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Unlocking Indonesia's Renewables Future

The Economic Case of 333 GW of Solar, Wind, and Hydro Projects

Unlocking Indonesia’s Renewables Future:
the Economic Case of 333 GW of Solar, Wind and Hydro Projects

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Foreword

Indonesia stands at a pivotal moment in its energy transition. As the world accelerates its shift away from fossil fuels, renewable energy has emerged as the cornerstone of future energy systems. With its abundant solar, wind, and hydro resources, Indonesia has a unique opportunity to harness clean energy to drive economic growth, enhance energy security, deliver affordable electricity to its citizens, and meet its climate commitments. This study, *Unlocking Indonesia's Renewable Future: The Economic Case for 333 GW of Solar, Wind, and Hydro Power,* provides a comprehensive assessment of the country's renewable energy potential and its economic viability.

Renewable energy is not just an environmental imperative but also an economic opportunity. Over the past decade, solar and wind power costs have plummeted, making them highly competitive against fossil fuels. In many parts of the world, solar and wind are the cheapest electricity sources. The falling costs of energy storage and grid integration technologies further strengthen the case for renewables as a reliable and cost-effective alternative to coal and gas. With proper planning and policy support, Indonesia can accelerate the deployment of renewable energy, reducing its reliance on fossil fuels while ensuring energy affordability and security.

This study evaluates hundreds of potential sites across Indonesia, demonstrating that at least 333 GW of economically viable renewable energy capacity is within reach and ready to be deployed to meet the country's energy transition goal. This vast potential is more than sufficient to meet the country's growing energy demand while supporting its commitment to achieving net-zero emissions by 2050. By capitalizing on its renewable resources, Indonesia can modernize its power system, attract investments, and create new jobs in a low-carbon economy.

However, realizing this potential requires decisive policy action. Strengthening regulatory frameworks, improving grid infrastructure, and fostering investment-friendly policies will be critical in unlocking Indonesia's renewable energy future. A clear roadmap, backed by strong political will, is essential to accelerate deployment at scale and ensure a just and inclusive energy transition.

This publication aims to serve as a guiding resource for policymakers, utilities, investors, and stakeholders in Indonesia's energy sector. By providing data-driven insights into the economic feasibility of renewable energy, we hope to contribute to informed decision-making and a collective push toward a cleaner, more sustainable energy system.

The transition to renewables is not just a necessity—it is an opportunity for Indonesia to build a resilient and prosperous future. The time to act is now.

Jakarta, February 2025

Fabby Tumiwa

Executive Director

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List of Abbreviations

AEP	:	Annual energy production
CapEx	:	Capital expenditure
CFADS	:	Cash Flow Available for Debt Service
CF	:	Capacity factor
CPI	:	Climate Policy Initiative
DFI	:	Development financial institution
DSCR	:	Debt Service Coverage Ratio
DSRA	:	Debt Service Reserve Account
EBITDA	:	Earnings Before Interest, Taxes, Depreciation, and Amortization
EIRR	:	Equity Internal Rate of Return
EPC	:	Engineering-Procurement-Construction
ERA5	:	The European Centre for Medium-Range Weather Forecast (ECMWF) Reanalysis 5th Generation.
FGD	:	Forum Group Discussion
G20	:	Group of Twenty
GFANZ	:	Glasgow Financial Alliance for Net Zero
GW	:	Gigawatt
Ha	:	Hectare
HV	:	High-voltage
IDC	:	Interest during construction
IDR	:	Indonesian Rupiah
IESR	:	Institute for Essential Services Reform
IIF	:	Indonesia Infrastructure Finance
InaRISK BNPB:	:	Indeks Risiko Bencana Indonesia
IPP	:	Independent Power Producer
IUCN	:	International Union for Conservation of Nature
JETP CIPP	:	Just Energy Transition Partnership Comprehensive Investment and Policy Plan
km	:	Kilometer
LCOE	:	Levelized Cost of Energy
MDB	:	Multilateral development banks
MEMR	:	Ministry of Energy and Mineral Resources
MMRA	:	Major Maintenance Reserve Account
N/A	:	Not available
NDC	:	Nationally Determined Contributions
NPV	:	Net Present Value

NREL	:	The National Renewable Energy Laboratory
O&M	:	Operation and Maintenance
OpEx	:	Operational expenditure
OSS	:	One Single Submission
P50	:	50% probability
P90	:	90% probability
PIPPIB	:	Peta Indikatif Penundaan Pemberian Izin Baru
PIRR	:	Project Internal Rate of Return
PLN	:	Perusahaan Listrik Negara (State Electricity Company)
PLTB	:	Pembangkit Listrik Tenaga Bayu (Wind Power Plant)
PLTM	:	Pembangkit Listrik Tenaga Mikrohidro (Micro Hydro Power Plant)
PLTS	:	Pembangkit Listrik Tenaga Surya (Solar PV Power Plant)
PPA	:	Power Purchase Agreement
PR	:	Presidential Regulation
PT SMI	:	PT Sarana Multi Infrastruktur
PV	:	Photovoltaic
PVOUT	:	Photovoltaic power output
RE	:	Renewable Energy
RUPTL	:	Rencana Umum Penyediaan Tenaga Listrik (National Electricity Supply Business Plan)
RTRW	:	Rencana Tata Ruang Wilayah (Regional Spatial Plan)
SHL	:	Shareholder loan
SNDC	:	Second Nationally Determined Contributions
SPV	:	Special Purpose Vehicle
SRTM	:	Shuttle Radar Topography Mission
UNEP-WCMC	:	UN Environment Programme World Conservation Monitoring Centre
UNESCO	:	United Nations Educational, Scientific and Cultural Organization
USD	:	US Dollar
WACC	:	Weighted Average Cost of Capital
WDPA	:	World Database on Protected Areas

Executive Summary

Indonesia has pledged to achieve net zero emissions by 2060 or earlier through the current Enhanced Nationally Determined Contribution (ENDC)–and aims to reduce emissions by 31.89% unconditionally without global support and 43.2% with global support in 2030. However, the unconditional ENDC leaves a gap of approximately 1000 $MtCO_2e$ to align with the 1.5°C Fair Share target (CAT, 2024). Currently, Indonesia's commitment on energy transition is being updated through the Second Nationally Determined Contribution (SNDC), which is expected to increase Indonesia's climate ambition and reduce the emission gap, including ensuring an emission peak in 2030 (IESR, 2024a). Achieving these goals requires a stronger commitment, especially in decarbonizing the power sector. This means that a more ambitious target for the renewable energy share is required, as IESR's study indicates that it must reach 40-45% by 2030 to align with the 1.5°C trajectory (IESR, 2024b). To meet this target, stronger enabling conditions—such as regulatory support, infrastructure development, and financial mechanisms—are essential to accelerate renewable energy deployment in the critical years ahead.

This study aims to identify economically viable renewable energy projects in Indonesia, considering the technical potential (capacity based on natural resources), land availability, and economic viability (equity internal rate of return greater than the weighted average cost of capital). This study emanates from the difficulties in understanding renewable energy potential economically and the policy and implementation uncertainties faced by investors and policymakers.

This study combines geospatial analysis of solar PV, wind, and hydro technical potential in Indonesia with financial modeling for the best available technologies today. It builds upon the previous IESR study published in 2021 under the title Beyond 443 GW: Indonesia's Infinite Renewable Energy Potential, which assessed the technical potential for solar PV, wind, hydro, and biomass energy sources.The criteria for identifying technically feasible sites were improved, and the economic and financial viability of the chosen renewable energy sites were further assessed. Only three types of technology at the utility scale—solar PV power plant (PLTS), wind power plant (PLTB), and mini-hydro power plant (PLTM)—were selected.

The geospatial analysis results show that the technical potential for renewable energy capacity development is 584.5 GW from ground-mounted solar PV, onshore wind, and micro- to mini-hydro power, obtained from over 1,500 suitable site locations. After evaluating those sites using the financial model approach, the findings highlight that powering Indonesia with 333 GW (632 site locations) through renewable energy power plants (utility-scale) is economically viable. The financial simulation results show that the total capacity of economically viable ground-mounted solar PV is 165.9 GW, onshore wind is 167.0 GW, and micro- to mini-hydro is 0.7 GW. A summary of the total technical potential capacity and economical viability for solar PV, wind, and mini-hydropower plants presented in Figure 1-3.

Results from this study emphasize that Indonesia has enough economically viable renewable energy to kickstart the energy transition and meet the ambitious target by 2030 or 2035. Even compared to Indonesia's NDC targets, the 75 GW renewable energy target under the RUPTL, or the 34% of renewable energy share under the Just Energy Transition Partnership Comprehensive Investment and Policy Plan (JETP CIPP), the available renewable energy potential is sufficient to enable a faster and more substantial transition away from fossil fuels. The combination of declining renewable technology costs, massive deployment, more high-yield renewable sites, and increasing demand for clean energy makes renewable energy projects economically attractive, increasing investor interest in participating in the transition agenda. Moreover, the advancements in technology, infrastructure enhancement (e.g., grid expansion, modernization), and supporting policy (e.g., tariffs, permitting process) will significantly influence the number of economically viable renewable energy sites.

Figure 1. Suitable sites and the technical potential of renewable energy in Indonesia

Solar PV Power	Wind Power	Hydro Power
781 potential site locations (highest in: East Nusa Tenggara, South Papua, Maluku, and South Sulawesi)	314 potential site locations (highest in: East Java, Central Java, West Java, and South Sulawesi)	458 potential site locations (highest in: North Sumatera, East Java, and South Sulawesi)
336.5 GW total technical potential of ground-mounted solar PV power	**246.2 GW** total technical potential of onshore wind power	**1.7 GW** total technical potential of micro- to mini-hydro power

Figure 2. Economic viability of renewable energy in Indonesia

Solar PV Power	Wind Power	Hydro Power
290 potential site locations	203 potential site locations	139 potential site locations
(highest in: Papua and East Kalimantan)	(highest in: Maluku, Papua, and South Sulawesi)	(highest in: West Sumatera and North Sumatera)
165.9 GW total capacity of economically viable ground-mounted solar PV power	**167.0 GW** total capacity of economically viable onshore wind power	**0.7 GW** total capacity of economically viable micro- to mini-hydro power

Figure 3. Top 5 sites: the highest returns and highest financially viable potential capacity

Solar PV Power	Wind Power	Hydro Power
Jayapura-Papua 4 (EIRR 37.4%); Jayapura-Papua 9 (EIRR 36.5%); Jayapura-Papua 5 (EIRR 34.6%); Sorong-South West Papua 1 (EIRR 33.9%); Jayapura-Papua 7(EIRR 27.9%)	South West Maluku, Maluku 17 (EIRR 30.9%); Tanimbar Islands, Maluku 27 (EIRR 29.0%); Boven Digoel, South Papua 3 (EIRR 24.9%); Fak Fak, Faur Island Fak Fak-West Papua 1 (EIRR 24.7); Tanimbar Islands, Maluku 49 (EIRR 24.5%);	South Solok 1-West Sumatera (EIRR 10.6%); Central Tapanuli 1-North Sumatera (EIRR 10.6%); North Tapanuli 8-North Sumatera (EIRR 10.5%); Lebong-Bengkulu (EIRR 10.5%); Padang Panjang- West Sumatera (EIRR 10.5%)
Paser-East Kalimantan 17(16,422.5 MWp); Madiun-East Java 63 (6,522.3 MWp); Tuban-East Java 90 (3,283.8 MWp); Jombang-East Java 88 (3,126.9 MWp); Singkawang-West Kalimantan 25 (2,899.2 MWp)	Asmat-South Papua 5 (14,780 MW); Sumba Timur-East Nusa Tenggara 43 (10,664 MW); Boven Digoel-South Papua 3 (7,552 MW); Wajo-South Sulawesi 6 (5,216 MW); Makassar-South Sulawesi 7 (5,096 MW).	Central Tapanuli 2-North Sumatera (9 MW); Pakpak Bharat 2-North Sumatera (9 MW); South Aceh 2-Aceh (9 MW); North Tapanuli 21-North Sumatera (9 MW); Palopo 1-South Sumatera (9 MW)

This study provides understanding on the resource-based potential of renewable energy in Indonesia, its economic viability, and the various factors influencing the deployment of renewable energy in the country for policymakers, private individuals, and practitioners. While this report underscores the abundance of economically viable projects, realizing their full potential will require strong support from both policy frameworks and market mechanisms. Several strong recommendations are intended for policymakers, PLN, and renewable energy developers to unlock the potential of economically viable renewable energy, as presented in the following figure below.

Figure 4. Key recommendations

For Policymakers

Accommodate land use allocation for renewable energy in regional spatial planning	**Streamline land procurement process to reduce investment risk**	**Set region-specific targets on renewable energy utilization**
Integrate renewable land use classification into regional spatial planning (RTRW) and synchronize energy planning with other sector planning documents at the national and regional levels.	1. Enhance Indonesia's One Single Submission (OSS) system to integrate land use permits, environmental approvals, and energy business permits. 2. Expand the current digital database to include renewable energy zoning and land suitability data to improve transparency.	Set specific RE development targets for areas with high economic potential, guided by the national government and implemented locally.

For PLN

Improve transmission planning and expansion to accommodate integration of high-return renewable sites	**"Bundle smaller and nearby with other sites" to large-scale capacity to provide a cost-effective and more efficient RE procurement process**
Prepare a comprehensive expansion plan for the substation and transmission line by considering the proximity to the location of the renewable energy sites that provide high-return.	1. Reformulate existing procurement mechanisms to accommodate bundled renewable energy procurement (bulk procurement). 2. Refine the partnership standards to be more transparent for developers.

For Developers

Prioritize high-return projects	**Optimize project design and financial planning**
Use the study's findings to identify and prioritize projects in regions with the greatest economic viability.	Leverage the data to enhance project designs, ensure cost efficiency, and improve the competitiveness of bids in the marketplace.

1. Introduction

Indonesia has declared to achieve net-zero emissions by 2060 or earlier, which is also elaborated in the Enhanced Nationally Determined Contribution (ENDC), aiming for a 31.89% emission reduction unconditionally without global support and 43.2% with global support in 2030. Currently, Indonesia's commitment to energy transition is being updated through the SNDC (Second Nationally Determined Contribution), with rising expectations that this update will strengthen the country's climate ambition and emission reduction target (IESR, 2024a).

In November 2023, Just Energy Transition Partnership (JETP), an initiative of the Government of Indonesia with the International Partners Group (IPG) comprised of G7 countries, launched Comprehensive Investment and Policy Plan (CIPP) as a follow-up on the previous USD 20 billion financing commitment by IPG and Glasgow Financial Alliance for Net Zero (GFANZ) during JETP launching at G20 Summit in 2022. The JETP agreed on several joint conditional targets, such as achieving peaking power sector emissions by 2030 and accelerating the renewable deployment to reach 34% of the energy mix of all power generation by 2030. The CIPP Investment Focus Area (IFA) highlights the renewable energy (RE) capacity acceleration target, including large-scale solar photovoltaic (PV), wind, geothermal, and hydropower projects.

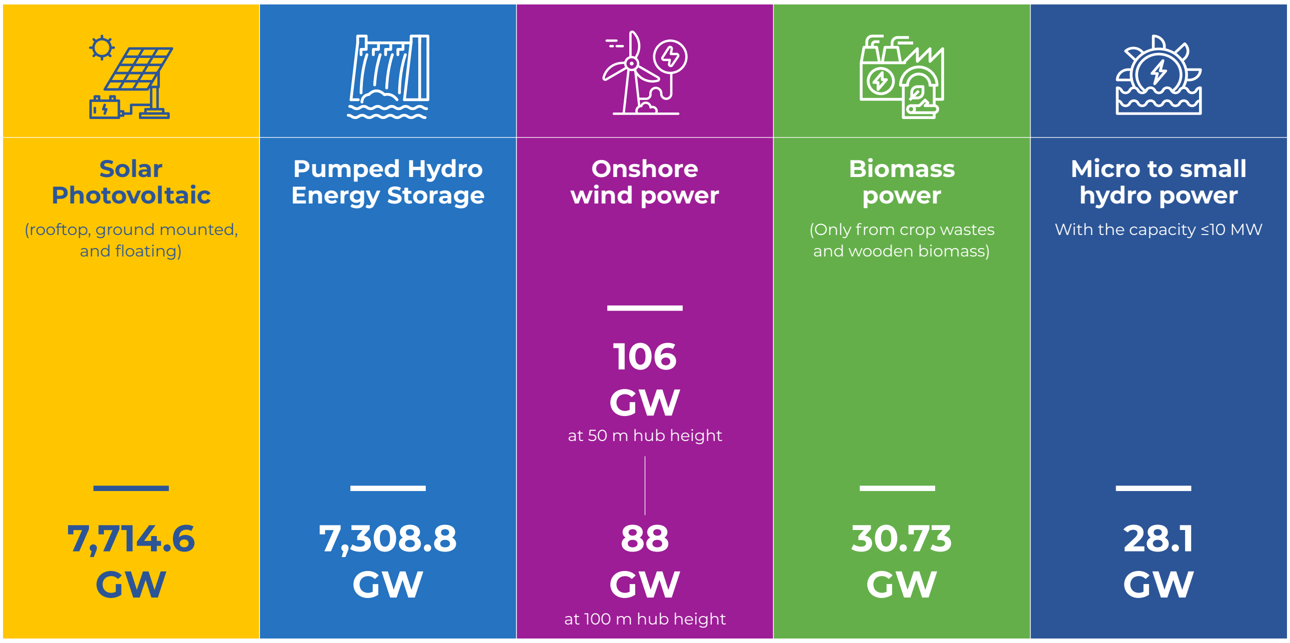


Figure 5. Total technical potential capacity per technology that can be applied in Indonesia if there is no restriction on land use surface
Source: IESR, 2021

Indonesia has a massive amount of RE potential to supply the power demand, up to 7,714.6 GW from solar, wind, and hydropower, if there is no restriction in the surface coverage utilization (IESR, 2021). Despite this vast potential, the actual utilization of these resources remains minimal, as the installed capacity for RE power plants stands at 15.14 GW as of 2024, accounting for only 15% of installed capacity (MEMR, 2025). The renewable installed capacity has only grown by 854.57 MW annually over the past few years, far below the fossil fuel which has increased by 4.58 GW. This slow growth of renewable plants highlights the need for enhanced regulation, infrastructure, and financial mechanisms to increase the deployment of these RE potentials to achieve national targets, as stated in JETP CIPP.

One of the key narratives within the JETP is the bankability of RE projects in Indonesia, which has long been viewed as a high-risk investment due to regulatory uncertainties and a heavy reliance on coal. From 2018, RE investments have significantly lagged behind fossil fuels (IESR, 2023). Among RE sources, hydropower has attracted the largest share of investment from 2019 to 2021, totaling USD 3.48 billion from independent power producers (IPPs) through equity (USD 2 billion) and market-rate loans (USD 1.4 billion), with a significant portion coming from private domestic and international sources (CPI, 2024). Solar PV and wind received smaller investments: USD 0.16 billion in loans and equity for solar and USD 0.07 billion in concession loans for wind (CPI, 2024). Moreover, project-level challenges persist, including opaque land-acquisition and permitting processes, imbalance risk allocation in project contracts, and project financing constraints (Halimatussadiah et al., 2024).

Project financing is important in RE development because the financing structure allows a large group of sponsors to realize projects despite having a small own balance sheet (Steffen, 2018). Project financing means the use of a Special Purpose Vehicle (SPV), which manages the project's assets, liabilities, and risks independently and relies solely on future project cash flows without recourse to the sponsors' other businesses (Steffen, 2018). RE projects often require enormous capital outlay for equipment, construction, and permits in the early stages but provide relatively predictable and stable cash flows once operational. Project financing allows these projects to proceed without placing the entire financial burden on sponsors. Non-recourse financing is particularly effective for large, capital-intensive projects, as it limits the sponsor's risk exposure. Align with this, the most essential starting points to improve project bankability based on important bankability criteria are project specificity and project financial structure (Zhu & Chua, 2018). Therefore, this study uses the project financing structure to indicate the economic viability of RE projects that will support developers in preparing bankable research during the preparation stage of RE development in Indonesia.

Efforts to increase RE investment in Indonesia are often constrained by unsupportive policies and regulatory barriers, as well as weak planning-procurement nexus (Halimatussadiah et al., 2024). Additionally, the lack of comprehensive, reliable data on Indonesia's RE potential—spanning various regions and renewable sources—compounds uncertainty for investors and policymakers. Without this data, it becomes difficult to gauge the overall economically viable potential of RE projects in Indonesia, which may deter investment and limit supportive policy. This study aims to bridge this knowledge gap by mapping economically viable RE projects in Indonesia, considering the technical potential (capacity based on natural resources), land availability, and economic viability (equity internal rate of return greater than the weighted average cost of capital). By providing spatial analysis—to generate location-based data, such as land costs, interconnection requirements, and RE resource potential—and financial analysis that takes into account the project financing structure, the study aims to empower policymakers, investors, and utility actors with a clearer understanding of RE economic viability, further contribute to more supportive policies on RE development and increase RE project development across Indonesia.

2. Methodology and Assumptions

A variety of data analysis methods were used in this study to integrate technical and non-technical dimensions of RE development. The methodology combined geospatial analysis with financial modeling, allowing for a comprehensive assessment of RE site suitability and its economic viability. This study built upon the previous IESR study on RE technical potential, published in 2021, titled Beyond 443 GW: Indonesia's Infinite Renewable Energy Potential, which focused on calculating the technical potential for solar, wind, hydro, and biomass energy sources (IESR, 2021). In this enhanced version, the technical criteria for identifying the technically feasible sites were refined, and formulas to calculate the economic viability of the identified suitable RE sites, focusing on three types of technology on utility scales—solar power plant (PLTS), wind power plant (PLTB), and mini-hydro power plant (PLTM)—were developed. Overall, the flow of analysis is presented in Figure 6 below.

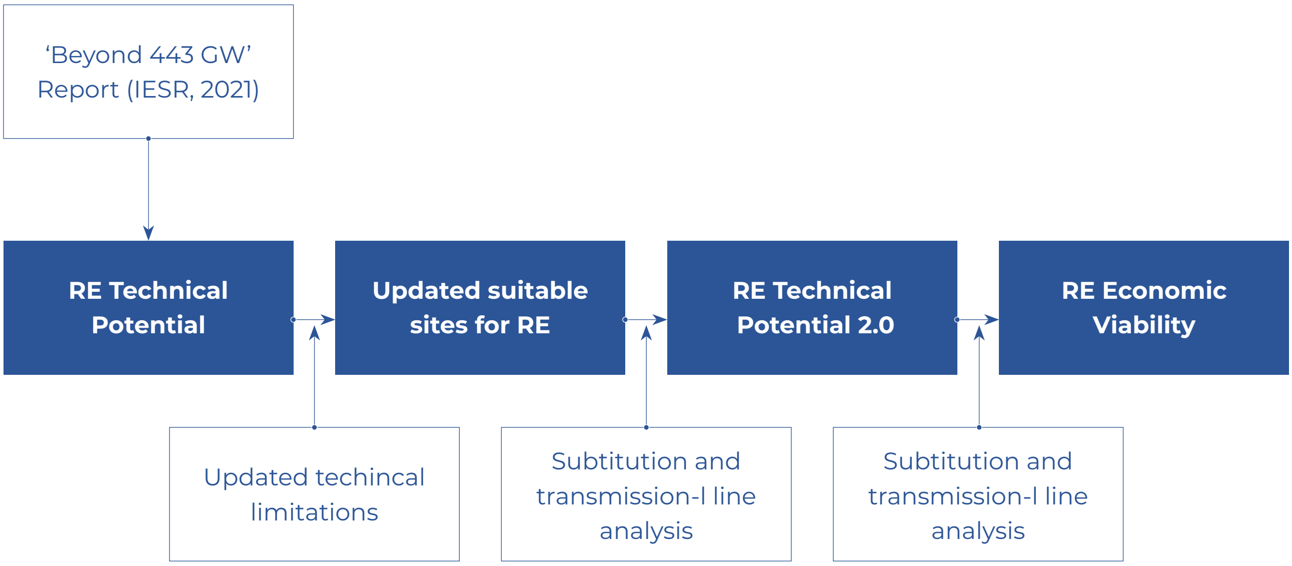


Figure 6. Research flow analysis

The data required for this analysis was collected through secondary data from government documents and websites, as well as primary data from interviews and Focus Group Discussions (FGDs) with private sectors and financiers. Detailed elaboration on data collection and analysis are provided below.

a. Renewable Technical Potential Parameters

This section outlines the technical constraints and parameters used to determine site suitability and estimate capacity and annual energy production for solar, wind, and mini-hydropower projects. Based on IESR (2021), the previous potential location of each RE was chosen by the filtering method, which basically excluded protected areas, water bodies, roads, electricity networks, airports, and other restricted areas. In this study, the criteria for determining RE technical potential were updated with newer data sources and assumptions. All land use constraints were updated with area buffers with various ranges. Rivers were potential locations for mini-hydropower but were excluded for other technologies. Protected areas, lakes, and coastlines were area constraints. Infrastructure such as airports, harbors, railways, roads, and electricity networks were constraints, and added area buffers were considered as an exclusion. The more significant changes to the study were environmental and socially sensitive areas, which were also added as constraint parameters. In addition, hazard conditions, namely areas with potential disaster risks such as volcanic, liquefaction, floods, and droughts, were added as constraints based on the risk of specific technologies. The distance from the potential site locations to the high-voltage (HV) lines was also added as an additional constraint parameter in this study. The criteria specific to each RE technology are elaborated below.

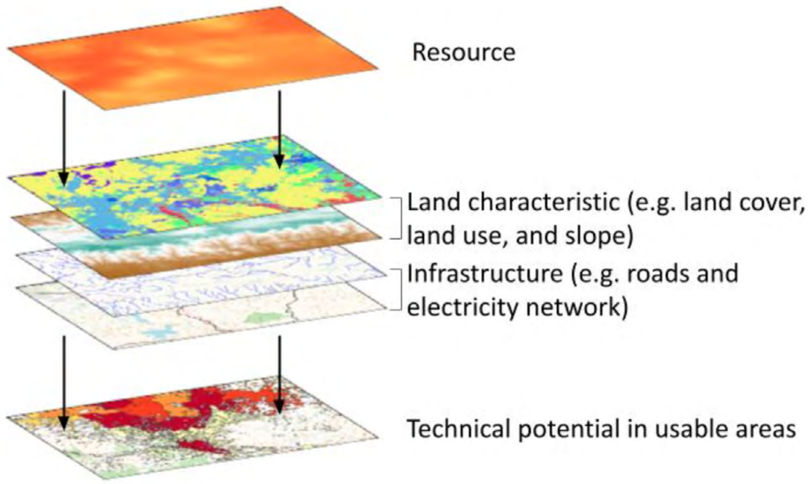


Figure 7. Exclusion method to calculate technical potential in usable areas
Source: Beyond 443 (IESR, 2021)

i. Solar PV Power

Updated Parameters for Potential Site Assessment

In the previous study (IESR, 2021), potential areas for solar PV power included shrubs, savannahs, residential areas, bare lands, minings, transmigration areas, and dams. However, in this study, potential sites analysis focused only on ground-mounted solar PV power—not considering rooftop and floating solar PV. Therefore, some parameters were updated and adjusted to obtain potential sites for ground-mounted solar power. Spatial parameters, including updated ones, to assess potential site locations for solar power are presented in Table 1.

Table 1. Spatial parameters to define suitable sites for solar power

No	Criteria	Constraint/ Parameter	Source	Resolution	Years
1	Settlements area	Yes	Copernicus: Global Human Settlement Layer	100 m	2023
2	Topography	Slope < 15°	SRTM Digital Elevation Data Version 4	90 m	2000
3	Airport	Yes	*Direktorat Jenderal Perhubungan Udara*	N/A	2024
4A	Hazard restriction	Volcanic (Zones 2 and 3)	*Pusat Vulkanologi dan Mitigasi Bencana Geologi* MEMR	N/A	Various years
4B		Liquefaction (High risk)	MEMR	N/A	2019
5	Land use	The moratorium on new permits for primary forests and peatlands	PIPPIB 2023 Period I	N/A	2023
		National park/ protected area/conservation area	UNEP-WCMC and IUCN: Protected Areas (WDPA)	N/A	2022
		Protected flora/fauna area	IUCN: Key Biodiversity Area (keybiodiversityareas.org)	N/A	2016
6	Environmental and social	Cultural sensitive area / World Heritage	UNESCO	N/A	-
7	River	200 m buffers	Rupabumi Indonesia	125 m	2019
8	Lake	200 m buffers	Rupabumi Indonesia	125 m	2019

No	Criteria	Constraint/ Parameter	Source	Resolution	Years
9	Harbour	Yes	*Direktorat Kepelabuhan* (MoT)	N/A	2024
10	HV Line	50 m buffers	RUPTL 2021-2030	N/A	-
11	Railway	50 m buffers	Humanitarian OpenStreetMap Team	N/A	2024
12	Roads	50 m buffers	*Bina Marga* (National & Province Road)	N/A	2019
13	Coastline	200 m buffers	*Badan Informasi Geospasial* (BIG)	25 m	2021

Besides the constraints above, several additional parameters were prepared to obtain technically feasible potential sites for solar PV power development, including:

1. A buffer area of a 10 km radius from the substation and HV lines up to 150 kV (not considering capacity hosting).
2. The location had a minimum potential of 4.5 kWh/m^2/day solar irradiance.
3. Coverage areas below 10 ha were excluded from the potential list due to capacity limitations.

Potential Capacity and Annual Energy Production

Solar PV power capacity was determined based on the potential site areas obtained from geospatial analysis. Based on the best practices approach in solar PV power development (ground-mounted system), a single-hectare area could be used to develop 1 MWp solar power (1 MWp/ha). Meanwhile, the annual energy production (AEP) for solar power was estimated based on equation (1) below.

$$AEP = CF \times Availability \times Solar\ PV\ Power\ Capacity \quad (1)$$

The capacity factor (CF) was estimated by dividing the photovoltaic power output (PVOUT) value by 24 hours. The PVOUT value was derived from the Global Solar Atlas using GIS software in accordance with the potential site coordinate. This approach ensures that the energy yield estimation can reflect the RE resources of each potential site location. In this study, the estimated annual energy production was assumed to be equal to the P50 energy output. Meanwhile, the P90 was estimated to be 90% of the P50 energy output.

ii. Wind Power

Updated Parameters for Potential Site Assessment

Several parameters was updated from previous studies for wind power (IESR, 2021). Parameter changes in spatial analysis to determine potential site locations were carried out by considering the best practices of current wind power development. Thus, the results of the analysis would provide an overview of potential site locations that are economically feasible for wind power development. Spatial parameters, including updated ones, to assess potential site locations for wind power are presented in Table 2.

Table 2. Spatial parameters to define suitable sites for wind power

No	Criteria	Constraint/ Parameter	Source	Resolution	Years
1	Settlements area	500 m buffers	Copernicus: Global Human Settlement Layer	100 m	2023
2	Topography	Slope < 15°	SRTM Digital Elevation Data Version 4	90 m	2000
3	Airport	15 km	*Direktorat Jenderal Perhubungan Udara*	N/A	2024
4	Hazard restriction	Volcanic (Zones 2 and 3)	Pusat Vulkanologi dan Mitigasi Bencana Geologi MEMR	N/A	Various Years
		Extreme wind speed	InaRISK BNPB	N/A	-
5	Land use	The moratorium on new permits for primary forests and peatlands	PIPPIB 2023 Period I	N/A	2023
		National park/ protected area/conservation area	UNEP-WCMC and IUCN: Protected Areas (WDPA)	N/A	2022
		Protected flora/fauna area	IUCN: Key Biodiversity Area (keybiodiversityareas.org)	N/A	2016
6	Environmental and social	Cultural sensitive area / World Heritage	UNESCO	N/A	-
7	River	200 m buffers	Rupabumi Indonesia	125 m	2019
8	Lake	200 m buffers	Rupabumi Indonesia	125 m	2019
9	Harbour	100 m buffers	Direktorat Kepelabuhan (MoT)	N/A	2024
10	HV Line	300 m buffers	RUPTL	N/A	-
11	Railway	300 m buffers	Humanitarian OpenStreetMap Team	N/A	2024
12	Roads	300 m buffers	Bina Marga (National & Province Road)	N/A	2019

In addition to the constraints from the table, more filtering was carried out for wind potential site locations assessment, including:

1. Potential site locations should have the potential for a minimum wind speed of 5.5 m/s at 100 masl.
2. Sites within a 40 km radius from the substation were considered to be more feasible.
3. These selected sites were then clustered in an aggregate orthogonal method to obtain potential areas that are adjacent with no more than 10 km away from each other. Grids were made on this potential area according to wind turbine specifications of 4 MW.
4. Coverage areas below 10 ha were excluded from the potential list due to capacity limitations.

Potential Capacity and Annual Energy Production

Wind power capacity was determined based on the number of wind turbine units implemented at each potential site location. The units were determined using a spatial approach, which is a grid with a dimension of 450x750 m[1] clipped at the potential site locations. This grid represented one wind turbine unit with

[1] According to the SNI 9120:2022, the micro sitting of the wind turbine units is designed with a minimum space of 3D in one row and 5D in one column, where D is the rotor diameter. Based on general data provided by thewindpower.net, a 4 MW wind turbine has a rotor diameter of 150 meters.

a capacity of 4 MW. Meanwhile, the annual energy production for wind power was estimated based on equation (1) by replacing the solar PV power capacity with the wind power capacity. Utilizing this grid-clipping methodology resulted in a generalization of calculated potential installed capacity and, therefore, had drawbacks in terms of accuracy. For example, sites with scattered and small areas, such as in Figure 8, have the potential to overestimate the number of grids. As such, ideally, each site would need micro-sitting to improve the accuracy while optimizing the energy yield.

Figure 8. Assumed grid of potential site illustration

The CF refers to the Global Wind Atlas for IEC Class III (low wind speed). By using GIS software, CF data from the Global Wind Atlas was extracted to obtain specific data for each potential site location. Therefore, the energy yield estimation that is generated from wind power can reflect the RE resources of each potential site location. In this study, the estimated annual energy production was assumed to be equal to the P50 energy output, while the P90 was estimated to be 90% of the P50 energy output.

iii. Mini-Hydropower

Updated Parameters for Potential Site Assessment

Site assessment for mini-hydropower focused on land cover, landforms, natural conditions, and hazard restriction. A buffer area with a radius of 20 km from the substation and transmission lines was included in the constraint parameters to determine potential site locations for mini-hydro power. Spatial parameters, including updated ones, to assess potential site locations for mini-hydropower are presented in Table 3.

Table 3. Spatial parameters to define suitable sites for mini-hydro power

No.	Criteria	Constraint/Parameter	Sources	Resolution	Years
1	Protected Area	National park/rotected area/conservation area	UNEP-WCMC and IUCN: Protected Areas (WDPA)	N/A	2022
2	Hazard restriction	Flood Hazard	InaRISK BNPB	100 m	Oct 2021
3		Drought Hazard	InaRISK BNPB	100 m	Oct 2021
4	Landform	Slope ≥ 2.5 m and at least on 500 masl	SRTM Digital Elevation Data Version 4	90 m	2000
5	Run-off water	Runoff at least 200 m per month per 1 m2 of map grid (or following the design boundaries)	ERA5 reanalysis	250 m	2019

Potential Capacity and Annual Energy Production

Ideally, the capacity of mini-hydropower is determined based on the head and annual water flow of the river (for example, by using flow duration curve (FDC) specific to the potential site location, including selecting the type of turbine technology to be used). However, because of the limitation of this study, the capacity of mini-hydropower was determined based on equation (2) below (IESR, 2021):

$$Cap_{mhp} = \eta \cdot \rho \cdot g \cdot h \cdot Q \qquad (2)$$

Cap_{mhp} is the potential capacity of mini-hydropower plants in kW, η is power plant efficiency that is assumed to be 75%, ρ is water density in kg/m^3, h is the head between inlet and outlet which is assumed to be 2.5 m, and Q is surface run-off water that is obtained from Copernicus.

The annual energy production for mini-hydropower was estimated through equation (1) by replacing the solar PV power capacity with the mini-hydropower capacity. The CF was assumed to be 50%, which is a typical CF for mini-hydropower in Indonesia (DJK, 2024). The estimated annual energy production was assumed to be equal to the P50 energy output, while the P90 was estimated to be 90% of the P50 energy output.

b. Financial Model Simulation

The suitable sites for RE were then evaluated using financial structure. Inputs such as electricity price, rated capacity, location factors, and costs (interconnection, land, logistics) influenced production and cash flow, with fiscal regimes affecting revenue and tax costs. These factors generated the cash stream (revenue, operating costs, capital costs, taxes), which fed into an economic evaluation. Financial valuation indicators like Economic Internal Rate of Return (EIRR), Net Present Value (NPV), Project Internal Rate of Return (PIRR), profitability, and payback were calculated, and the evaluation was completed with financial modeling, including debt, equity, and financing fees.

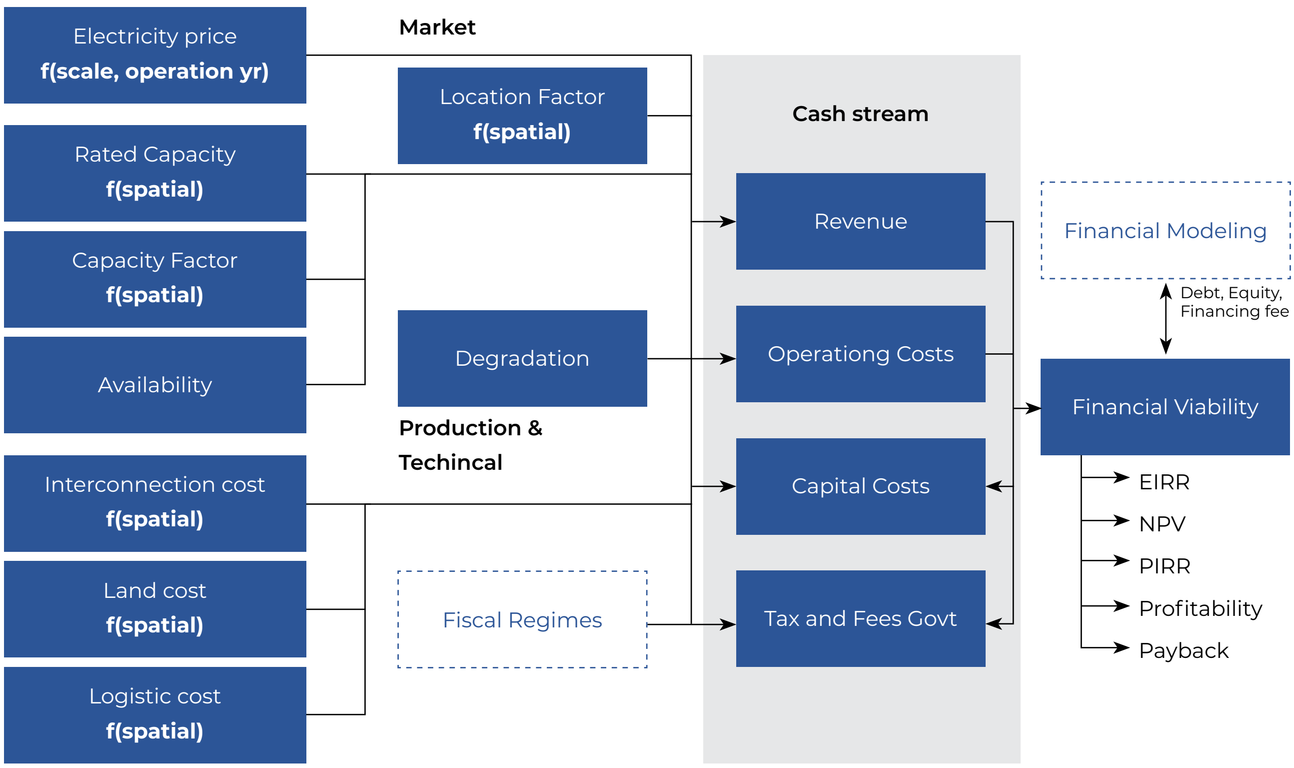


Figure 9. Translating technical (spatial) parameters into financial viability parameters

i. Project Financing

The project financing structure forms the basis for developing the financial modeling used in this study. This non-recourse project financing structure brings key principles, including:

1. The lender will rely on the assets owned by the Special Purpose Vehicle (SPV) as collateral with work in progress and isolate the project's assets and liabilities, thereby protecting the sponsor's balance sheets;
2. Cash flow-based repayment, where the debt is repaid solely from the project's future cash flows;
3. All risks are transferred from the Project Company to the responsible parties;
4. Lenders typically have higher standards for insurance requirements, contracts with Engineering-Procurement-Construction (EPC) and Operation and Maintenance (O&M), and due diligence requirements, which include extensive technical, legal, and financial assessments to mitigate risks prior to financing.

Lenders, sponsors (SPV shareholders, such as IPP and PLN subsidiaries in Gencos), EPC contractors, suppliers, O&M providers, off-takers, third-party due diligence consultants, government entities, landowners, insurers, and brokers/reinsurers are among the many stakeholders involved in project financing, with the SPV serving as the project's focal point.

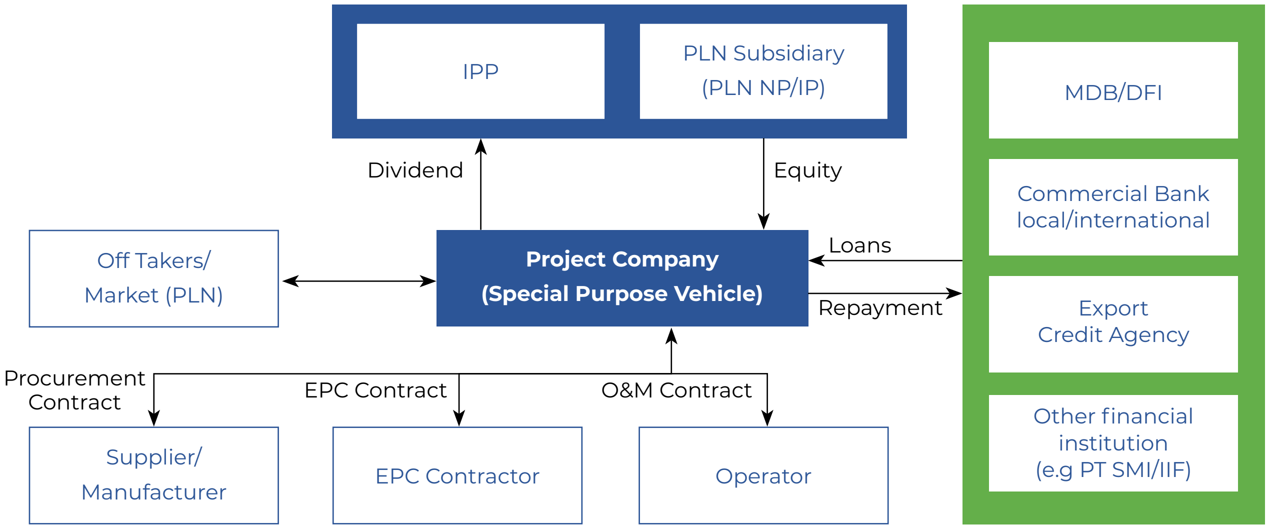


Figure 10. Non/limited-recourse project financing

ii. Project Structure

This study simulated a mandatory or voluntary partnership between IPPs and PLN subsidiaries that serve as gencos (such as PLN Nusantara Power or Indonesia Power). In this arrangement, the PLN subsidiary was simulated to hold a minority share of 30% (typically ranging between 10-30% depending on the subsidiary's investment appetite). The share of ownership between IPP and PLN was represented in equity, and due to the simulation of pro-rata/balance risk, the share in each equity form (shareholder loan and equity subscription) would be the same as the ownership share. Total equity was divided into two forms: equity subscriptions and shareholder loans. Equity subscriptions comprised 10% of the total equity (typically ranging between 10-20%), while the remaining 90% came from shareholder loans. Typically, the proportions of equity subscriptions and shareholder loans were arranged to optimize tax obligations.

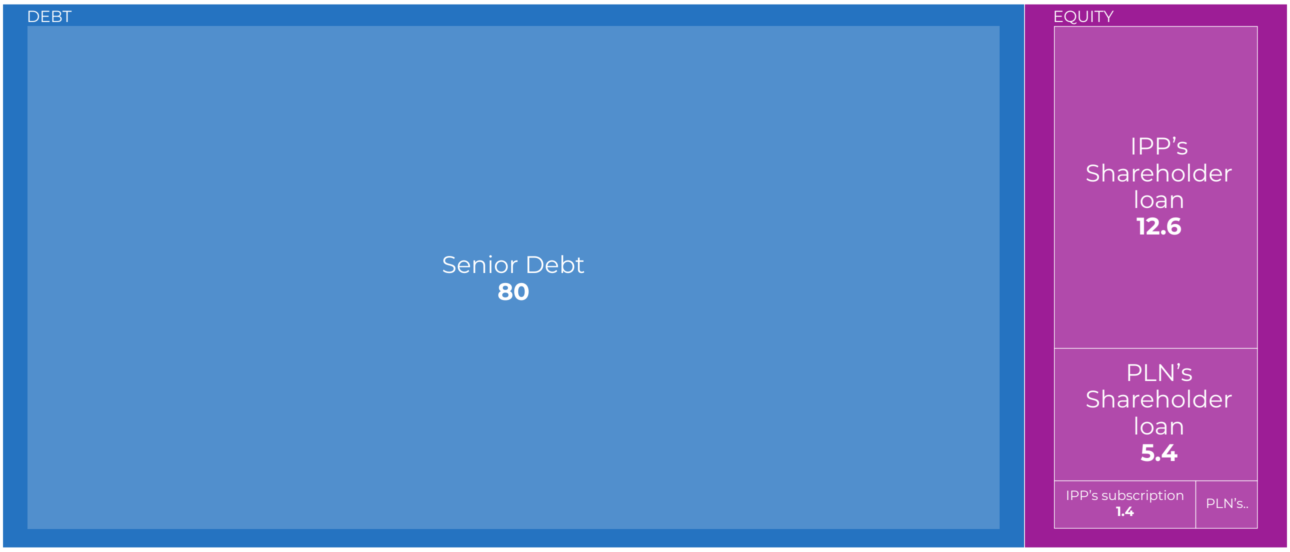


Figure 11. Share of debt and equity used in this study

Following the Ministry of Finance Regulation Number 169/PMK.010/2015 Article 2 Paragraph (1), the maximum debt-to-equity ratio was set at 4:1, or 80% debt. The financial structure included senior/junior debt, seniority over shareholder loans and equity. The interest rate for senior debt was calculated based on the Secured Overnight Financing Rate (SOFR) plus an additional lender margin, i.e., concessional loans, such as those provided through JETP financing or other blended finance sources. A concessional or 'soft' loan is a type of financing offered at below-market interest rates, resulting in lower margins compared to standard commercial loans. These senior debt facilities, which are bound by strict payment requirements and penalties for non-compliance, generally cover 50-80% of the total project cost depending on targeting the WACC and factoring in a targeted Debt Service Coverage Ratio (DSCR) to maintain financial stability while ensuring compliance with PMK 169/2015.

It should be noted that based on this research's discussions and interviews, there were different scenarios compared to the assumptions made in this study. For example, the ideal conditions of pro-rated/balanced risk are not realized because one party's appetite is not in line with equity capabilities. The condition becomes unbalanced in terms of risk and the share of the total amount of funds required due the partner needing to cover that lack of equity capacity (in shareholder loan/ SHL form). This condition implies that the party covered by others will have a higher EIRR than the total EIRR due to lower risk, while the party covered by the fund will have an EIRR lower than the total with higher risk. Additionally, the partner will be responsible for paying the higher financial fee if the SHL rate is set lower than the bank rate. It is important to recognize this unhealthy state and take action to improve the investment climate.

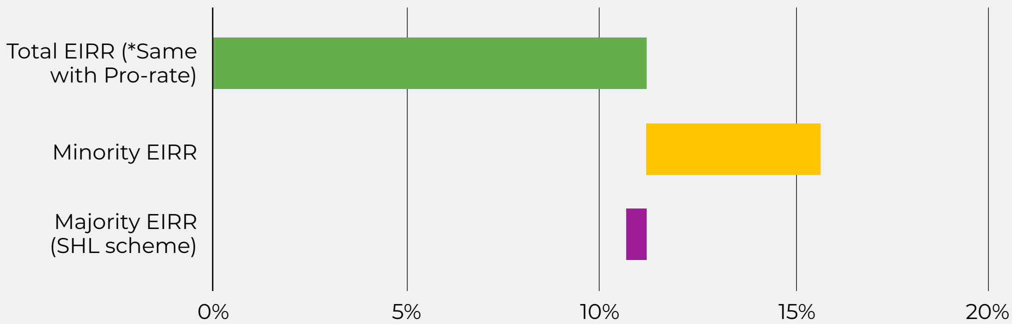


Figure 12. Imbalance risk practice illustration

Source: IESR, 2024

iii. Financial Model

The total capital expenditure (CapEx) was divided into Hard CapEx, additional financing fees such as interest during construction (IDCs), upfront fees, due diligence costs, and reserves like Debt Service Reserve Account (DSRA)/Major Maintenance Reserve Account (MMRA) and bonds. The funding sources were split between equity and debt, where the equity portion was further broken down into subscriptions from PLN and IPP and SHL from both parties. Most projects were typically financed through senior or + junior debt, highlighting its reliance on leveraged financing.

Several financial indicators influenced project performance and debt sizing, including revenue, CapEx, operational expenditure (OpEx), targeted DSCR, financing parameters assumption, and WACC. These factors were locked in the model to calculate debt sizing and evaluate project performance metrics such as EIRR, PIRR, NPV, payback period, and the profitability index. While multiple indicators evaluated economic viability, EIRR was used as the main indicator, as it considered only the return and those cash flows relevant to an equity holder in a project–suitable for an RE project. The graph below summarizes the financial flows in this study, which were run by iterative flows due to many interdependent parameters in terms of total debt, financing fees, and cash flow. This financial model was run using Microsoft Excel with a VBA macro to handle the iterative calculations.

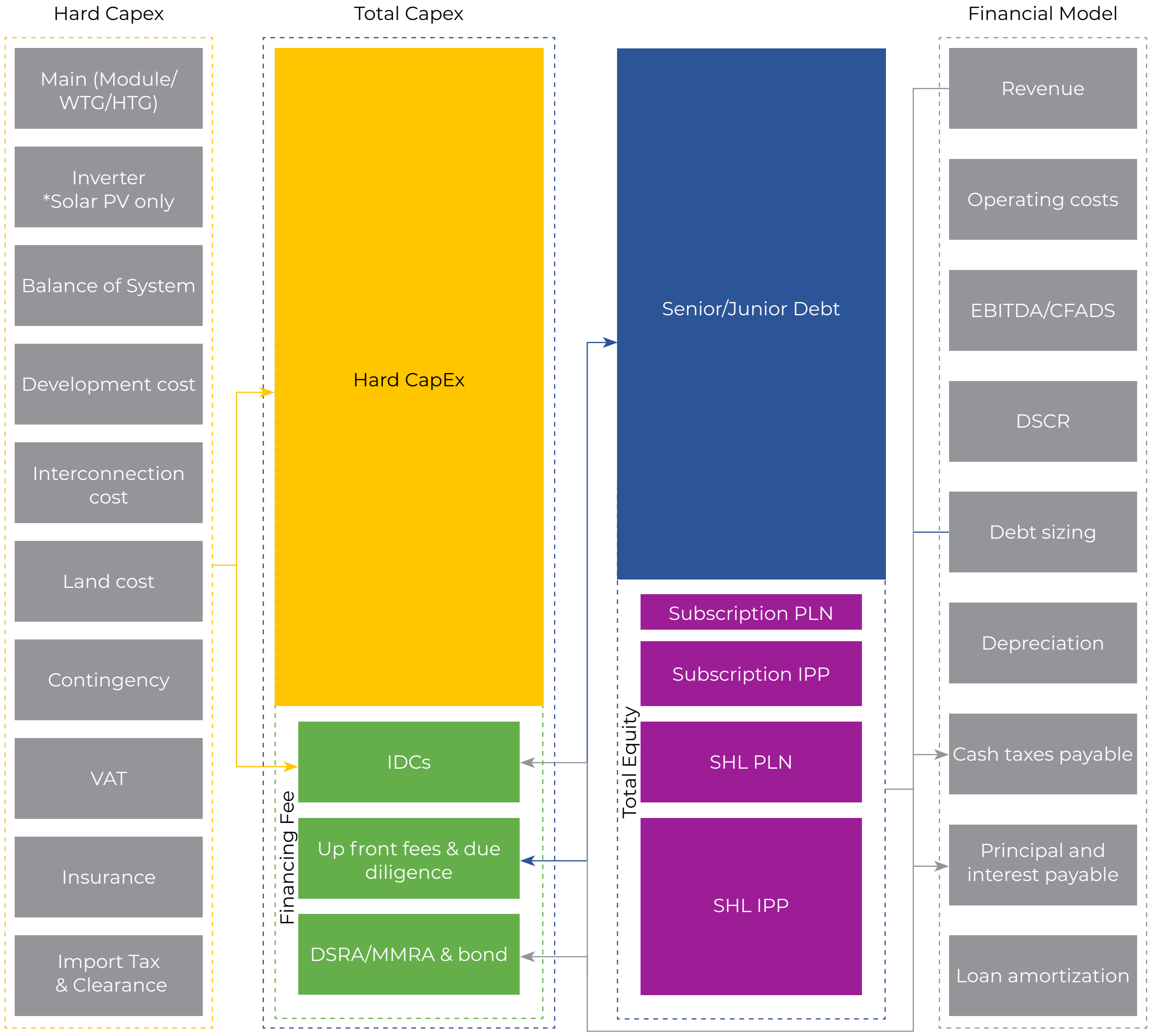


Figure 13. Financial model used in this study

iv. Financial Assumptions

There were more than 20 parameters used in this study, including type of financing, corporate tax rate, WACC, depreciation method, construction duration, Power Purchase Agreement (PPA) term, PPA model, escalation, withholding tax (WHT) on revenue, repayment methods, debt tenor, interest during construction, SHL rate, big bond/letter of credit (LC) rate, performance bond/LC rate, DSCR, max debt, financing cost, DSRA, and exchange rate. The assumptions for all these parameters were collected from the desk studies and then validated by financial experts and business entities on RE development. The parameters of construction duration, debt tenor, and DSCR were assumed specifically in accordance with each RE technology project. As for due diligence costs, the assumption was based on IESR's previous research on pre-feasibility study.

In addition, this study also provided IDC costs as a financial parameter. The IDC cost was another expense included in the financing fees category. The IDC cost was determined by the total Hard CaPex, construction period, and disbursement distribution at the same rate as the all-in rate (SOFR + margin). The disbursement model in this model was set up to distribute 30% in the first month, 30% in the fifth month, and 40% in the twelfth month for all technologies. Financial parameter assumptions are presented in Appendix A, and due diligence cost assumption is provided in Appendix B.

In typical project financing, less disbursement from debt during the early stages of construction is preferable to reduce the IDC. However, this implies that EPC partners and suppliers must be willing to defer payments closer to the end of the construction period to optimize IDC. On the other hand, if the project is delayed in reaching the commercial operation date (COD), the IDC will continue to accumulate, which leads to increased CapEx.

v. Revenue Structure

The revenue calculation was based on the energy yield estimation or AEP and follows the ceiling price in Perpres 112/2022 for the PPA pricing as the basis (see Appendix C). It was assumed that all electricity produced would be absorbed and paid, following a Take-or-Pay (ToP) contractual mechanism, with no curtailment or adjustments to the predicted capacity matrix.

Although the prevailing ceiling price for RE PPA is set by Perpres 112/2022, which replaced Permen ESDM 4/2020, the off-taker (PLN) frequently applied the Permen ESDM 4/2020 pricing rules, which cap the price to 85% of the electricity generation cost of PLN (BPP). This usually happens when the ceiling price exceeds the PPA treatment under Permen 4/2020, known as "pseudo ceiling price", especially for solar PV and wind power projects.

However, in real project implementation, applying this revenue structure may potentially provide a price that is below the Perpres 112/2022 ceiling price. The resulting revenue and profitability parameters from this research provide valuable insights. The results should not be translated as sites with maximized project returns but instead indicate the affordability of the final PPA price agreed upon between the seller (developer) and the buyer (off-taker) for each specific site. Additionally, these parameters can serve as the basis for calculating the total potential project that is financially feasible under the current ceiling price of Perpres 112/2022.

vi. CapEx and OpEx Assumptions

CapEx for solar, wind, and mini-hydropower development was divided into 10 components, consisting of main equipment cost, balance of system (BoS) cost, development cost, land cost, interconnection cost, administration, import tax and clearance, insurance, contingency, and value-added tax (VAT). The main equipment and BoS costs were structured specifically for solar, wind, and mini-hydropower development. Data on main equipment and BoS cost were obtained from several references and audiences with relevant stakeholders to provide the latest updates. Land and interconnection costs were obtained using the spatial function approach. Meanwhile, the development cost, administration, import tax and clearance, and insurance were determined based on the financial best practices for renewable power plant development in Indonesia, referring to experts in the field of financial modeling. Contingency and VAT were assumed to be 3% and 11%, respectively, as a common practice for RE development in Indonesia. Detailed CapEx for solar PV, wind, and mini-hydropower are presented in Appendix D.

Meanwhile, the OpEx was determined based on the general approach for RE operations. In this study, OpEx for solar PV, wind, and mini-hydropower was assumed to be the same, with contingency and VAT values of 3% and 11%, respectively, as for CapEx. Detailed OpEx estimations for solar PV, wind, and mini-hydropower are presented in Appendix E.

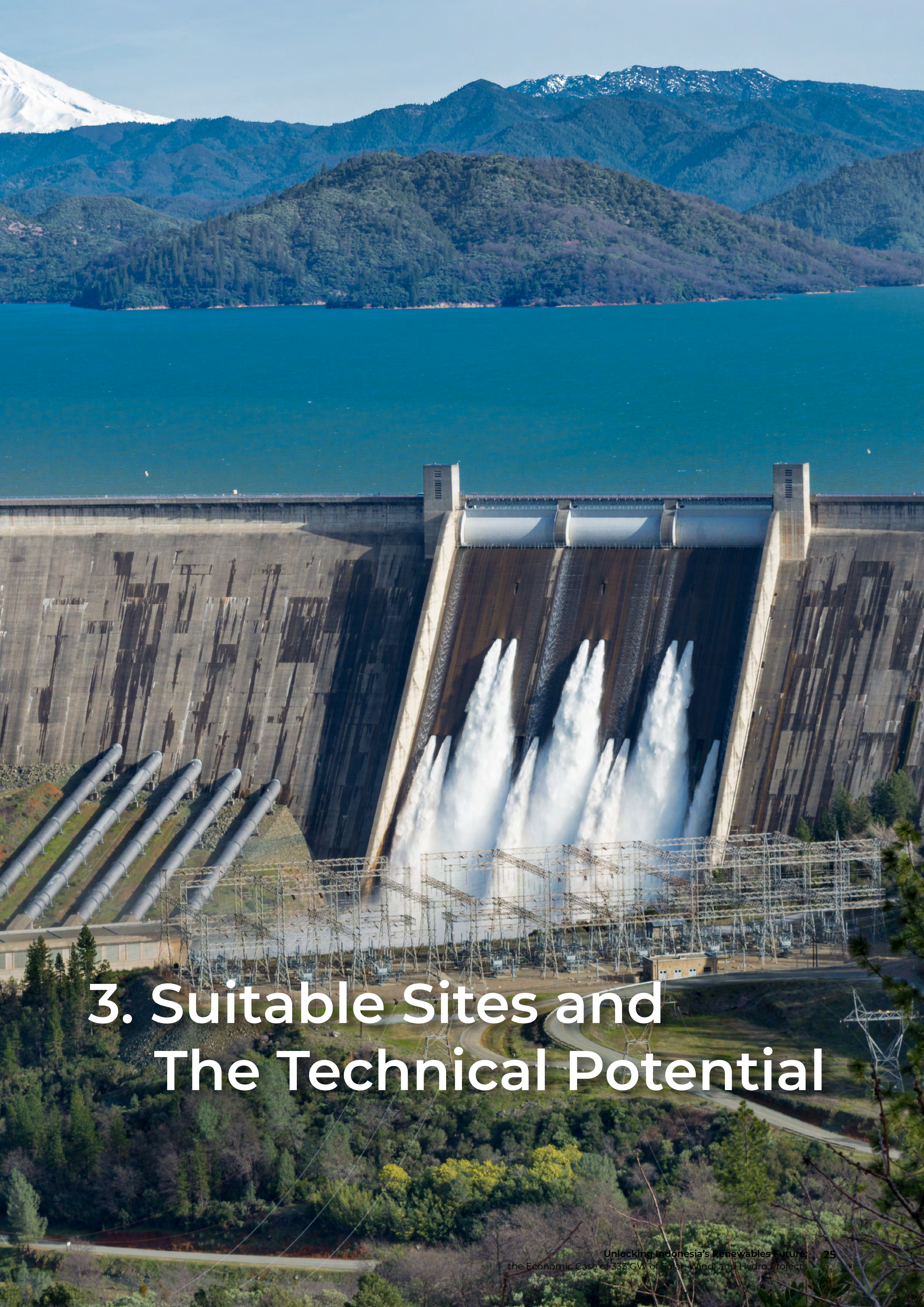
vii. Land and Interconnection Cost Assumption

As stated in the CapEx Assumptions subchapter, the land and interconnection costs were determined through the spatial function approach. Cost determination with this approach was conducted by multiplying the area from the results of geospatial analysis (to determine potential site locations for solar, wind, and mini-hydropower) by the land price per square meter referring to the BHUMI.atrbpn application database belonging to the Ministry of Agrarian Affairs and Spatial Planning. There were several additional assumptions used to determine the cost, especially for interconnection cost, including:

- High-voltage transmission lines on land range from USD 400,000 to 800,000 per kilometer, which stems from global averages, with specific costs varying based on local factors such as geography, labor, materials, and regulatory requirements.
- HV interconnection cost is USD 400,000/km or IDR 6.400.000.000/km (with a conversion rate of USD 1 equals IDR 16,000), and MV interconnection cost is IDR 500.000.000/km.
- Land cost for interconnection works is 3.5 % of the total price (interconnection includes land acquisition for the interconnection tower), which was also added.

viii. Insurance Assumptions

This study emphasized the incorporation of detailed insurance into the CapEx and OpEx structures to improve the confidence of developers and financial institutions by mitigating the risk associated with RE projects and operations. Otherwise, in this assumption, a single number with a low reinsurance premium rate for all of the technology (wind, solar, or mini-hydro) was used. The numbers (assumptions) are provided in Appendix F.



3. Suitable Sites and The Technical Potential

Based on the results of geospatial analysis with updated constraint parameters, **341** potential site locations for wind power, **781** site locations for solar power, and **458** site locations for mini-hydropower are identified. The total capacity that can be installed at all these site locations is around **584.53 GW**. The potential site locations are distributed in all provinces of Indonesia, as shown in Table 14. Provinces with the highest wind potential are East Nusa Tenggara, South Papua, Maluku, and South Sulawesi. For solar power, those with the highest technical potential are found in East, Central, and West Java and also South Sulawesi. As for mini-hydro power, provinces with the highest potential are located in North Sumatera, East Java, and South Sulawesi.

Table 4. Refiltered technical potential capacity

Criteria	Technical Potential Capacity (MW)		
	Solar Utility Scale	Wind Utility Scale	Mini-hydro Utility Scale
Aceh	7,740.53	2,152.00	50.58
Bali	740.76	20.00	82.54
Banten	3,926.53	980.00	5.97
Bengkulu	1,425.62	12.00	27.72
Yogyakarta	4,293.93	700.00	0
DKI Jakarta	0	0	0
Gorontalo	3,755.37	1,892.00	13.61
Jambi	3,298.15	120.00	0
West Java	22,308.14	6,184.00	119.85
Central Java	38,794.01	8,320.00	40.44
East Java	93,510.29	7,256.00	260.32
West Kalimantan	10,093.06	2,116.00	0
South Kalimantan	10,611.28	604.00	0
Central Kalimantan	15,721.80	540.00	0
East Kalimantan	26,676.75	12.00	0
North Kalimantan	2,061.05	464.00	0
Bangka Belitung Islands	1,870.12	108.00	0
Riau Islands	2,547.99	472.00	0
Lampung	265.46	424.00	42.73
Maluku	1,397.57	41,120.00	0.80
North Maluku	111.69	144.00	0
West Nusa Tenggara	3,809.05	7,972.00	7.69
East Nusa Tenggara	9,556.13	65,624.00	10.03
Papua	1,434.79	40,00	0
West Papua	0	4,588.00	0
Southwest Papua	1,283.84	38.00	0
Papua Mountains	0	1,432.00	0
South Papua	0	53,536.00	0
Central Papua	0	168.00	0
Riau	5,387.77	36.00	0
West Sulawesi	3,222.78	944.00	29.31
South Sulawesi	13,720.18	25,260.00	150.41

Criteria	Technical Potential Capacity (MW)		
	Solar Utility Scale	Wind Utility Scale	Mini-hydro Utility Scale
Central Sulawesi	6,667.57	5,996.00	140.44
Southeast Sulawesi	6,084.96	796.00	0
North Sulawesi	12,989.12	2,820.00	135.72
West Sumatera	5,019.97	1,000.00	134.93
South Sumatera	5,292.00	184.00	31.51
North Sumatera	10,933.55	1,776.00	493.85
Total	**336,551.79**	**246,200.00**	**1,778.44**

a. Solar PV Power

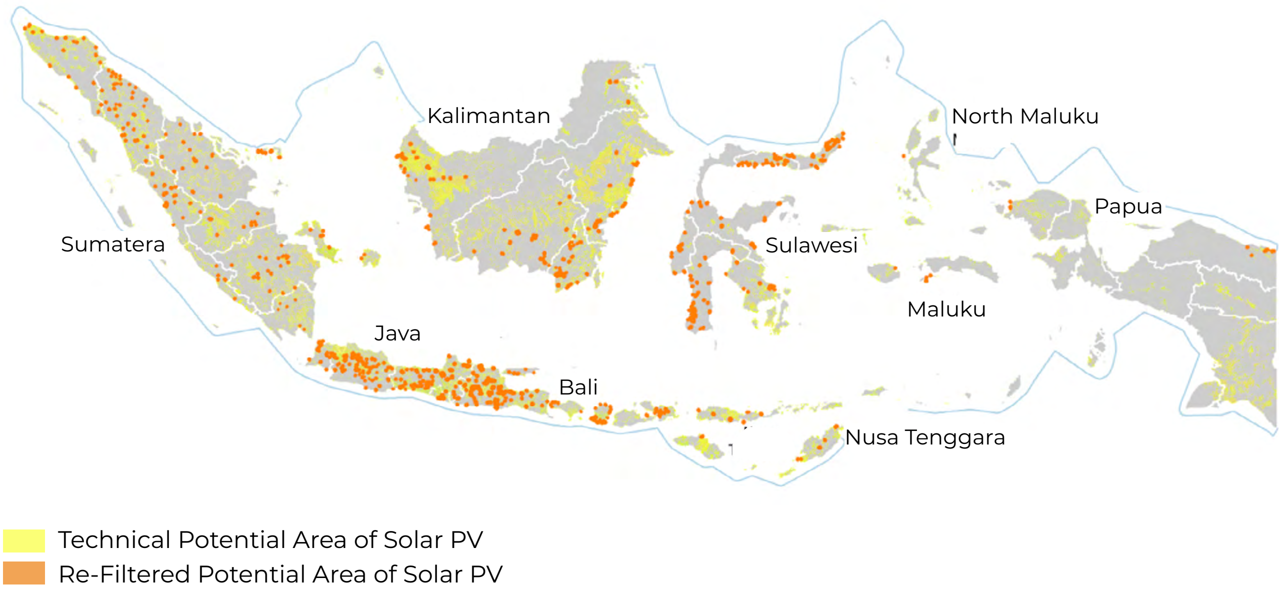


Figure 14. Technical potential area of solar power in Indonesia

Solar power has the highest technical potential among other RE sources based IESR's earlier findings (2021). Re-filtered results in Figure 14 show that the total technical potential of ground-mounted solar power in Indonesia is **336.5 GW**. There is a significant decrease in suitable land for solar PV of more than 90% from the previous study. This decrease is caused by stricter parameters being implemented for filtration. Two most significant factors are the limitation of solar irradiance threshold being kept at the limit of 4.5 kWh/m2/day and the selection of only a 10 km radius buffer area from the substation and HV line. Furthermore, new parameters such as the exclusion of residential areas, water bodies, or dams and adding hazard restrictions also significantly reduced the total potential area's size. As a result, there are 781 sites with an average of **428.43** Ha per potential site. The provinces with the most potential sites for ground-mounted solar power implementation are West Java, Central Java, and East Java. Based on the three provinces, the total solar power capacity that can be implemented is around **76.37** GW.

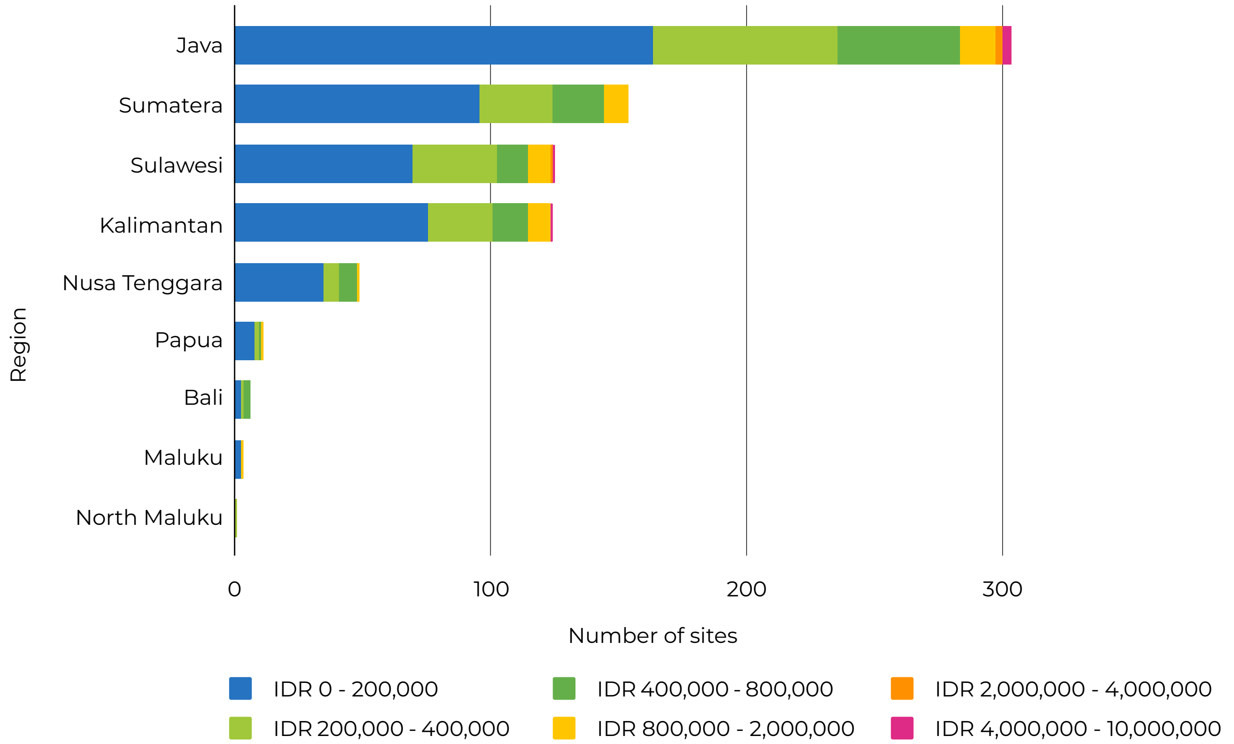


Figure 15. Solar potential site's land price variation by region

Land price distribution for solar potential sites varies in each region. On average, the sites occupy land with prices ranging from IDR 10,000 to IDR 10,000,000 per m². As shown in the Figure 15, most of the solar sites are located at the lower to middle prices between IDR 100,000 and IDR 300,000. By region, Java has the most land price variation ranging from lowest to highest price. With a land use assumption of 0.01 km²/MW, the relatively expensive land cost conditions will impact the investment viability in solar power development—which will be explained in the next chapter.

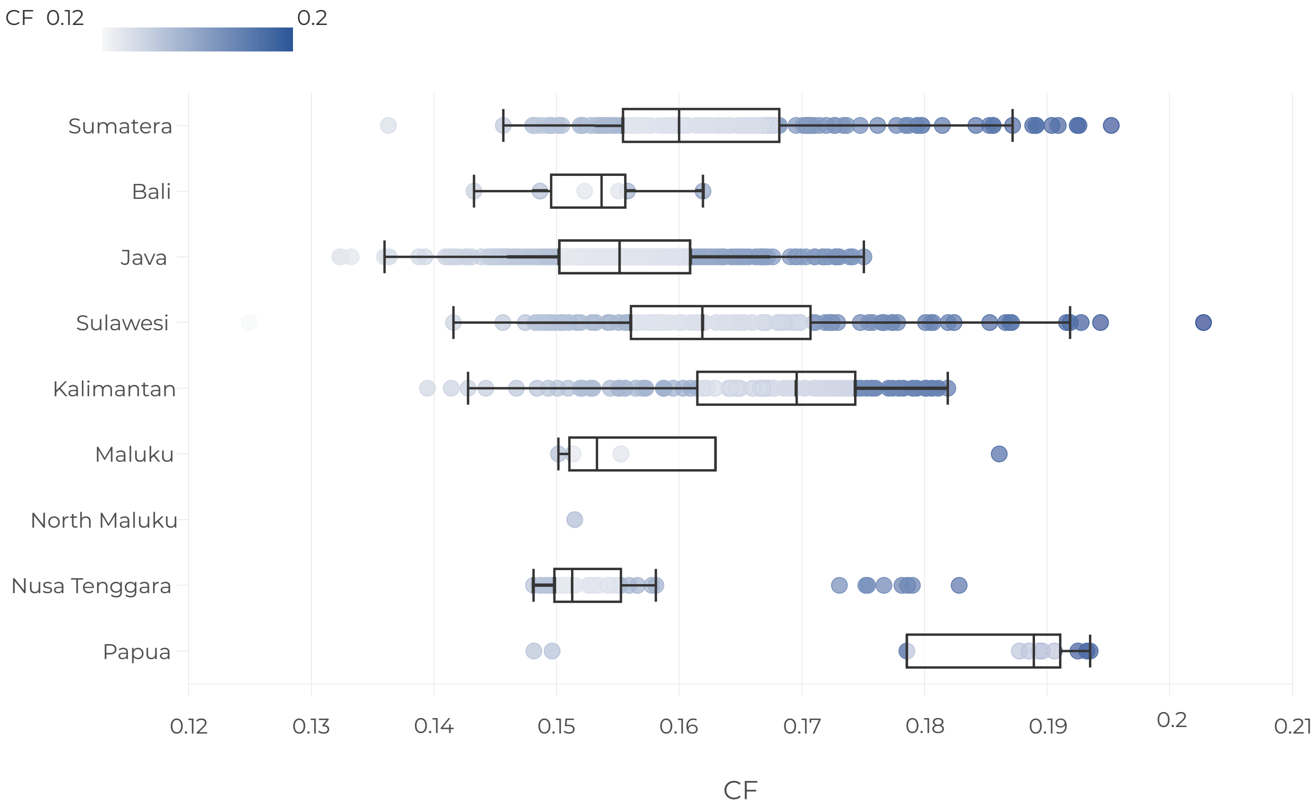


Figure 16. Solar capacity factor distribution per region

On average, the CF of solar power at 781 potential site locations is around 16.2%, with a range of 12.5-20.3%. Based on the results of geospatial analysis, the lowest CF value is in Java, while the largest CF is concentrated in Sumatera, Sulawesi, and Papua. Sites with the largest CF will have an increased feasibility due to the higher electricity generation compared to other locations.

b. Wind Power

Figure 17. Technical potential area of wind power in Indonesia

Wind power has a total technical potential of **246.2 GW** scattered across Indonesia. Although the mean annual wind speed in Indonesia is only 4.9 m/s, a minimum wind speed of 5.5 m/s at 100 meters hub was applied to the model to acquire as much potential area of wind resource as possible, thus adding more area from previous limitation of 6.6 m/s at 100 meters hub. After applying constraints and other parameters, the result is a total area of **843.72 Ha** with **341 potential sites**. To determine the overall potential capacity of each site, grids were created based on turbine specifications with a capacity of 4 MW in those potential areas. The findings show that most of the wind sites are located in the eastern part of Indonesia. All provinces in Indonesia have wind power potential, with the highest being East Nusa Tenggara, South Papua, and Maluku.

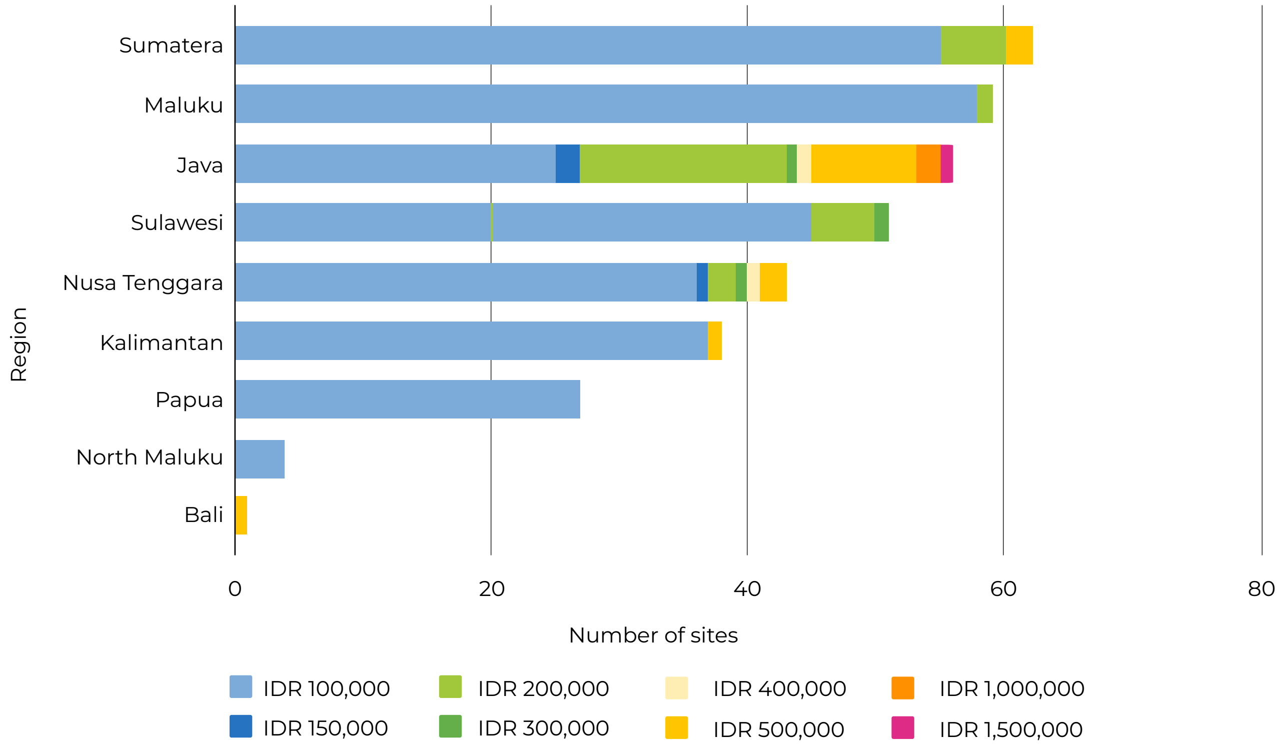


Figure 18. Wind potential site's land price variation by region

On average, wind potential sites occupy land with prices ranging from IDR 100,000 to Rp 1,500,000 per m². As shown in the Figure 18, most of the wind sites are located on land with relatively low prices. By region, Java has the most land price variation ranging from lowest to highest price. In contrast, more isolated regions like Papua and Maluku have the lowest range or below IDR 200,000 per m².

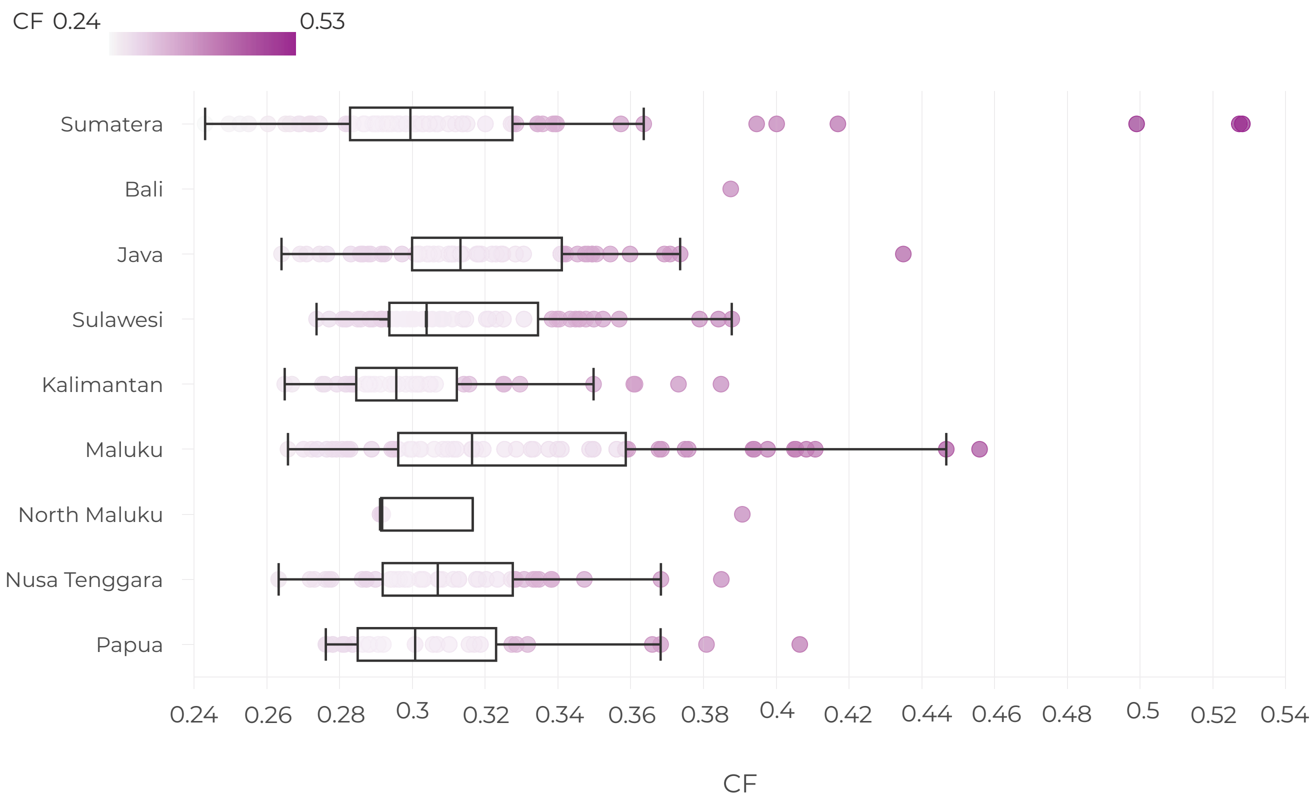


Figure 19. Wind capacity factor distribution per region

On average, the CF of wind power at 341 potential site locations is around 31.5%, with a range of 24.3-52.8%. Based on the results of geospatial analysis, the lowest CF value is in Sumatera, while the largest CF is also in the same region. Sites with the largest CF will increase the feasibility of wind power projects because the potential energy that can be produced will be higher than in other locations.

c. Mini-hydro Power

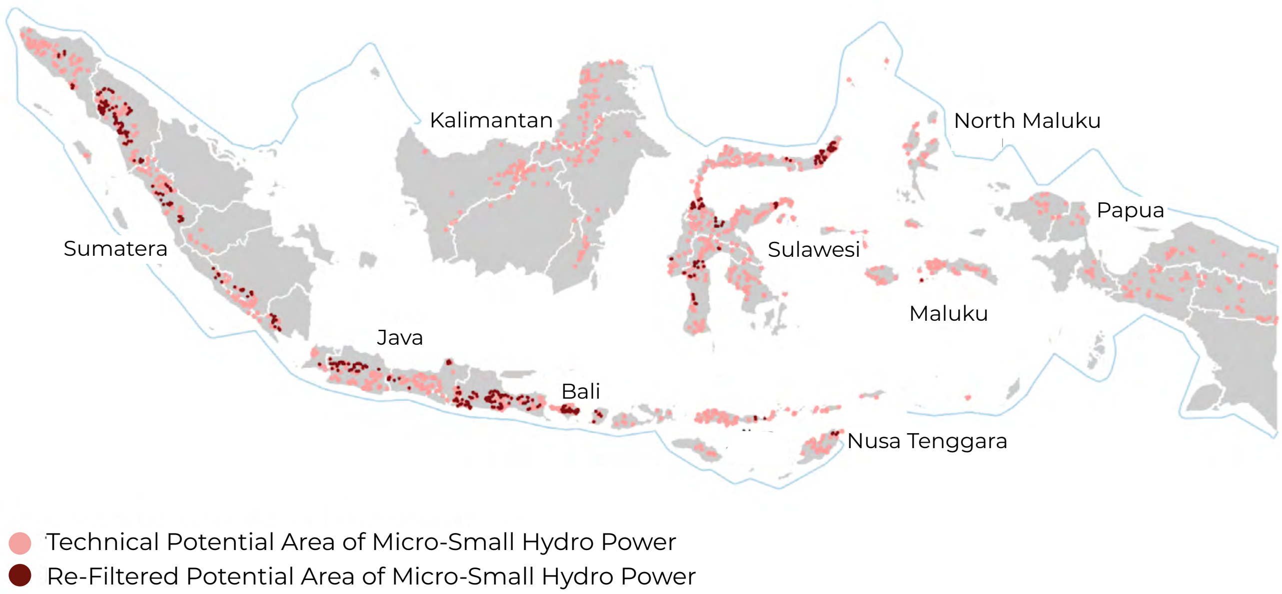


Figure 20. Technical potential sites of micro to small hydro-power in Indonesia

Hydropower is more reliable and less dependent on weather conditions compared to solar and wind. It can also provide flexible energy generation to meet fluctuating demands. Based on IESR (2021), micro and small hydropower can reach a potential of up to 28 GW in Indonesia. Updated parameters and constraints further filter the potential, resulting in 1.7 GW remaining technical potential of micro to small hydropower. There are a total of 458 potential sites, which are primarily distributed in East Java, North Sumatera, and North Sulawesi.

Hydro sites are mainly located in locations with a low range of land prices of around IDR 100,000. By region, Java has the most land price variation ranging from lowest to highest price of IDR 100,000 to IDR 10,000,000. Although the potential sites are more distributed in Sumatra and Sulawesi, most sites have low land price ranges, which indicates that more feasible development could be implemented there. Hydro sites have relatively low land costs due to their minimum land requirements conditions compared to solar or wind farms. Unlike solar and wind energy, which are intermittent and dependent on weather conditions, hydropower provides a stable and continuous energy supply from surface run-off. Therefore, it could become a supplementary source for other RE sources utilization and attract more investment.

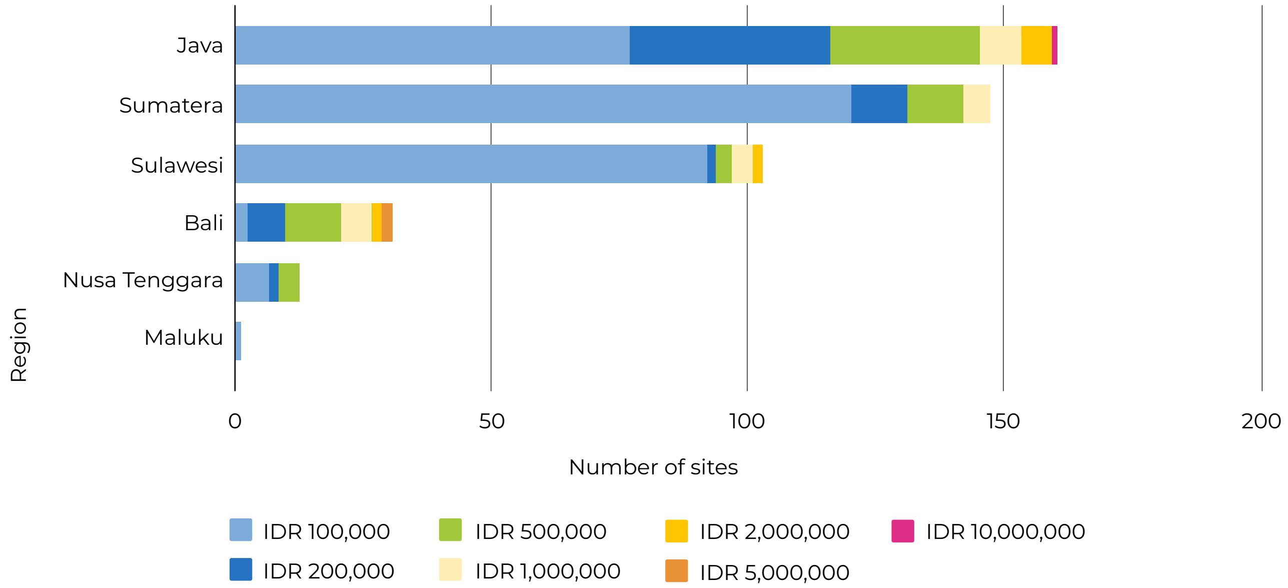


Figure 21. Hydropower potential site's land price variation by region

Studies and historical data showcase that run-of-river mini-hydro projects generally have a typical CF in the range of 40-60%, in accordance to experts' input and the common practice of mini-hydropower design in Indonesia. Therefore, to simplify the model, the CF for mini-hydropower is assumed to be 50% at all potential site locations. However, the determination of these assumptions has the consequence that the energy yield from mini-hydropower is less representative of the river water flow conditions in each potential site location.

4. Economic Viability of RE Projects

Powering Indonesia with 333 GW of RE is economically viable. A project's IRR should exceed its WACC to be considered economically viable. This ensures the project generates returns above the minimum required to justify the investment. For RE projects, acceptable IRR benchmarks often range from 6% to 10% for low-risk projects, while higher-risk projects may require IRRs above 15% or more. In this study, the economically viable RE projects are at least exceeding their WACC of 6.96%.

a. Solar PV Power

The total capacity of economically viable solar PV power plant sites in Indonesia is estimated at 165,942 MW (165.9 GW) across 290 sites, as shown in Table 15. Solar PV power plant projects with an EIRR above 10% are predominantly located in Sumatera, Kalimantan, and Sulawesi, making these regions particularly attractive for high-return solar energy investments. In addition, solar PV power projects with moderate EIRR values, ranging from 6.96-8% and 8-10%, have been identified in several other regions, including Sumatera, Java, Kalimantan, Sulawesi, Nusa Tenggara, Maluku, and Papua.

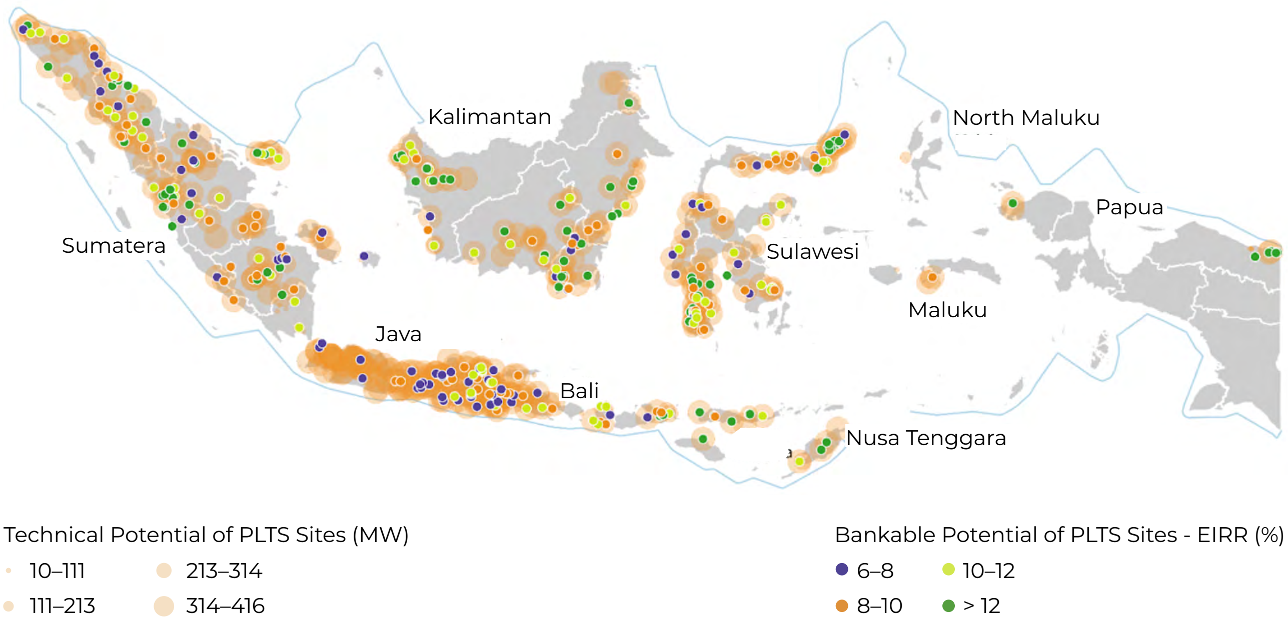


Figure 22. Economic viability of solar PV power in Indonesia

When combined with the data on their CFs, sites with high CFs and high investment returns of solar PV power plants are mostly found in Papua, followed by some in Kalimantan, Sulawesi, and Riau. These regions appear to offer the most favorable combination of solar PV potential and economic returns. Conversely, projects in Java and other regions result in lower EIRR values, indicating moderate financial attractiveness despite having relatively higher CF.

All top five locations of suitable solar PV power sites are located in Papua Island, four in Papua, and one in Southwest Papua; each has an EIRR of more than 27% and a combined potential of more than 1.6 GW. Furthermore, the top five locations with the largest capacity potential and economic viability, all exceeding an EIRR of 8.9%, are East Kalimantan (1 location with capacity of 16,422.5 MW), East Java (3 locations with capacity of 6,522 MW, 3,283.8 MW, and 3,126.9 MW), and West Kalimantan (1 location with capacity of 2,899.2 MW). The capacity of each site is represented by the size of the bubble or dot in the EIRR-CF graph (Figure 22).

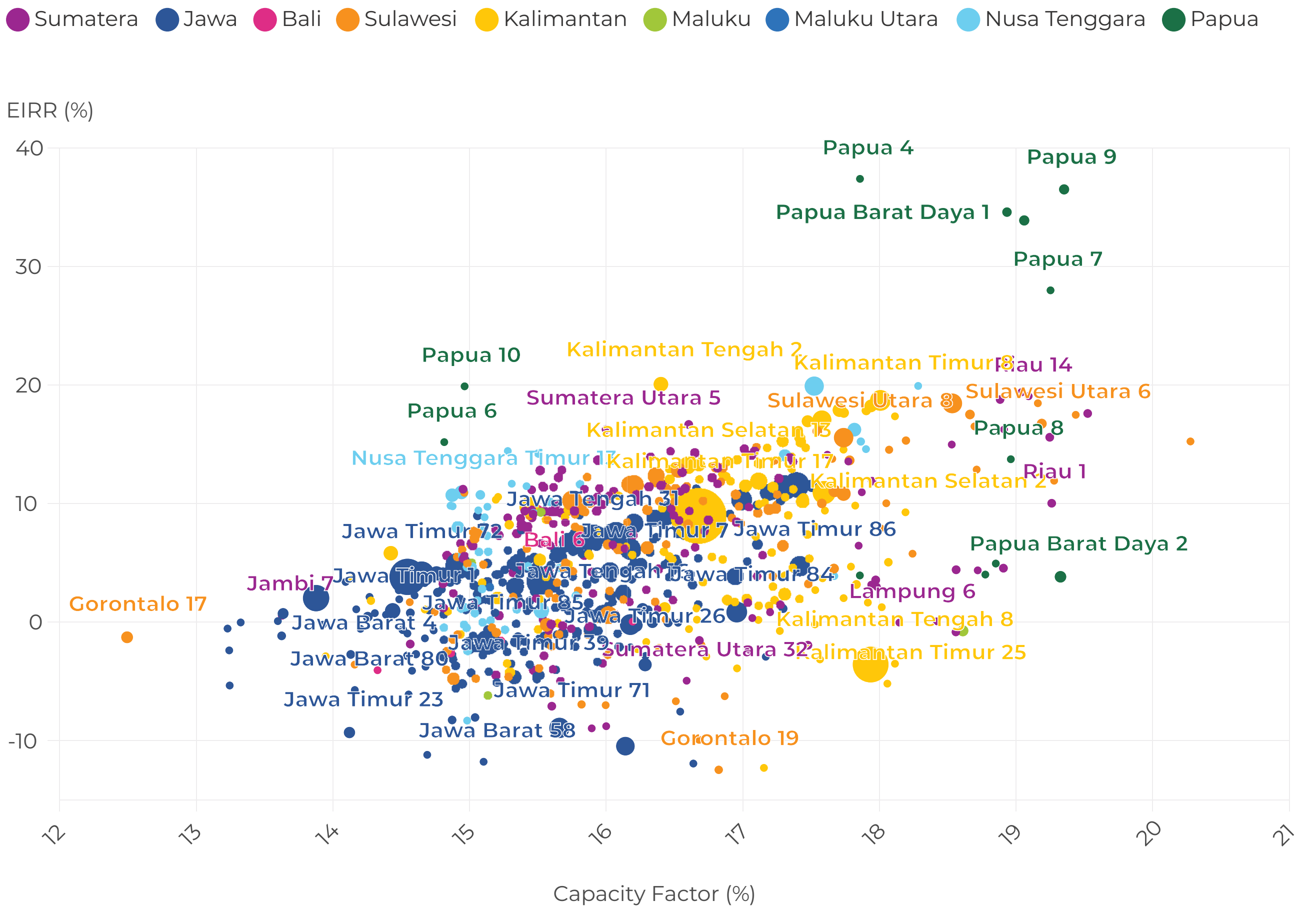


Figure 23. EIRR compared to capacity factor of solar power plants in Indonesia

Table 5. Financial viability potential capacity per EIRR range of solar power plants

Province	Capacity (MW) per EIRR range				Total capacity (MW)	Total Sites
	6.96-8	8-10	10-12	>12		
Aceh	834.2	1,251.5	1,479.5	811.1	4,376.3	11
Bali	-	11.1	-	-	11.1	1
Bengkulu	416	823.6	-	-	1,239.6	3
Yogyakarta	2,531.5	-	-	-	2,531.5	2
Gorontalo	-	1,060.5	10.3	-	1,070.8	5
Jambi	-	1,651	-	-	1,651	4
West Java	10.5	-	-	-	10.5	1
Central Java	6,838.1	6,505.9	101.3	-	13,445.3	12
East Java	6,866.3	10,761	13,505	-	31,131.8	29
West Kalimantan	136.5	749.9	5,016.1	2,716.1	8,618.6	19
South Kalimantan	159.5	2,276.9	55.1	4,809	7,300.6	16
Central Kalimantan	-	473.4	2,773.9	3,091.5	6,338.7	11
East Kalimantan	-	16,958	800.3	4962.2	22,720.6	12
North Kalimantan	-	-	-	1,027.9	1,027.9	1
Bangka Belitung Islands	89	414.7	-	-	503.7	2
Riau Islands	-	-	1,138.6	1,106.2	2,244.8	6

Province	Capacity (MW) per EIRR range				Total capacity (MW)	Total Sites
	6.96-8	8-10	10-12	>12		
Lampung	-	-	152.7	-	152.7	2
Maluku	-	386.3	-	-	386.3	1
West Nusa Tenggara	770.5	821.7	1,060.5	20.5	2,673.2	14
East Nusa Tenggara	-	380.8	2,009.4	5,338.2	7,728.4	11
Papua	-	-	-	1,364.3	1,364.3	7
Southwest Papua	-	-	-	562.4	562.4	1
Riau	-	805.9	407.8	1,152	2,365.6	6
West Sulawesi	935.8	-	12.4	-	948.1	3
South Sulawesi	-	2,614.1	5,106.9	3,406.7	11,127.7	29
Central Sulawesi	-	999.7	2,378.8	-	3,378.5	7
Southeast Sulawesi	116.2	556.4	4,311.2	10.4	4,994.2	8
North Sulawesi	503.2	603.8	1,488.6	8,308.6	10,904.3	16
West Sumatera	121.6	155.6	1,217.6	2,529	4,023.7	15
South Sumatera	109.6	1,565.8	807.5	1,205.7	3,688.6	14
North Sumatera	129.7	2,604.1	2,476.3	2,211.4	7,421.5	21
Total	**20,568.1**	**54,431**	**46,309.9**	**44,633**	**165,942.4**	**290**

b. Wind Power

The total capacity of economically viable wind power plant sites in Indonesia is estimated at 167,024 MW (167.0 GW) across 203 sites. Wind power plant projects with an EIRR above 10% are predominantly located in Maluku, Sulawesi, Papua, and several areas in Sumatera Island (especially Aceh Province), making these regions particularly attractive for high-return wind energy investments. Meanwhile, wind power projects with moderate EIRR values, ranging from 6.96-8% and 8-10%, have been identified in several other regions, including Sumatera, Kalimantan, and Nusa Tenggara.

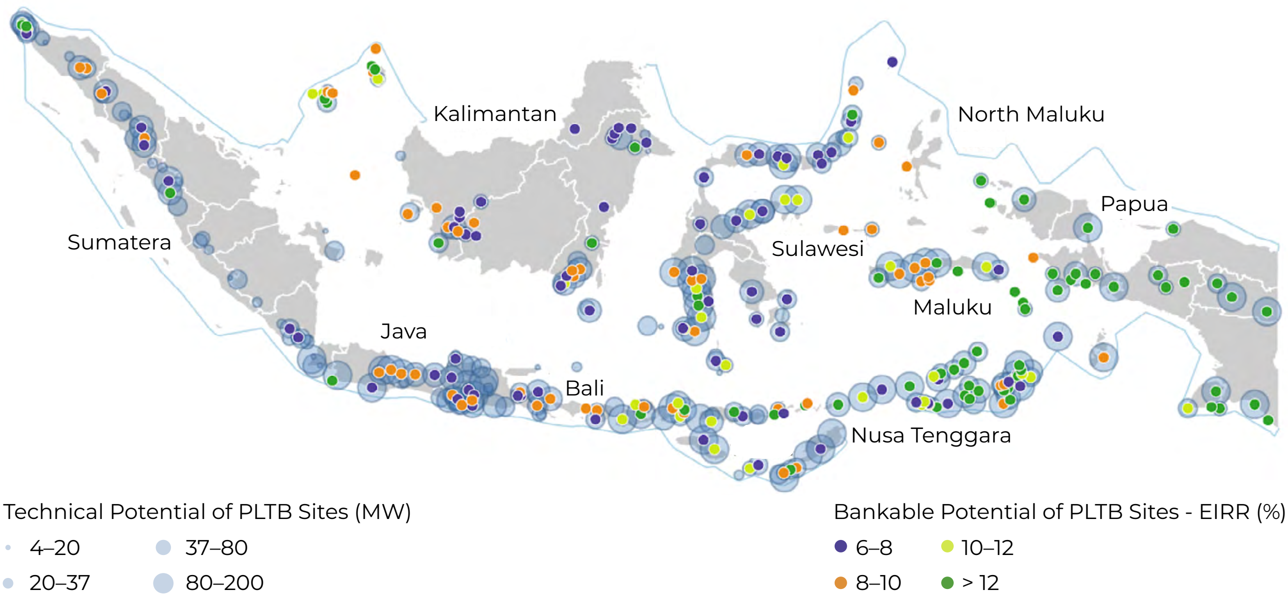


Figure 24. Economic viability of wind power plants in Indonesia

When combined with the data on its CF, sites with high CF and high investment returns of wind power plants are mostly found in Maluku and South Papua. These regions appear to offer the most favorable combination of wind potential and economic returns. Conversely, projects in Aceh, Sulawesi, and other regions with lower EIRR values show moderate financial attractiveness despite relatively higher CF.

The largest technically and financially feasible capacities and the highest EIRR sites are spread across several Indonesian regions, mainly in eastern Indonesia. The top five areas with the highest EIRR are three sites in Maluku (30.9%, 29.0%, and 24.5%), one site in South Papua (24.9%), and one site in West Papua (24.5%). However, these values remain indicative for revenue generation as they are based on average CFs at the site level (area-based) and have not yet been optimized through micro-siting adjustments (nodal-based).

A number of regions that have the largest potential capacity, both technically and financially feasible, are mostly located in eastern Indonesia (South Papua, East Nusa Tenggara, and South Sulawesi). South Papua has the most potential with an EIRR of 19.7% and a total capacity of 457.8 GW, followed by East Nusa Tenggara with an EIRR of 10.2% and a potential capacity of 10.2 GW. Another noteworthy location is in South Papua, with an EIRR of 24.9% and a potential capacity of 755.2 MW. Further, there are two sites in South Sulawesi; one offers 521.6 MW with an EIRR of 10.3%, while the other offers 509.6 MW with an EIRR of 10.5%, indicating a significant potential in the region. Additionally, it is important to note that in our financial simulations, the financial parameters are derived from the total technical potential capacity. This means that the results may vary if the capacity is adjusted or reduced.

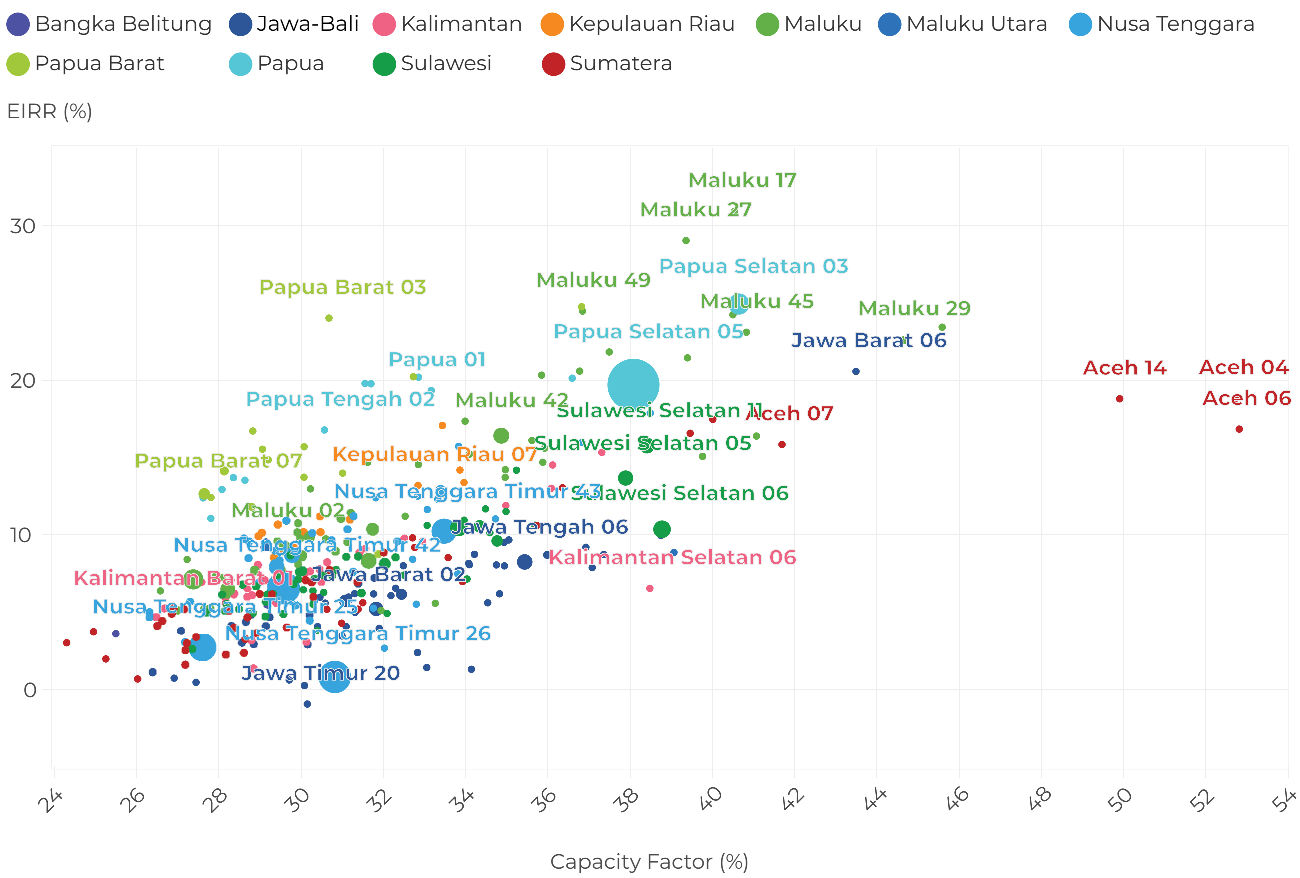


Figure 25. EIRR compared to capacity factor of wind power plants in Indonesia

Table 6. Financial viability potential capacity per EIRR range of wind power plants

Province	Capacity (MW) per EIRR range				Total capacity (MW)	Total Sites
	6.96-8	8-10	10-12	>12		
Aceh	-	496	480	912	1,888	9
Bali	-	20	-	-	20	1
Yogyakarta	-	84	-	-	84	1
Gorontalo	700	320	852	-	1,872	4
West Java	-	48	-	16	64	2
Central Java	528	5,648	-	-	6,176	4
East Java	1,172	1,108	-	-	2,280	8
West Kalimantan	80	60	-	92	232	5
South Kalimantan	-	988	460	80	1,528	5
Central Kalimantan	532	72	-	-	604	5
East Kalimantan	76	-	-	40	116	4
North Kalimantan	12	-	-	-	12	1
Riau Islands	-	136	124	212	472	16
Lampung	88	-	-	-	88	1
Maluku	10,896	11,260	4,488	8,184	34,828	50
North Maluku	-	144	-	-	144	4
West Nusa Tenggara	200	3,812	1,272	2,212	7,496	11
East Nusa Tenggara	3,896	376	11,132	624	16,028	16
Papua	-	-	-	40	40	1
West Papua	-	16	-	4,572	4,588	9
Southwest Papua	-	-	20	368	388	5
Papua Mountains	-	-	-	1,432	1,432	3
South Papua	-	-	92	53,444	53,536	6
Central Papua	-	-	-	168	168	3
West Sulawesi	-	944	-	-	944	1
South Sulawesi	1,004	4,952	10,792	8,080	24,828	11
Central Sulawesi	1,096	-	4,060	-	5,156	6
Southeast Sulawesi	184	-	-	-	184	2
North Sulawesi	424	20	92	144	680	5
West Sumatera	648	-	-	240	888	2
North Sumatera	-	260	-	-	260	2
Total	**21,536**	**30,764**	**33,864**	**80,860**	**167,024**	**203**

c. Mini-hydro Power

The total capacity of economically viable mini-hydro power plant sites in Indonesia is estimated at 729.0 MW across 139 sites. Mini-hydro power plant projects with an EIRR above 10% are predominantly located in Sumatera, Sulawesi, and a small area in Java. In addition, mini-hydro power projects with moderate EIRR values, ranging from 6-8% and 8-10%, have also been identified in the same regions, such as Java and Sumatera, as well as in Bali.

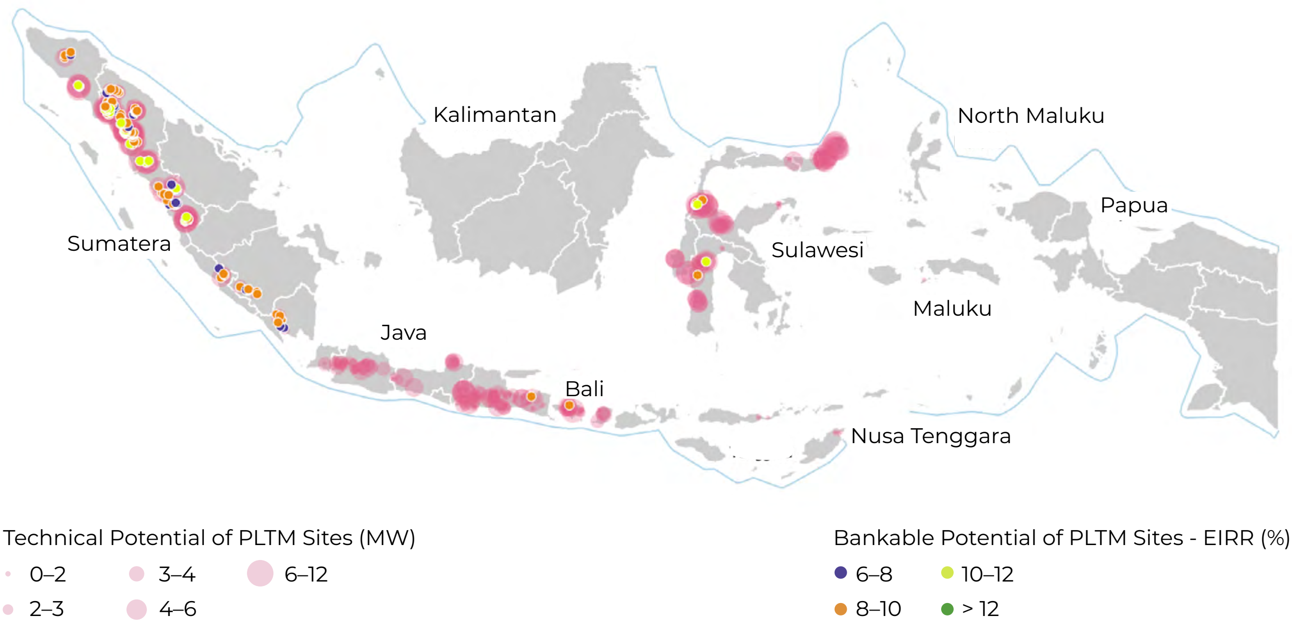


Figure 26. Economic viability of mini-hydro power plants in Indonesia

When combined with the data on their surface run-off, sites with high surface run-off and high investment returns of mini-hydro power plants are mostly found in Sumatera, Sulawesi, and some in Java Island. These regions appear to offer the most favorable combination of mini-hydro potential and economic returns.

Unlike solar and wind, which are predominantly technically and financially feasible in eastern Indonesia, mini-hydro projects are particularly attractive in Sumatera, especially in West and North Sumatera. Based on our financial simulation, which identified sites with an EIRR above 10.5%, the highest EIRR locations are found in two sites in West Sumatera (South Solok and Padang Panjang), two in North Sumatera (Central Tapanuli and North Tapanuli), and one in Lebong, Bengkulu. These sites vary in capacity, ranging from 6 to 9 MW. However, their capacities can be adjusted, designed as cascade systems, or modified by increasing the head height, which in our preliminary analysis was standardized at only 2.5 meters.

It should be noted that these results remain indicative of the annual revenue potential, as they are based on surface run-off estimates without considering the year-round continuity typically represented by a flow-duration curve (FDC). Any adjustments to the CF, whether an increase or reduction, may impact the probability of achieving a certain production capacity over the year.

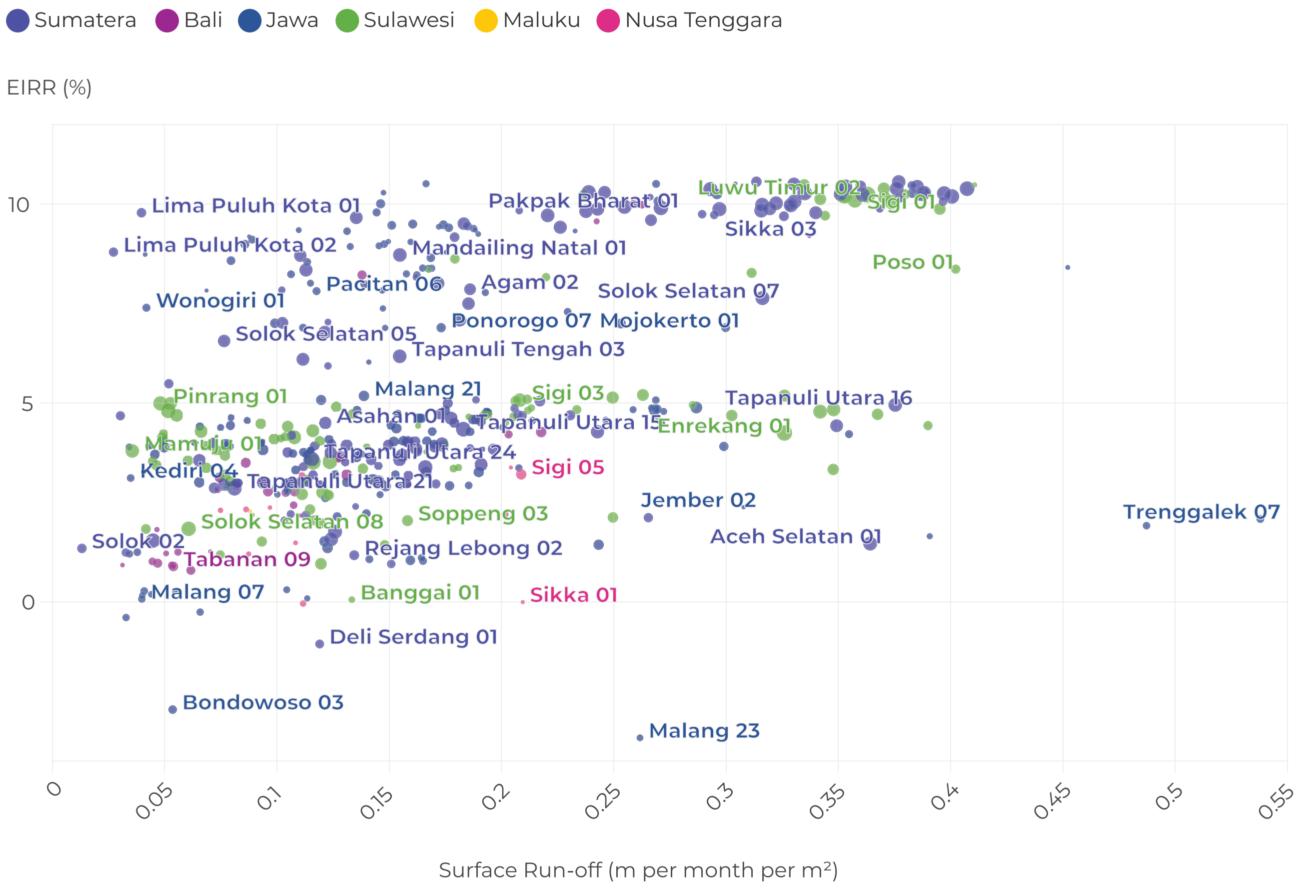


Figure 27. EIRR compared to surface run-off of mini-hydro power plants in Indonesia

Table 7. Financial viability potential capacity per EIRR range of mini-hydro power plants

Province	Capacity (MW) per EIRR range			Total capacity (MW)	Total Sites
	6.96-8	8-10	10-12		
Aceh	2.29	13.09	27.03	42.41	7
Bali	2.34	-	-	2.34	1
Banten	-	5.97	-	5.97	2
Bengkulu	-	14.14	5.68	19.81	4
Gorontalo	-	-	13.61	13.61	2
West Java	4.10	-	11.33	15.43	4
Central Java	4.89	-	-	4.89	2
East Java	-	14.49	-	14.49	5
Lampung	2.75	27.09	-	29.84	9
West Sulawesi	-	-	23.72	23.72	3
South Sulawesi	-	-	8.59	8.59	1
Central Sulawesi	-	26.15	-	26.15	7
North Sulawesi	3.74	-	-	3.74	2
West Sumatera	8.08	51.31	49.31	108.70	21
South Sumatera	5.62	5.58	-	11.20	4
North Sumatera	8.68	171.28	218.18	398.14	65
Total	**42.49**	**329.09**	**357.44**	**729.02**	**139**

d. Sensitivity Analysis

As shown by the sensitivity analysis (Figure 28) of CF and land cost across three technologies, the technical potential represented by CF has a significant impact on the financial viability evaluation compared to the land cost. An increase in CF by just 20% (from 15.9% to 19.1% for solar PV, 30.2% to 36.3% for wind, and 50% to 60% for mini-hydro) leads to a significantly greater improvement in EIRR. It could increase from 10.58% to 30.30% for solar PV, 10.18% to 21.58% for wind, and 10.25% to 26.19% for mini-hydro (assuming 100% absorption of generated electricity under a ToP scheme with no curtailment). Also, if we consider the increase of the global weighted average CF for new RE technologies from 13.8% to 16.2% for solar PV, 27% to 36% for wind onshore, and 44% to 53% for hydro over just 13 years (2010-2023), and combine it with a doubling of efficiency and significant reductions in total installed costs per kW, then it is no surprise that generation and selling prices are expected to decrease rapidly in this decade (IRENA, 2024). On the other hand, the sensitivity analysis of CF reduction highlights the nonlinearity of its impact. A 20% reduction in CF has a relatively lower effect on EIRR's impact than a 20% increase, as the reduction causes only about half the impact of the 20% increase.

Given the possibility of increasing land costs, a sensitivity analysis on land cost impacts on financial parameters was also conducted. The results show that solar PV is more sensitive to land cost changes compared to wind and hydro, primarily due to its larger land requirements. When moderate EIRR solar PV value was selected as a reference, a 20% increase in the reference land cost (IDR 100,000) resulted in a -21.9% impact on EIRR, decreasing it from 10.58% to 9.57%.

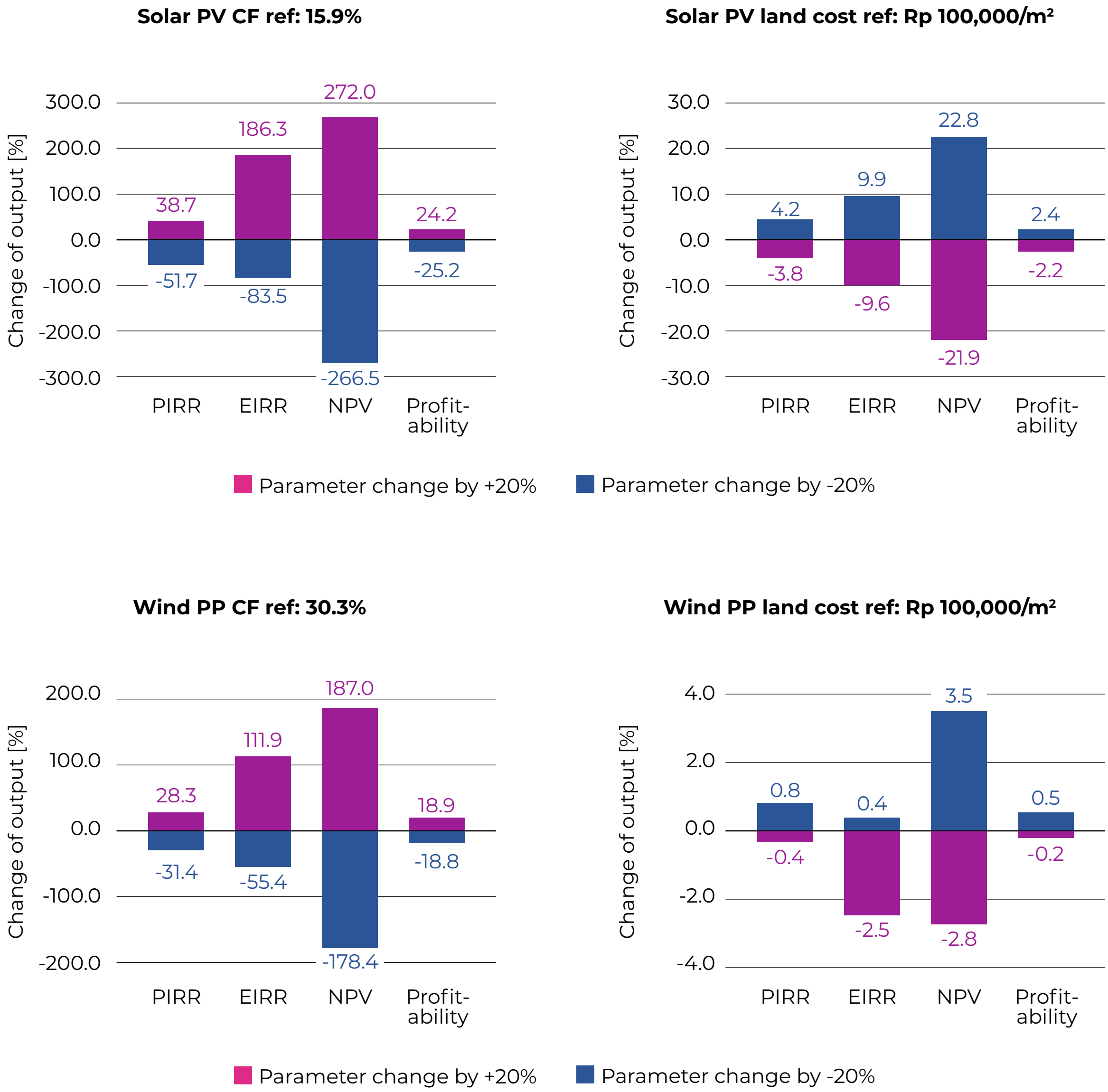


Figure 28. Sensitivity analysis for solar PV, wind, and mini-hydro on CF and land cost (1)

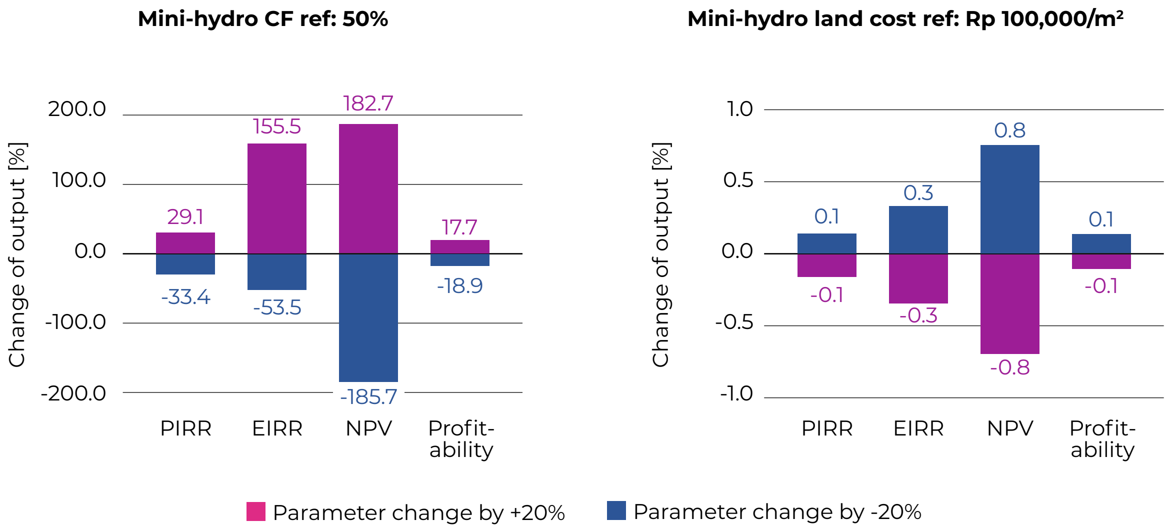


Figure 28. Sensitivity analysis for solar PV, wind, and mini-hydro on CF and land cost (2)

To describe the practice of imbalance risk allocation in partnership contracts, an analysis of three technologies was also conducted by varying the SHL contribution from one party, proportional to ownership shares. Specifically, PLN's capability or willingness to provide SHL in proportion to its 30% ownership share was simulated, with a sensitivity analysis of ±20% variation in SHL contribution.

This analysis demonstrates that if PLN, with a 30% ownership share, can only provide 24% in SHL, the remaining 6% must be covered by the partner's SHL contribution. As presented in Figure 28, the PLN's subsidiary in gencos gain benefits in terms of EIRR changes (in percent): +0.45 for solar PV (from 10.58), +0.33 for wind (from 10.18), and +0.42 for mini-hydro (from 10.25). However, this imbalanced practice shifts the financial burden to the partners, which reduces their EIRR by -0.32, -0.34, and -0.27 for solar PV, wind, and mini-hydro, respectively.

This practice is common in several cases and often places IPPs (partners) at a disadvantage, affecting the attractiveness of both the project and partnerships with PLN. Therefore, ensuring transparency and improving partnership standards is critical to improving the project outcomes and encouraging collaboration with PLN.

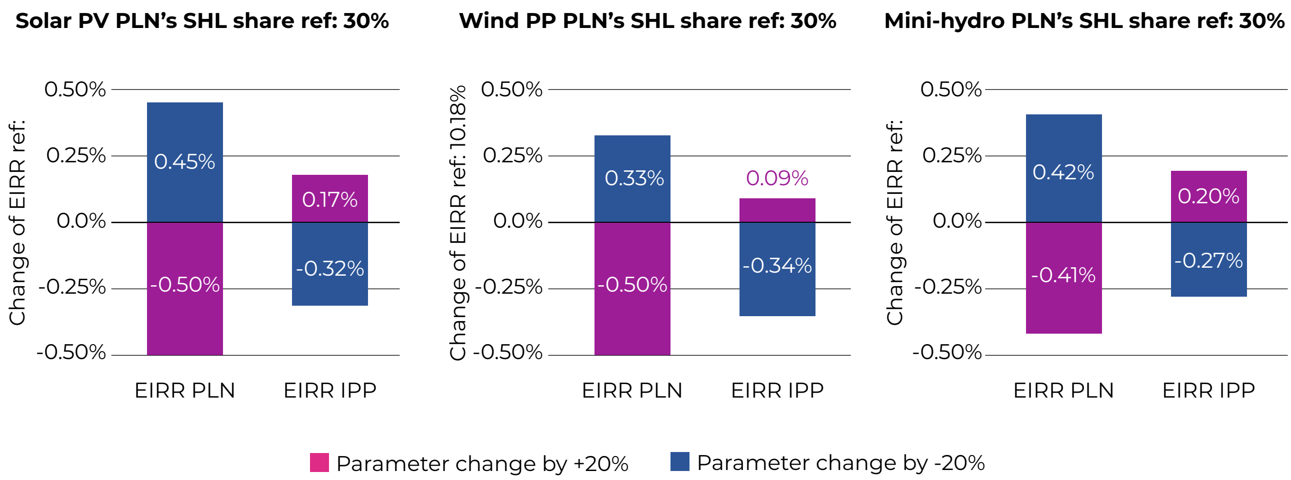


Figure 29. Sensitivity analysis for solar PV, wind, and mini-hydro on PLN's SHL share

5. Moving Forward to Realize The Full RE Potentials

a. Conclusions

Indonesia has abundant potential for RE, and this study showcases a substantial RE potential even with economic evaluation criteria. The total capacity of economically viable RE projects, which in this report are defined as projects with an EIRR of at least 6.96% of WACC, is 333 GW, consisting of 165.9 GW from solar PV power, 167.0 GW from wind power, and 0.7 GW from mini-hydropower. This figure includes higher-return projects with an EIRR of at least 10%, amounting to 205.9 GW (or 61% of the total technical potential of solar PV, wind, and mini-hydropower) in Indonesia. However, in reality, the acceptable capacity size and rate of return vary for each developer and are often determined through business negotiations between generation companies and the off-taker.

Interestingly, each type of RE exhibits distinct regional dominance due to the natural condition and supporting existing infrastructure. Mini-hydro resources are concentrated in Sumatera, while wind power potential thrives in Sulawesi, Nusa Tenggara, Maluku, and Papua. Solar PV power, on the other hand, stands out for its widespread viability, with high investment returns identified in regions like Sumatera, Kalimantan, and Sulawesi. In addition, infrastructure development (transmission and distribution line) will unlock the opportunities to increase the capacity of RE, especially wind and solar PV power, because the resource conditions are spread across various areas in Indonesia.

The spatial distribution of these resources presents significant opportunities for region-specific energy development. Solar PV and wind power's presence across all provinces highlights its adaptability and potential to play a central role in meeting the nation's RE goals. Meanwhile, mini-hydropower projects can address localized energy needs. Further understanding of individual projects is required, as this study has limitations in its modeling approach and the range of financial assumptions employed, which may vary for each project. Furthermore, the identification of economically viable project sites across diverse provinces suggests a strategic opportunity for policymakers to consider clustering smaller-capacity projects into larger integrated developments to attract greater investment, reducing the cost of project development and lowering the RE tariff.

The difference in CF values across provinces, especially for solar PV and wind power in this study, has been shown to significantly impact the economic feasibility of RE projects. The higher the CF, the higher the estimated energy yield that can be generated by RE. However, the CF value of RE is determined not only based on the RE resources available at the location but also on the influence of the technology being used. Therefore, utilizing the matching technology with resources should be identified during the planning stage of RE project development to optimize energy yield and cost.

Certainty of land procurement, including ease of obtaining land use permits, is an important factor to consider when investing in RE. Unlike other cost components, such as equipment cost, which will be cheaper when the capacity of RE is scaled up, land costs tend to remain the same or even increase when RE plans in a location have been announced (i.e., landowner increasing the price above standard market price upon hearing of the plan). Higher land costs can potentially reduce the economic viability of RE projects, as shown by the results of this study. Reducing the risk in land procurement, including the uncertainty in land cost, could help in supporting more competitive tariffs from RE projects. These findings further showcase the importance of detailed spatial planning to support land use for RE infrastructure.

b. Recommendations

Realizing the full potential of economically viable renewable projects will require robust support from both policy frameworks and market mechanisms. Based on current policy and conclusions from this study, several recommendations are intended for policymakers, PLN, and RE developers.

As this report builds upon a combination of geospatial analysis and project financing modeling, the importance of comprehensive energy and land use planning in Indonesia to support the RE development in Indonesia is highlighted. The policy recommendations for policymakers include:

i. **Accommodate land use allocation for RE in regional spatial planning.**

The study identifies economically viable RE projects across Indonesia without restricted and unsuitable spatial zones. However, land use in Indonesia is already designated for specific use under the RTRW (Rencana Tata Ruang Wilayah). Consequently, RE development must align with existing land use classifications. To ensure the full deployment of RE infrastructure, it is crucial to integrate RE land use classification into regional spatial planning or RTRW. This recommendation also builds upon the need to synchronize energy planning and other sector planning documents both at national and regional/local levels (e.g., RUED and RTRW at the provincial level).

Integration of RE land allocation in land use planning could enhance resource and asset potential while also minimizing environmental and social impacts. Establishing designated RE zones will simplify land use permits for investors, providing greater assurance for project implementation.

ii. **Streamline land procurement process to reduce investment risk**

As mentioned previously, acquiring land for energy project development is complex and time-consuming. Developers must secure a Location Permit from the regency with jurisdiction over the site and complete all land acquisition transactions within a set timeframe or risk permit revocation. Thus, the complexity of the land acquisition process and its potential implications for existing land users are evident (Kennedy, 2020).

To reduce these risks and accelerate project implementation, an improved system for the land procurement process with one-stop services and a comprehensive open information database is essential. Enhancing Indonesia's One Single Submission (OSS) system that integrates land use permits, environmental approvals, and energy business permits will help minimize bureaucratic delays and improve regulatory clarity. Additionally, expanding the current digital database, such as the One Map Policy, to include RE zoning and land suitability data will improve transparency, helping developers make informed decisions and avoid disputes.

iii. **Region-specific targets on RE utilization**

As this study showcases diverse potential across Indonesia, region-specific RE targets are powerful to alleviate RE project deployment. Each province may set tailored RE goals based on the economic viability of those projects, for example, prioritizing hydropower in West Sumatera, solar PV in Papua, and wind in Maluku and Sulawesi. These targets could be incorporated in RUEN or RUED and implemented with synergy with regional governments, PLN, and private developers. In addition, regarding the planning of new industrial zones, the government can also consider the proximity of the industrial zone to economically viable RE to establish green industrial zones. By developing region-specific targets, regional incentives, such as tax exemptions and feed-in tariffs, could exist to attract more investment in high-potential areas.

Recommendations for PLN include:

i. **Improve transmission planning and expansion to accommodate the integration of high-return renewable sites**

The spatial analysis conducted in this study is constrained by the RE potential located near the existing substation and transmission line. To unlock the potential of RE that is still relatively far from the existing substation and transmission line and to reduce investment costs for interconnection, PLN needs to prepare a comprehensive expansion plan for the substation and transmission line by considering the proximity to the location of the RE potential, especially to the high-return sites.

ii. **"Bundle smaller and nearby with other sites" to large-scale capacity to provide a cost-effective and more efficient RE procurement process**

This study has presented several RE potentials that are economically viable, spread across several sites in one area. By clustering based on the type of renewable technology or demand in a specific region, PLN can bundle several economically viable RE projects that are located close to each other as a work package to be tendered to developers (known as bulk procurement). Through the bulk procurement mechanism, PLN can establish a cost-effective and efficient procurement process to ramp up RE deployment. However, to ensure that the bulk procurement process encourages the deployment of RE projects, PLN needs to reformulate existing procurement mechanisms to accommodate bundled RE procurement and refine the partnership standards to be more transparent for developers. More transparent partnership standards will increase the developers' interest in partnering with PLN to establish a successful RE procurement process.

Recommendations for developers include:

i. Focus on high-return projects

Developers must prioritize high-return projects in regions with high RE potential and robust grid infrastructure. This study provides initial locational insights, enabling developers to focus exploration efforts on specific sites with the highest feasibility. By concentrating on well-identified locations, RE projects can be accelerated, allowing developers to shift their focus towards next works after initial potential identification, such as securing financing mechanisms for deployment.

ii. Optimize project design and financial planning

Optimizing project design and financial planning through innovative financing mechanisms, such as green bonds, blended finance, and PPPs, will help developers secure long-term funding and enhance project viability. To attract investors, developers must demonstrate financial feasibility, risk mitigation strategies, and long-term revenue potential through well-structured power purchase agreements PPAs and stable policy frameworks.

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Appendices

Appendix A - Financial parameter assumptions

Variable	Assumption	Variable	Assumption
Financing	Non-recourse project financing	Debt tenor	10 yrs (PLTM), 20 yrs (PLTB, PLTS)
Corporate tax rate	22%	All-in rate/IDC	SOFR + Margin rate (5.3 + 2)%
Discount rate (WACC)	6.96% (*Debt:Equity = 4:1)	SHL rate	5.5%
Depreciation method	Straight line	Bid bond/LC rate	1%/1%
Construction duration	24 months (PLTB), 12 months (PLTS), 12 months (PLTM).	Performance bond /LC rate	5%/1%
PPA term	30 years	DSCR P50/P90	(1.25x/1.10x for PLTM) (1.5x/1.3x for PLTB) (1.25x to 2.25x / 1.10x for PLTS)
PPA model	Staging (Presidential Regulation 112/2022)	Max debt	80% (MoF PMK 169/2015)
Escalation *CPI in USD	2%	Financing cost • Upfront fee • Commitment fee	 1.5% 0.4%
WHT on revenue	1.5%	DSRA	6 month
Repayment	Semi Annual	Exchange Rate of 1 USD	IDR 16.000

Appendix B - Due diligence cost assumption

Due Diligence Cost Components	Hydropower*	Wind Power*	Solar PV Power*
Technical Advisor/Appraisal	10	100	50
Financial Model & Tax Auditor	7	80	40
Legal Advisor	7	150	30
Insurance Advisor	3.5	40	20
E & S Advisor	7	80	3

* Value in thousand USD

Appendix C - Ceiling price of solar PV, wind, and hydropower and the location factor (f)

C-1. Ceiling price of solar PV power (PLTS)

Capacity	Staging 1 (1 to 10 years) (¢/kWh)	Staging 2 (11 years and above) (¢/kWh)
≤1 MW	11.47	6.88
>1 to 3 MW	9.94	5.97
>3 to 5 MW	8.77	5.27
>5 to 10 MW	8.26	4.96
>10 to 20 MW	7.94	4.76
>20 MW	6.95	4.17

C-2. Ceiling price of wind power (PLTB)

Capacity	Staging 1 (1 to 10 years) (¢/kWh)	Staging 2 (11 years and above) (¢/kWh)
≤5 MW	11.22	6.73
>5 to 20 MW	10.26	6.15
>20 MW	9.54	5.73

C-3. Ceiling price of hydropower (PLTMH, PLTM, PLTA)

Capacity	Staging 1 (1 to 10 years) (¢/kWh)	Staging 2 (11 years and above) (¢/kWh)
≤1 MW	11.23	7.02
>1 to 3 MW	10.92	6.82
>3 to 5 MW	9.65	6.03
>5 to 20 MW	9.09	5.68
>20 to 50 MW	8.86	5.54
>50 to 100 MW	7.81	4.88
>100 MW	6.74	4.21

C-4. Location factor (f)

Regions	Location Factor for All Capacity
Jawa-Bali	1
Sumatera	1.1
Riau Islands	1.2
Bangka Belitung	1.1
Kalimantan	1.1
Sulawesi	1.1
Nusa Tenggara	1.2
North Maluku	1.25
Maluku	1.25
West Papua	1.5
Papua	1.5

Appendix D - CapEx estimation for renewable energy development

D-1. CapEx estimation for solar PV power development

Cost Components	Assumption
Supply & Installation • Module • Structure • PCS & Inverter • BoS & Trafo	 0.09 $/Wp 0.05 $/Wp 0.04 $/Wp 0.17 $/Wp
Development Cost	3% * Supply & Installation
Land	f(spatial)
Interconnection Cost	f(spatial)
Administration	10 k$
Import Tax & Clearance	10% * Supply & Installation
Insurance	See Appendix F
Contingency	3%
VAT	11%

D-2. CapEx estimation for wind power development

Cost Components	Assumption
Wind Turbine • Rotor • Nacelle • Tower	 0.28 $/W 0.39 $/W 0.23 $/W
BoS • Foundation • Site Access, Staging, and Facilities • Assembly and Installation • Electrical Infrastructure • Wind Turbine Transport	 0.12 $/W 0.05 $/W 0.10 $/W 0.07 $/W 0.19 $/W
Development Cost	3% * Supply & Installation
Land	f(spatial)
Interconnection Cost	f(spatial)
Administration	10 k$
Import Tax & Clearance	10% * Supply & Installation
Insurance	See Appendix F
Contingency	3%
VAT	11%

D-3. CapEx estimation for mini-hydropower development

Cost Components	Assumption
Supply & Installation • Turbine and Generator • Others • Waterway Metalworks (penstock, gates, etc.)	 1.84 $/W 0.26 $/W 0.40 $/W
Installation & Construction Works • Civil Works (Dams, Intakes, Powerhouse, Canals & Tunnels) • Electrical	 0.88 $/W 0.24 $/W
Development Cost	3% * Supply & Installation
Land	f(spatial)
Interconnection Cost	f(spatial)
Administration	10,000 $
Import Tax & Clearance	10% * Supply & Installation
Insurance	See Appendix F
Contingency	3%
VAT	11%

Appendix E - OpEx Estimation for Renewable Energy Operations

Cost Components	Assumption
Asset Management	5% * (technical maintenance)
Technical Maintenance	0.014 $/W
G & A (incl. legal/audit/admin)	10.0 k$
Insurance	See Appendix F
E & S Monitoring	10.0 k$
Utility Cost	10.0 k$
Contingency	3%
VAT	11%

Appendix F - Insurance in CapEx and OpEx assumptions

Insurance in CapEx	
CAR (Construction "All-Risk")	0.371% of total CapEx
Marine Cargo	0.045% of total CapEx
DSU (Delay in Start-Up)	0.084% of 1 yr revenue
Marine Cargo DSU	0.232% of 1 yr revenue
Insurance in OpEx	
BI (Business Interruption)	0.56% of half year revenue
OAR (Operation "All-Risks")	0.29% of total CapEx
TPL (Third Party Liability)	(*included in CAR)

Note: Marine cargo ideally only charged for the goods that are transported by sea or other waterways

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