	1,00	2_IBT75_CBNG #3	75,2	2_BKSI - 2_PDKL #1a	90,2
	2_KIARAPAYUNG5	146,0	0,97	2_CIRATA FPV5	158,1	1,05				
AREA 3	PEDAN-TSKBR 1	497,5	1,00	3_SWITCHING GRINDULU7	508,4	1,02	3_IBT75_PDAN #4	78,8	3_PWDD - 3_KDMB #1	89,1
	3_PUDAKPAYUNG5	144,6	0,96	3_PEDAN5	157,2	1,05				
AREA 4	4_GRESIK BARU7	503,6	1,01	4_WATUDODOL/KALIPURO7	517,9	1,04	4_IBT54_DRYO #1	98,2	4_MNRO - 4_DLOP #1	93,3
	4_BULUKANDANG5	146,3	0,98	4_SURABAYA BARAT/KRIAN5	156,2	1,04				
AREA 5	5_ANTOSARI7	517,9	1,04	5_ANTOSARI7	517,9	1,04	5_IBT75_ASRI #1	23,7	5_PBWG - 5_PMRN #1b	58,1
	5_PAYANGAN5	150,6	1,00	5_ANTOSARI5	155,0	1,03				

After the Connection of 2200 MW PV, The integration of 2200 MW of PV caused some changes in the system. Voltage levels remained stable, but a few transmission lines and transformers experienced higher loading. However, these were still within their capacity limits. Overall, the grid remained stable, and the additional PV capacity was successfully integrated without critical issues.

4.2 GRID IMPACT STUDY :
SHORT CIRCUIT ANALYSIS BEFORE CONNECTION

Substation	Nominal Voltage (kV)	Ib (kA)	ikss (kA)	Ik (kA)	Ip(kA)
1_TIGARAKSA5	150	44,2	44,2	44,2	106,3
3_TANJUNG JATIB7	500	41,0	43,2	40,4	112,6
1_RANGKASBITUNG BARU5	150	35,7	35,7	35,7	83,8
4_TUBAN5	150	33,6	34,2	33,5	84,7
4_SITUBONDO5	150	33,0	33,1	33,0	82,9
1_PLTU BANTEN5	150	29,3	30,7	28,9	74,5
3_WELERI5	150	28,8	28,8	28,8	66,0
2_CIAMIS5	150	25,4	25,5	25,4	65,1
3_SLUKE/PLTU REMBANG5	150	22,6	23,9	22,2	59,0
2_KARANGNUNGGAL5	150	21,0	21,2	20,9	53,3
2_MEKARSARI5	150	20,5	20,5	20,5	53,9
3_SEMEN INDONESIA5	150	20,4	20,6	20,3	48,7
4_MLIWANG5	150	18,3	18,3	18,3	41,4
2_PATUHA5	150	16,4	16,8	16,3	40,4
3_PALUR5	150	15,2	15,2	15,2	33,3
5_BATURITI5	150	14,2	14,2	14,2	28,2
3_CEPU5	150	9,1	9,1	9,1	18,9
4_GENTENG5	150	7,6	7,6	7,6	16,5
4_SUMENEP5	150	5,4	5,4	5,4	11,2
2_BABAKAN4	70	5,3	5,3	5,3	10,3
2_HAEURGEULIS5	150	4,6	4,6	4,6	10,9
2_PARAKAN4	70	3,8	3,9	3,7	7,6

Before the Connection of 2200 MW PV, The short-circuit current levels across various substations remained within the safe operational limits, ensuring that protective devices, such as circuit breakers, could handle the fault currents effectively. The system was capable of managing three-phase faults, which represent the worst-case scenario in power systems, without exceeding equipment capacity.

4.2 GRID IMPACT STUDY : SHORT CIRCUIT ANALYSIS AFTER CONNECTION

Substation	Nominal Voltage (kV)	Ib (kA)	ikss (kA)	Ik (kA)	Ip(kA)
1_TIGARAKSA5	150	44,3	44,3	44,3	106,5
3_TANJUNG JATIB7	500	41,3	43,5	40,6	113,4
1_RANGKASBITUNG BARU5	150	35,7	35,7	35,7	83,9
4_TUBAN5	150	33,7	34,3	33,5	84,8
4_SITUBONDO5	150	33,0	33,1	33,0	82,9
1_PLTU BANTEN5	150	29,5	30,8	29,1	74,7
3_WELERI5	150	28,9	28,9	28,9	66,3
2_CIAMIS5	150	25,5	25,6	25,4	65,1
3_SLUKE/PLTU REMBANG5	150	22,7	24,0	22,3	59,2
2_KARANGNUNGGAL5	150	21,0	21,2	21,0	53,3
2_MEKARSARI5	150	20,5	20,7	20,5	49,0
3_SEMEN INDONESIA5	150	20,5	20,5	20,5	53,9
4_MLIWANG5	150	18,3	18,3	18,3	41,4
2_PATUHA5	150	16,4	16,8	16,3	40,4
3_PALUR5	150	15,2	15,2	15,2	33,3
5_BATURITI5	150	14,2	14,2	14,2	28,2
3_CEPU5	150	9,1	9,1	9,1	18,9
4_GENTENG5	150	7,6	7,6	7,6	16,5
4_SUMENEP5	150	5,4	5,4	5,4	11,2
2_BABAKAN4	70	5,3	5,3	5,3	10,3
2_HAEURGEULIS5	150	4,6	4,6	4,6	10,9
2_PARAKAN4	70	3,8	3,9	3,7	7,6

After Connection of 2200 MW PV: Following the integration of 2200 MW PV, the short-circuit current levels increased slightly at some substations but remained within acceptable limits. For instance, the fault current at Tigaraksas5 reached 44.2 kA, indicating that, while the short-circuit levels increased, they were still within the capabilities of the protective equipment.