Indonesia Solar Energy Outlook 2023

The emergence of solar PV in fueling Indonesia's energy transition

IESR
Institute for Essential Services Reform

Imprint

Indonesia Solar Energy Outlook 2023

Authors (alphabetically):

Akbar Bagaskara
Daniel Kurniawan
His Muhammad Bintang
Ronald Julion Suryadi
Shahnaz Nur Firdausi

Reviewers:

Handriyanti Diah P.
Julius Christian
Marlistya Citraningrum
Fabby Tumiwa

Editor:

Fabby Tumiwa

Please cite this report as follows:
IESR (2022). Indonesia Solar Energy Outlook 2023. Jakarta: Institute for Essential Services Reform (IESR).

Publication:
October 2022

Foreword

Indonesia's solar-powered decarbonization

The term "Net Zero" has recently gained popularity as the climate crisis has exacerbated and harmed many countries. More countries have pledged to achieve net-zero emissions. As of September 20, 2022, approximately 140 countries had announced or were considering net zero targets, accounting for nearly 90% of global emissions.

Last year, the Indonesian government stated that it hoped to achieve net-zero emissions by 2060 or sooner. Since then, some research has been conducted to better understand the options and pathways for decarbonizing the energy system over time. The IEA and the Ministry of Energy and Mineral Resources released a report titled "An Energy Sector Roadmap to Net Zero Emissions in Indonesia" in September. Renewables are the central pillar of NZE's path to net-zero electricity by 2040, with a goal of reaching 90% by 2040. Solar and wind energy will account for approximately 55% of total generation, or 350 GW, by 2040, and 500 GW by 2050.

Solar PV, like in the IEA's report, is the backbone of the energy transition, according to the recently published MEMR & IRENA's Indonesia Energy Transition Outlook. Solar PV reached 800 GW, or 80% of total generation, in 2050 under the 1.5-S RE100 scenario. Similarly, the IESR's Deep Decarbonization report published last year, which modeled Indonesia's energy sector's decarbonization to meet the Paris Agreement's 1.5°C target, came out with more ambitious installed capacity for solar as the cheapest source of electricity. As a result, solar PV will provide more than 80% of future energy generation capacity in 2050.

Despite the fact that Indonesia was once a pioneer in solar PV application in the region and has been installing solar home systems (SHS) to provide electricity in remote areas since the 1980s, solar PV development has lagged behind other energy sources. In comparison to other countries in the region, Indonesia lags behind in solar energy utilization. Solar PV has struggled to enter mainstream energy planning for decades due to the perception that it is unreliable, expensive, and only suitable for small and off-grid applications.

Things have improved in the last five years, as solar PV has begun to be installed on the roofs of residential, commercial and industrial buildings. Rooftop PV progressed following the establishment of the One Million Solar Rooftop Initiative, followed by the enactment of MEMR Regulation No. 49/2018. Rooftop PV connected to PLN's grid with net metering had reached 70 MW as of September this year, primarily from industrial installations. Only the restrictions imposed by PLN since early this year have slowed the growth of rooftop PV that could double the capacity otherwise.

Despite all of the obstacles to PLN's grid connection, rooftop PV and ground mounted PV are growing faster outside of PLN's electricity business license areas, as is the use of ground mounted PV with battery to replace diesel generators in coal mining areas. More and more industries are looking to install rooftop PV as a means to cut cost and reduce its carbon footprint.

ISEO 2023 provides an update on the progress of solar PV as the primary energy source in Indonesia's energy transition, as well as its challenges and market opportunities. Previously, solar progress was included in the IESR's annual flagship report Indonesia Energy Transition Outlook (IETO), but this year we made it into a separate publication. This demonstrates our genuine dedication to the development of solar PV in Indonesia.

We hope this report can become a primary reference for policymakers, regulators, financiers, and the public to get insight into solar PV development in Indonesia. Let's make solar PV a driving force in Indonesia's energy transition!

Jakarta, October 27, 2022

Fabby Tumiwa
Executive Director, Institute for Essential Services Reform

Foreword

Renewable energy, and especially solar energy is today the fastest growing electricity source in the world. In 2021, the global investment in solar energy touched $200 billion, which is about the same as was invested in fossil fuel based electricity generation capacity in 2015, when the large scale shift from fossil fuel based electricity generation to renewable based electricity generation started. We note that in many geographies of the world, solar electricity is the cheapest form of electricity, though available only when the sun is shining. And, owing to its modularity and versatility, solar electricity is already deployed widely applications around the world ranging from running agricultural pumps to providing cooling for cold storages to providing power to electricity grids.

This change is the result of public policies and of technological development across the world. It is not as if the world has run out the fossil fuels, just as the large scale adoption of petroleum in the 1850s and 1860s was not driven by the decline in the population of whales and of whale oil. Whale oil, at that time, already had several cheaper substitutes in the market including camphene, turpentine etc. It was the (public policy led) tax on whale oil and its substitutes during the American Civil War which led to the technological development and deployment of petroleum-derived kerosene into the market. A very similar scenario is playing out today as we see solar electricity and other forms of renewable based electricity edging out fossil fuels, at least in the electricity domain.

In this emerging new world, the International Solar Alliance is delighted to welcome the Indonesia Solar Energy Outlook 2023, which carries out an in-depth review of the country's solar energy opportunities and risks, and presents apt recommendations that can unlock its full potential. It is heartening to see the replacement of the many utility-scale diesel-powered generating units with the solar and energy storage systems, and we hope that we will see a sharp rise in rooftop solar solutions as well. I particularly recommend the very balanced assessment of the potential environmental impacts and their trade-off with land-use issues.

The report also analyses the possibilities for Indonesia in the field of manufacturing of solar PV equipment, which is becoming all the all the more urgent because of the increasing utilization of solar PV panels across the world, as well as because of emerging chokepoints in logistics and supply chains for panels which is leading to the global uptick in solar panel prices.

The Indonesia Energy Outlook 2023, is an extremely useful reference document for both investors and decision makers. It highlights investment opportunities that are emerging in the Indonesian solar community, and I hope that it will succeed in bringing everyone on the same page, and thus enable the rapid growth of sector.

We noted, in the World Solar Investment report that ISA released in October 2022, that the large scale adoption of solar energy would require solar investment flows to increase by at least three times by 2030 till in order to meet the net zero goals, and I hope that this Report will help in mobilizing that investment.

We are living in a world of increasing natural disasters because of the already-committed climate change. We need to ensure that we do not add to this committed climate change any further. Economic development, job creation, and environmental quality have all been shown to have been achieved with solar growth far more cost effectively then with fossil fuel growth.

I look forward to this report propelling the Indonesian solar energy industry on to the fast track.

Dr. Ajay Mathur
Director General, International Solar Alliance

List of Abbreviations

APAMSI : Asosiasi Pabrikan Modul Surya Indonesia
BESS : Battery Energy Storage System
BPP : Biaya Pokok Produksi (generation cost)
C&I : Commercial and industrial
CCS : Carbon Capture and Storage
CFPP : Coal-Fired Power Plant
COP : Conference of Parties
CSP : Concentrating Solar Power
DMO : Domestic Market Obligation
FiT : Feed-in-Tariff
G20 : Group of Twenty
GHG : Greenhouse Gases
IPCC : Intergovernmental Panel on Climate Change
IPP : Independent Power Producer
LCOE : Levelized Cost of Electricity
LCRs : Local content requirements
MEMR : Ministry of Energy and Mineral Resources
MoF : Ministry of Finance
MoI : Ministry of Industry
MSOE : Ministry of State-Owned Enterprises
PLN : Perusahaan Listrik Negara
PPA : Power Purchase Agreement
PPU : Private Power Utility
PSN : Proyek Strategis Nasional
PV : Photovoltaics
RE : Renewable Energy
RUPTL : PLN's Power Development Plan
SOEs : State-Owned Enterprises
VRE : Variable Renewable Energy

Table of Contents

Executive Summary

- In 2022, solar has finally made its way into a larger part of Indonesia's net-zero emissions pathways. Several studies and analyses, including by IESR, IEA, and MEMR, have shown that solar will play a vital role in Indonesia's deep decarbonization by 2060 or by mid-century, requiring at least one-third of electricity generation, or 60% of installed power capacity, to come from solar by 2060. An accelerated pathway to align with the 1.5 °C target requires even more: up to 88% of solar electricity generation and 1,500 GWp of installed solar capacity by 2050. That said, Indonesia's current solar deployment has chronically fallen short of the deep decarbonization requirement, standing at only 0.2 GWp of installed capacity and generating only less than 1% of total electricity generation by the end of 2021.

- Despite having a very low deployment today, some significant progress has been made slowly in the sector. This is reflected in the decline of utility-scale solar PPAs. Between 2015 and 2022, solar PPA prices have declined by 78%, from $0.25/kWh to $0.056/kWh. Bids in 2020's equity partner solar auctions even revealed record-low bids to below $0.04/kWh, a 84% decline compared to 2015's PPA price ($0.25/kWh). In terms of project pipeline, there are currently eight projects that have been tendered totaling 585 MWp in capacity. These include Cirata 145 MWac FPV project, Bangka 10 MWp and Bali 2x25 MWp ground-mounted solar projects, and four projects from Indonesia Power's Hijaunesia equity partner auction; two of them are Saguling 60 MWac and Singkarak 50 MWac floating solar projects that have recently signed an MoU with PLN for the implementation.

- Floating solar is expected to continue leading utility-scale solar development within PLN's capacity addition plan. As of Q3 2022, there are at least three projects totaling 325 MWp in the pipeline (auctioned) and eight projects totaling 731 MWp that are still in pre-development stage. Partnering with PLN's subsidiaries (i.e., PLN Indonesia Power or PLN Nusantara Power—previously PJB) under a 51:49 project equity structure seems to be the preferred project development style going forward. This is apparent in the case of Cirata, Saguling, and Singkarak floating solar projects and is likely to be followed in other cases such as Kedung Ombo, Gajahmungkur, and Sutami that already have development agreements from either one of PLN's subsidiaries. Some FPV projects in Batam Island has also been identified and could enter construction phase in in the next two to three years.

- PLN's diesel conversion program has also taken place. In March 2022, PLN issued the RFP for the first phase of the diesel conversion to renewables program. The first phase of the program aims to convert 212 MW (out of 499 MW) diesel plants in 183 locations into solar+storage projects using location clustering (8 clusters), while the remaining 287 MW will be carried out in the second phase in a yet specified time frame. While location clustering improves auction volume and economics, developers note geographical and time-constraint challenges to make bids. The RFP originally expects PPA signing of the first two clusters by October 2022 but seems to be facing a delay.

- The much-anticipated release of Presidential Regulation 112/2022 is expected to bring a breath of fresh air to the sector. Not only does it set a new power purchase pricing policy for renewables, it also laid the groundwork for the acceleration of renewables deployment by setting out an instruction to accelerate the closure of coal power plants. The latter may pave the way for higher RE planning in future RUPTLs and could also open up the opportunity for contract renegotiation of rigid coal PPAs to be operated more flexibly during the transition times.

- Solar power export projects to neighboring country Singapore are faced with uncertainty after the Indonesian government mulled plans to ban clean power export. Developments might be expected to continue, however, given that Indonesia and Singapore has signed an MoU on energy cooperation in early 2022. If the projects are successful, it could open up a path toward realizing the ASEAN Power Grid (APG), a regional supergrid that allows multilateral electricity trading between the ten ASEAN member states, that has been a long-standing goal of ASEAN since 1997.

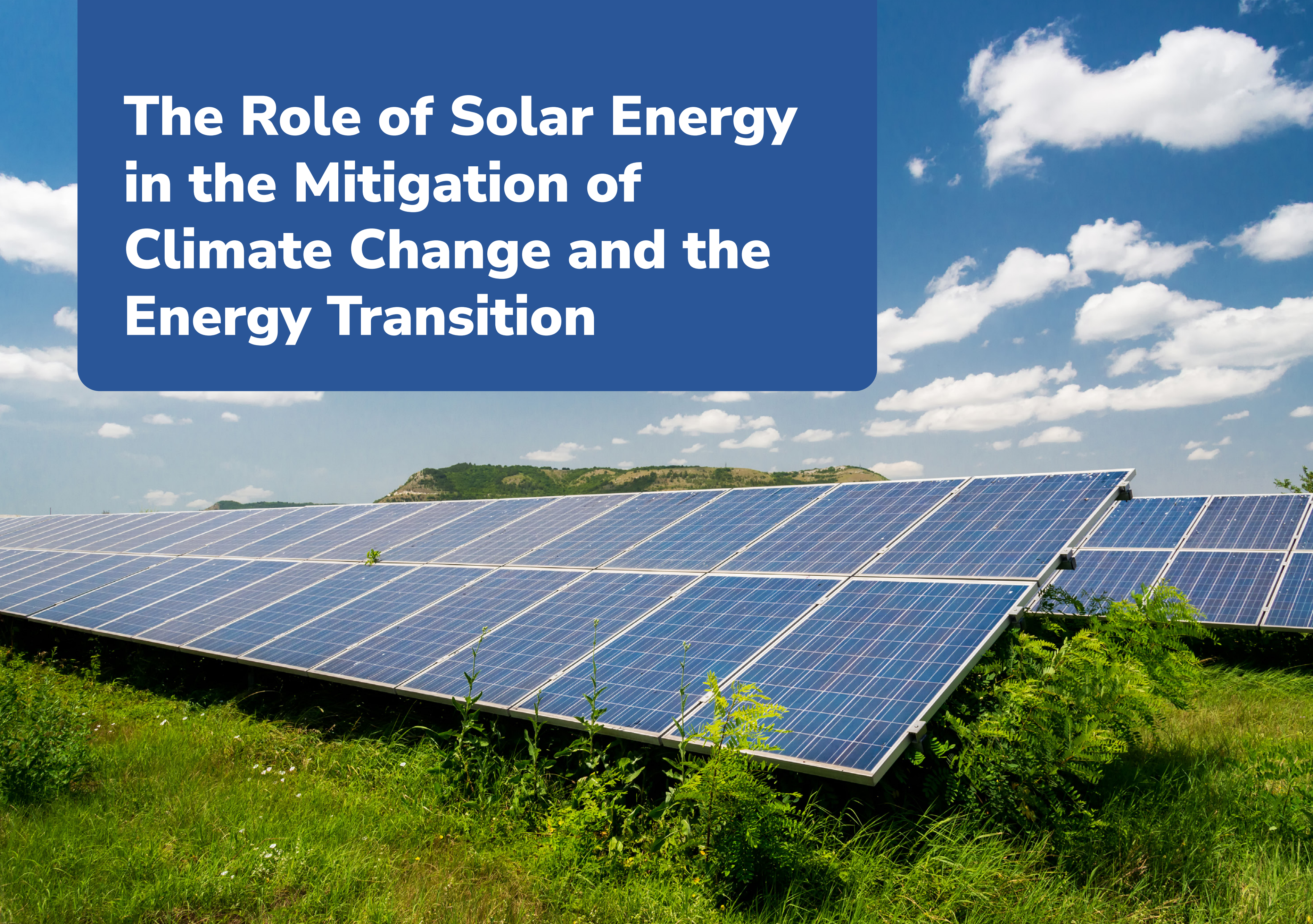
- Rooftop solar deployment, whilst has enjoyed modest growth in the past four years, has been stalled by the capacity limitation imposed by PLN in early 2022 due to concerns about overcapacity condition. The implementation of MEMR 26/2021, which upgrades the net metering ratio to 1:1 from 1:0.65, has also stalled due to the same reason. The government's 3.6 GW by 2025 rooftop solar PSN target is at risk should the capacity limitation persist into 2023. As much as 2.3 GWp of solar project pipeline from 31 declarators at the Indonesia Solar Summit 2022 is also at risk of being downsized into lower capacity or even non-realization when the business case changed.

- Deep decarbonization of Indonesia's energy system will require a massive deployment of solar PV. This means that Indonesia must consider how and where it gets the supply from. According to MEMR's NZE modeling, Indonesia would require at least 420 GW of PV capacity by 2060 only for the power sector's decarbonization. For a deep decarbonization of the entire energy sector (buildings, transportation, and industry), Indonesia would require at least 1,500 GW of installed PV by 2050. Globally, however, China has dominated the entire PV manufacturing value chain, holding at least more than 80% shares across the value chain, posing supply chain vulnerability in the foreseeable future. In contrast, Indonesia's domestic PV manufacturing capability is currently limited to only PV module assembly, with 1.6 GWp of annual module production capacity where 50% of the capacity is export-oriented, signifying the need for a comprehensive industrial policy strategy toward decarbonization.

- While Indonesia's relatively low energy prices and inexpensive labour present opportunities for cost-competitive solar PV manufacturing, at least for module and cell manufacturing, Indonesia's emission intensity today is quite high, exceeding the global average due to high shares of coal in its power mix. As Indonesia is transitioning to cleaner electricity, this could be an opportunity to plan and build domestic solar manufacturing with a cleaner power mix in the long run. Adjacent to that, local content requirements (LCR) of solar power plants, often cited as one of the major hurdles for solar deployment in the country, must also be carefully reconsidered so as not to impede deployment but complement it in a sustainable manner. This could be done by carefully tuning the LCR policy at solar auctions, as was shown by India's experience when designing its National Solar Mission.

- Lastly, despite the slow progress, solar continues to make its way into the bigger picture of Indonesia's pathway to climate neutrality. Several barriers related to coal overbuild has slowly been removed by the no new coal moratorium and accelerated closure of coal fleet instruction of the Presidential Regulation 112/2022. This will certainly pave the way for a higher planned solar capacity addition in the upcoming RUPTLs, owing to solar's abundant resource and cost-competitiveness. Ultimately, auction scheduling and auction design will be pivotal in realizing the many good potential of the presidential regulation and higher (eventual) solar planning and ambition.

The Role of Solar Energy in the Mitigation of Climate Change and the Energy Transition

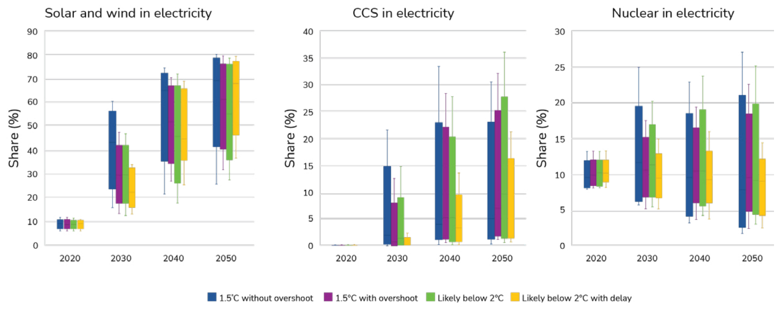


Solar energy will play an essential role in the decarbonization of the global energy system and the mitigation of climate change

- The 2022 IPCC report on the Mitigation of Climate Change (AR6 WGIII report) has found that all modeled mitigation pathways that limit warming to 1.5°C with no or limited overshoot[1] involve rapid and deep emissions reductions in all sectors[2]. This is especially so for the energy sector. In all modeled pathways that reach global net zero GHG emissions, almost 75% of the emissions reduction are achieved by CO_2 emissions reduction in the energy sector, whereas the remaining are achieved by CO_2 emissions reduction in the AFOLU sector (13%) and non-CO_2 emissions reduction from all sectors (13%), signifying the importance of a deep decarbonization of the global energy system.

- The IPCC also notes that in scenarios limiting warming to 1.5 °C, low- and zero-carbon technologies are projected to cover 97–99% of global electricity in 2050 (63–85% of primary energy in 2050). Solar, particularly photovoltaics[3], and wind energy are projected to be the primary contributor (40–80%) to the global electricity production in 2050 (with 70% being the median for the no overshoot scenario). This signifies the importance of both solar and wind (at about 50:50 shares) in the mitigation of climate change and the decarbonization of the energy systems.

Shares of low-carbon energy in global electricity generation in the assessed pathways and scenarios in AR6 WGIII report, 2020–2050



Source: IPCC (2022). Note: Low-carbon energy refers to renewables, nuclear energy, and fossil fuels with carbon capture and storage (CCS).

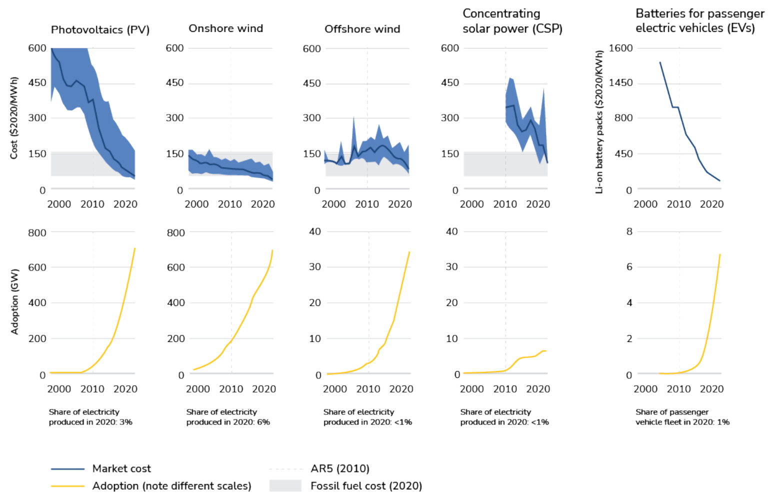
[1]Limited overshoot refers to exceeding 1.5°C global warming by up to about 0.1°C and for up to several decades (IPCC, 2022). Unless otherwise stated, limiting warming to 1.5 °C means with or no limited overshoot. [2]Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry, and Other Land Use (AFOLU), and Waste sectors (IPCC, 2019) [3]Photovoltaics refers to solar energy technology that directly converts sunlight into electricity. This is to distinguish it with other solar technologies such as concentrating solar power (CSP) and solar thermal that utilizes the sun's thermal energy using collectors (i.e., mirrors or lenses) to then be used to power a steam turbine to produce electricity,

The emergence of solar's role in the mitigation of climate change has been largely enabled by the falling unit cost of PV modules over the past decade

- The global costs per unit of energy ($/MWh) of several key low-emissions technologies such as solar energy, wind energy, and (lithium-ion) batteries have fallen significantly over the last decade, making the low-emission energy transitions through 2030 economically attractive. From 2010 to 2019, there have been sustained reductions in the unit costs of solar PV (85%), wind energy (55%), and lithium-ion batteries (85%). The cost of alternative solar technologies like concentrating solar power (CSP) have also declined by half over the same period, although its deployment and significance remain lower than PV in scenarios that limit warming to 1.5°C.

- A mix of policy instruments and strong government support, especially in the U.S. and Japan in 1970–1990s, Germany in the 2000s, and later China in 2000–2010s, have enabled these cost reductions and supported global adoption, although adoption in emerging economies have generally lagged due to weaker enabling conditions. By the end of 2021, global installed solar capacity has reached 940 GWp and has just reached 1 TWp mark in May 2022 from only 40 GW in 2010. China (308 GW cumulative installed capacity in 2021), US (123 GW), Japan (78 GW), India (60.4 GW), and Germany (59 GW), remain the top five largest market for solar in 2021 (IEA PVPS, 2022).

Unit cost reductions and global adoption in key low-emissions technologies, 2000–2020



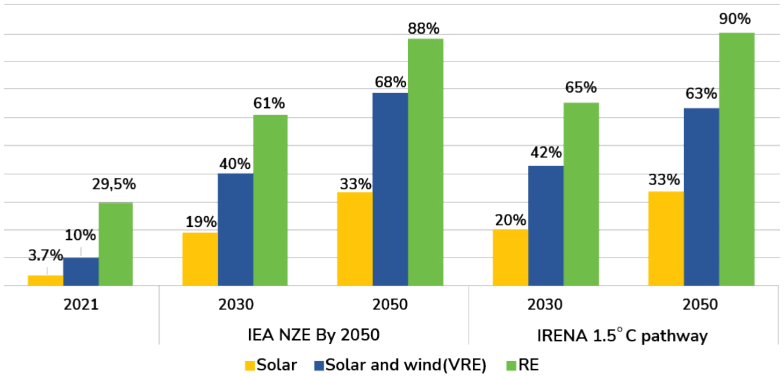
Source: IPCC (2022).

Despite accelerated and significant growth over the past decade, the current pace still falls short of what is required to limit warming to 1.5°C

- Accelerated growth of global solar deployment over the past decade has made significant progress in terms of electricity generation. In 2010, solar accounted for only 0.1% of global electricity generation. By the end of 2021, this has increased to 3.4% (10% when combined with wind), according to the IEA (2021b). Renewables in total accounts for 29.5% of global electricity generation in 2021.

- Despite the significant growth, global electricity generation from solar still falls short of what is required to limit warming to 1.5°C. According to IEA's Net Zero by 2050[4] scenario, which is consistent with a 50% chance of limiting warming to 1.5°C with no or limited overshoot, solar should represent 19% of global electricity generation by 2030 (40% VRE) and 33% by 2050 (68% VRE). Renewable energy in total should make up 61% of electricity generation by 2030 and 88% by 2050. IRENA similarly projected that VRE generation must account for 42% by 2030 and 63% by 2050. In terms of capacity, both IEA and IRENA expected around 5,000 GW of installed PV by 2030 and 14,500 GW by 2050 to align with the 1.5°C target.

Global electricity generation shares from solar, solar and wind (VRE), and renewable energy (RE) in several 1.5°C scenarios



Source: IEA, IRENA, IESR analysis. Notes: solar electricity generation share in IRENA's pathway in 2030 and 2050 are estimated due to unavailability of data

[4]*Net-zero CO_2 emissions from the energy sector scenario of the IEA covers not only energy-related emissions but also industrial processes CO_2 emissions*

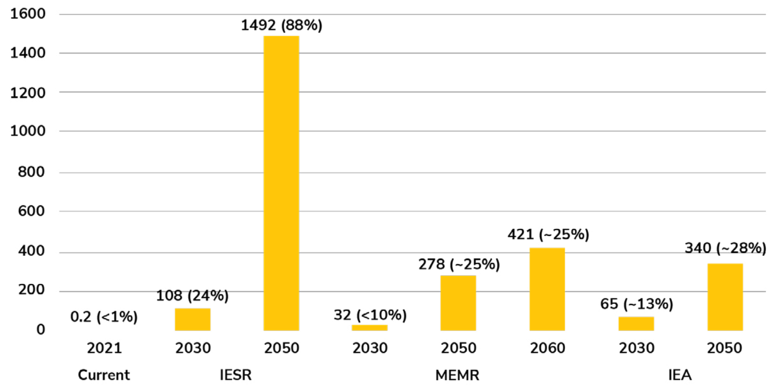
Solar is (also) set to play a vital role in Indonesia's deep decarbonization

- Solar is also expected to play a vital role in Indonesia's efforts to decarbonize. According to IESR's deep decarbonization study (2021), solar is expected to contribute 88% of electricity generation in 2050, with about 1,500 GW of mostly utility-scale solar installation (80%), coupled with energy storage systems, inter-island connections, and other grid flexibility options including power-to-X[5] technologies.

- Adjusting for recent policy development to achieve net-zero by 2060, the MEMR has also formulated NZE modeling scenario, in which solar is projected to take up at least one-third of total electricity generation in 2060, with about 420 GW (about 60%) of total installed power capacity. The IEA, under an official cooperation with the MEMR, also reported similar findings that solar, together with wind, will play a vital role in Indonesia's deep decarbonization. By 2030, installed solar capacity should reach 65 GW (out of 140 GW of renewables installed capacity, where renewables should represent one-third of electricity generation in 2030). By 2040, nearly 90% of electricity supply comes from renewables and unabated coal is phased out. Solar and wind together provide about 55% of electricity generation and maintain similar share from 2040 to 2060.

- While there have been many studies and models that show the important role of solar in Indonesia, Indonesia's current solar deployment has only reached **0.2 GWp by Q3 2022**[6], with solar's share in electricity generation of only *less than 1%*. Understanding the importance of solar in Indonesia's deep decarbonization, **Indonesia Solar Energy Outlook (ISEO) 2023** aims to track and analyze policy and market developments of solar in Indonesia, with the aim to inform policymakers and other relevant stakeholders in both the public and private sectors to accelerate solar deployment in Indonesia.

Solar capacity and generation mix in Indonesia's NZE energy sector pathways
Installed capacity, GWp (electricity generation share, %)



Source: MEMR, IEA, IESR analysis. Notes: IESR and IEA models covered the entire energy sector (i.e., power and the entire end-use sectors: industry, transportation, and buildings sectors), while MEMR model only covered the power sector and limited end-use sector. IESR scenario refers to the Best Policy Scenario (BPS) in IESR-Agora Energiewende-LUT's Deep decarbonization of Indonesia's system. MEMR scenario refers to Zero Emission (ZE) scenario in MEMR's energy sector net-zero emissions by 2060 modeling. IEA scenario refers to Net Zero Emissions by 2050 (NZE) scenario in IEA-MEMR's An Energy Sector Roadmap to Net Zero Emissions in Indonesia. Solar capacity and generation mix in the IEA model is estimated because the value are not specifically broken down (grouped together with wind).

[5] ***Power-to-X*** *is an umbrella term for conversion technologies that use surplus renewables-based electric power, generally during excess, into other forms of energy for storage and reconversion. This allows for the decoupling of electricity for use in the power sector and opens up possibilities for electricity use in other sectors, mainly in transportation and industry (heating) sectors, otherwise known as* ***sector coupling****. The "X" in the terminology can refer to power, heat, gas, hydrogen, chemicals, liquid/fuels, ammonia, and mobility (not exhaustive).*

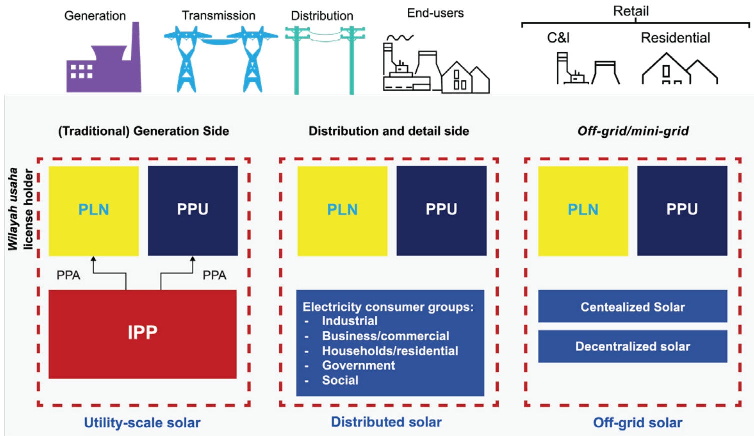
[6] *According to MEMR's 2021 data that includes only installation within PLN's wilayah usaha. It does not include a wider non-PLN's wilayah usaha data, which may still be underreported.*

Definitions

- In this report, **utility-scale solar** is defined as ground-mounted or floating solar projects (with a minimum capacity of ≥1 MWp) that sells and transmits electricity to an electric utility through a power purchase agreement (PPA). Colloquially, this is known as independent power producer (IPP) solar. In Indonesian context, this does not only refer to IPP projects that sell electricity to PLN (state-owned electric utility) but also to other *Wilayah Usaha* license holders, that is private power utilities (PPU). Large-scale (≥10 MWp), non-rooftop solar projects owned by PLN directly (without PPA) is also included in this category.

  While the term "utility-scale" in its literal sense may refer to its project size (which may vary and usually range between ≥1 MWp to ≥10 MWp), it is also often distinguished—and is useful to—by the way it is set up in the *traditional power generation sense* (that is a centralized power generation that feeds electricity into the grid, to be transmitted and distributed to end users through the power grid (IFC, 2015).

- In contrast, **distributed solar** refers to solar projects that generates power at or near the end user's location (on-site), rather than having to be transmitted like traditional power generation. This includes both small-scale system (<1 MWp) such as rooftop solar and large-scale system (≥1 MWp) such as large commercial and industrial rooftop solar, ground-mounted, and floating solar. A specific term "**captive power**" is also often used to describe distributed power generation used explicitly or mainly for self-consumption. Further, captive power is often distinguished by power generation that supply end user directly rather than to electric utility.



- **Off-grid solar** refers to centralized or decentralized solar projects in an isolated, off-grid/mini-grid system that involves small-scale electricity generation, which may range between 10 kW to 10 MW.

Utility-scale Solar

- Solar PPA and project pipeline development
- Policy update and analysis
- Solar power export project development

Utility-scale solar remains the largest contributor to Indonesia's total installed solar capacity, although nowhere near deep decarbonization requirement

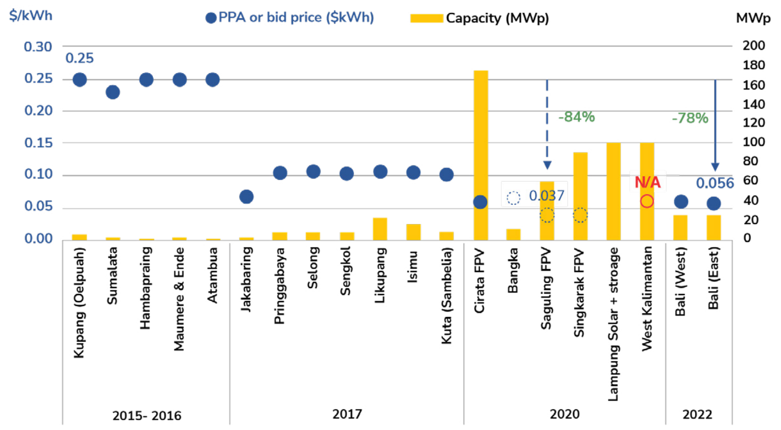
- By Q3 2022, there were 76.8 MWp of installed utility-scale solar projects, representing about 40% of Indonesia's total installed solar capacity. In terms of electricity generation, however, utility-scale solar accounts for only 0.04% of total grid-tied electricity generation in 2021 (excluding off-grid generation). This falls short of the deep decarbonization scenario that requires 24% of electricity generation share from solar by 2030, of which 80% are expected to be generated from utility-scale solar.

- While still evidently far from decarbonization requirement, utility-scale solar has shown a rather promising development in recent years:

  - Solar PPA prices have declined by 78% between 2015 and 2022 (from $0.25/kWh to $0.056/kWh), owing to the new PPA of Bali 2x25 MWp project signed in March 2022. In 2020, Indonesia Power's *Hijaunesia* equity partner solar auctions had also revealed record-low bids to below $0.04/kWh (84% decline compared to 2015's PPA price).

  - In terms of project pipeline, there are currently eight projects that have been at least tendered in some way, totaling 585 MWp in capacity. These include Cirata 145 MWac FPV project, Bangka 10 MWp and Bali 2x25 MWp ground-mounted solar projects, and projects from Indonesia Power's *Hijaunesia* equity partner auction.

Indonesia's solar PPA (and bid) prices, 2015–Q3 2022



Source: MEMR, IESR analysis. Notes: Year represents PPA signing year, not project commissioning. Dashed point represents awarded bid price, not final PPA price. Jakabaring PPA price was lower compared to average in the same year due to being funded using Joint Crediting Mechanism (JCM), see IESR's Hitting Record-Low Solar Electricity Prices for more details.

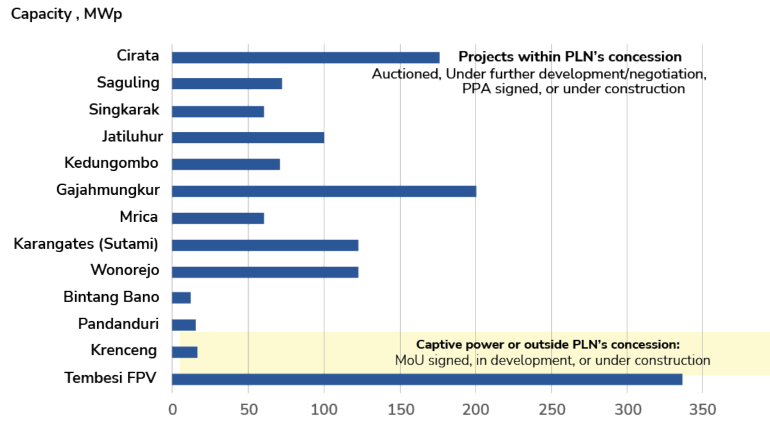
Floating solar is expected to lead utility-scale solar development; could also bring co-benefits when paired with hydropower

- Floating solar is expected to continue leading utility-scale solar development within PLN's capacity addition plan, although the project pipeline has not changed much since reported in IETO 2022. As of Q3 2022, there are at least three projects totaling 325 MWp in the pipeline (auctioned) and eight projects totaling 731 MWp that are still in pre-development stage (not yet auctioned). In RUPTL 2021, PLN plans to add 2.9 GW out of 4.7 GW of solar capacity using IPP scheme, where about 80% of that (2.4 GW) is expected to be operational by 2025.

- With regard to capacity addition plan in RUPTL, partnering with PLN's subsidiaries (i.e., PLN Indonesia Power or PLN Nusantara Power—previously PJB) under a 51:49 project equity structure seems to be the "preferred" project development style. This is apparent in the case of Cirata, Saguling, and Singkarak floating solar projects, owing also to their site specificity, and is likely to be followed in other cases such as Kedung Ombo, Gajahmungkur, and Sutami that already have development agreements from either one of PLN's subsidiaries.

- While the 51:49 structure is convenient for both SOEs and the private sector, PLN should also be open to a 100% (full) IPP scheme so as not to limit participation and increase competition in the auction. Retrospectively, solar tenders have been relatively opaque and has been carried out without clear scheduling years prior. To increase transparency and competitiveness of the remaining 2.9 GW to be procured using IPP scheme, PLN must prepare a clear, transparent, multi-year auction schedule ahead.

Floating solar project pipeline, as of Q3 2022



Source: IESR analysis. Notes: When only AC capacity (MWac) is known, a DC/AC ratio of 1.2 is assumed to reflect the DC capacity (MWp)

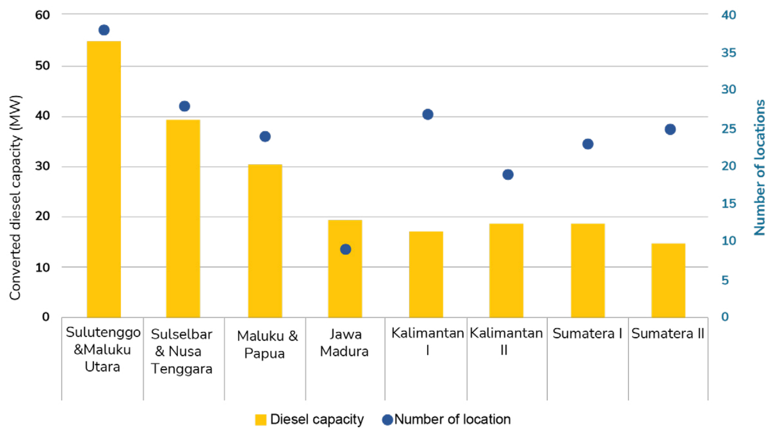
Box 1. Pairing floating solar with large hydropower could bring several co-benefits

- Lower PV curtailment when transmission constraint cause curtailment
- Conserve water by shifting hydropower generation to other periods of the year to maximise use of zero marginal cost generation from PV
- Reduce dependence of other peaker types generation (e.g., gas-fired generation) by reducing PV curtailment and more hydropower flexibility

Diesel conversion to solar+storage program has officially begun: while location clustering improves auction volume and economics, developers note challenges

- In March 2022, PLN finally issued the RFP for the first phase of the diesel conversion to renewables program. The first phase of the program aims to convert 212 MW (out of 499 MW) diesel plants in 183 locations into solar+storage projects, while the remaining 287 MW will be carried out in the second phase in a yet specified time frame.
- To improve auction volume and economics, the de-dieselization program introduced a clustering concept where the diesel generators scattered over 183 locations are grouped into eight clusters (14–55 MW of capacity/cluster). The first to be tendered were Jawa–Madura (cluster IV) and Kalimantan 1 (cluster V), replacing 19 MW and 17 MW of diesel generator capacity, respectively. It is important to note that the program is procured under an IPP scheme (consistent with RUPTL), where each cluster will have its own PPA with the selected bidder. The RFP originally expects PPA signing of the two clusters by October 2022 but seems to be facing a delay.
- While the clustering does improves auction volume, the complexity in bidding off-grid projects in scattered locations are challenging, especially given the short bidding time frame, developers note. This is because it takes time to physically survey and estimate the appropriate bid for the scattered locations with their site-specific load profiles.

PLN's diesel conversion to renewables phase 1



Source: PLN, IESR analysis

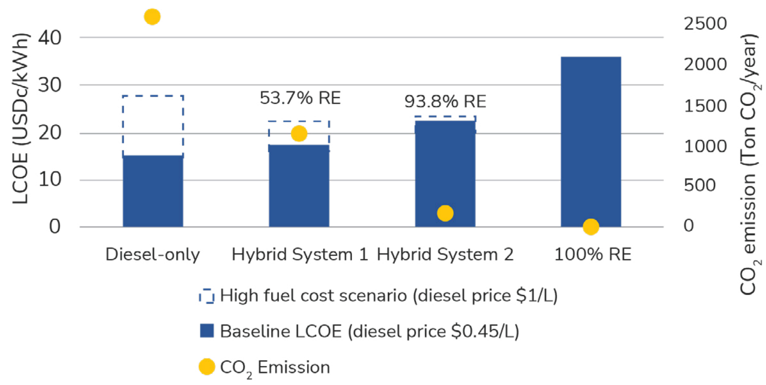
Off-grid solar+storage economics: The high RE fraction will be the most sustainable least-cost option, given the diesel price volatility

- Apart from the economical aspect, PLN needs to consider the sustainability of the new hybrid system. To achieve the program goal, tender winners should also include high renewable energy fraction in fulfilling the site-specific load, which will affect the fuel consumption and CO_2 emissions in the new system.

- Despite the potential of eliminating almost 1 kg CO_2/kWh of electricity produced by diesel generators, the cost of converting a diesel-only system to 100% PV+BESS is still expensive. For a site with a peak load of 720 kW, for example, the optimum system has an LCOE of 36 USD¢/kWh. Because of the current high price of BESS, the system might also be inefficient, requiring PV with a capacity of up to 10 times the peak load. Therefore, conversion to a hybrid system can be an executable temporary solution.

- To ensure economic sustainability and significant contribution to CO_2 reductions, the new hybrid system must have high RE fraction. In June 2022, the average price of one barrel of crude oil was above US$120 and is expected to stay around US$100/barrel by the end of the year, which translates to the diesel fuel price of US$1/L. This drives the generation cost of the diesel-based system to be at least 110% more expensive (to 28 USD¢/kWh) than PLN planned[7]. On the other hand, the generation cost of a systems with high RE fraction is already cheaper than the existing system at the high fuel cost scenario, while potentially reducing CO_2 emissions by up to 94%. Approving a low RE fraction system will prolong the reliance on imported oil with risks of increasing operating costs due to its sensitivity to the price of diesel.

Site-specific off-grid electricity system costs comparison



Source: IESR analysis. Notes: Analysed using HOMER Pro software assuming: 1) Discount rate: 6%, 2) project time 25 years, 3) retrofit diesel generator of 800 kW capacity, 4) Hypothetical community load profile (10,128 kWh/day) with 720 kW peak load, 5) 18% PV efficiency, 6) 3,3 MW PV capacity for hybrid systems cost $790/ kW, 7) 4.2 hour duration BESS with 15 years of lifetime cost $1790/kW, and 9) diesel-only system's fuel consumptions of 990 kL/year compared to 63 kL/year of hybrid systems with 93.8 RE fraction

[7]*Using the $0.45/L fuel cost reference stated in the RUPTL, the generation cost in the simulated system is 13.3 USD/kWh*

Presidential Regulation 112/2022 offers more attractive pricing compared to BPP-based pricing from MEMR 4/2020, making room for an improved return for RE developers

- The much-anticipated release of Presidential Regulation 112/2022 is expected to bring a breath of fresh air to the renewables sector in Indonesia. Not only did it set a new power purchase pricing policy for renewables, it also laid the groundwork for the acceleration of renewables deployment by setting out an instruction to accelerate the closure of coal power plants—an echo to Indonesia's commitment at COP 26's Global Coal to Clean Power Transition Statement—which provides a breakthrough for Indonesia's transition to low-carbon energy systems.

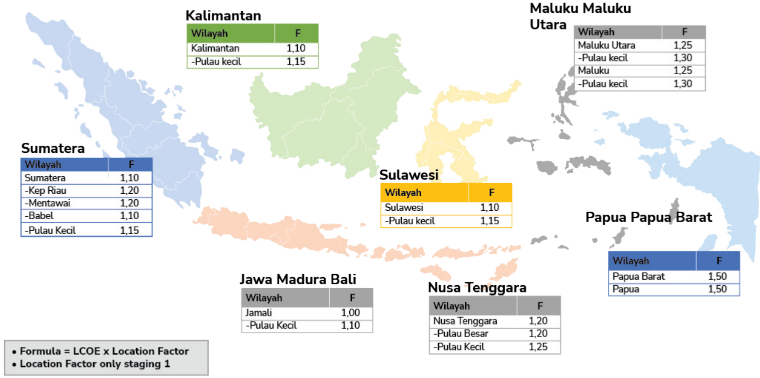
- For solar power purchase pricing, the presidential regulation now turns to ceiling price-based pricing from the previous system generation cost (BPP)-based pricing in MEMR Regulation 4/2020. The new pricing will be determined by competitive bidding using two-stage ceiling prices (for the first ten years and the year 11 to 30), a location factor (only for the 1st ceiling price), and will be without price escalation throughout the PPA. The regulation also set the ceiling price for solar+storage system, with 60% of the power purchase price as its ceiling price.

- Moving from BPP-based pricing[8] to ceiling price-based pricing will offer more room for developers to bid for a more favored return. This is especially true for smaller systems (≤10 MWp) where they have higher ceiling prices as it was intended to incentivize small producers who may not be able to get good economics (due to the lack of economies of scale), although the regulation originally intended to provide fixed feed-in tariff for small-scale solar (≤5 MWp). On the other hand, ceiling price is set lower for larger system (>20 MWp) since it is expected to have better economies of scale and, supposedly, lower financing cost. All these, however, will depend entirely on how the project or auction is set up.

New solar power purchase pricing in Presidential Regulation 112/2022

Solar PV Power Plant + battery

Capacity (MW)	Ceiling Price (HPT)																	
	(≤1MW)			>1MW s.d. 3 MW			>3MW s.d. 5 MW			>5MW s.d. 10 MW			>10MW s.d. 20MW			>20 MW		
	Stg th 1-10	Stg th 11-30	HPT Baterai	Stg th 1-10	Stg th 11-30	HPT Baterai	Stg th 1-10	Stg th 11-30	HPT Baterai	Stg th 1-10	Stg th 11-30	HPT Baterai	Stg th 1-10	Stg th 11-30	HPT Baterai	Stg th 1-10	Stg th 11-30	HPT Baterai
(cent $/kWh)	11,47 x F	6,88	5,85	9,94 x F	5,97	5,07	8,77 x F	5,26	4,35	8,26 x F	4,96	4,09	7,94 x F	4,76	3,94	9,95 x F	4,17	3,49
LCOE c$/kWh)	9,75			9,45			7,25			6,83			6,56			5,83		



- The regulation also laid out mandatory government support by relevant ministries to support renewable energy development. Few notable ones include: MEMR for renewable energy development planning, MoF for financial incentives (e.g., tax facility, import duty, and financing/guarantee facility), MSOE for setting renewable energy target for PLN, and MoI for supporting businesses by prioritizing domestic products by creating competitive domestic supply chain capabilities and preparing a roadmap for supporting industry on power (renewable energy) sector.

[8]BPP-based pricing is also a ceiling price-based pricing. Only, the ceiling price is determined by historical market price (the local BPP or national BPP) rather than being set by a predetermined policy price, which is typically at above market rate to incentivize development. It it important to note that although BPP is determined by historical generation cost, many indirect subsidies go into BPP (i.e., coal DMO and coal price cap at $70/ton, gas price cap for power plants at $6/MMBtu) making BPP artificially low (do not reflect true market price).

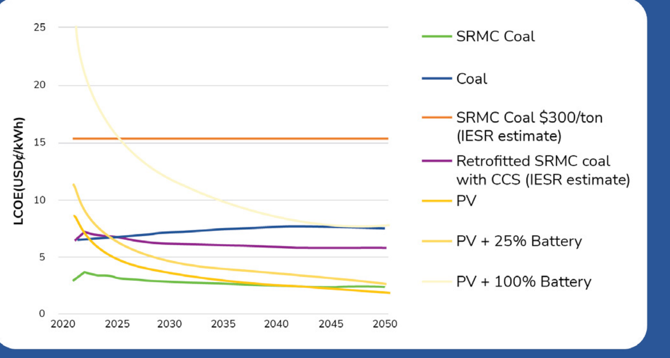
The acceleration of early closure of coal-fired power plants will pave the way for higher RE planning in future RUPTLs; could also open up opportunity for a more flexible operation of thermal power fleets during the transition times

- The instruction to accelerate coal-fired power plants' closure (Clause 3) in the regulation has positive and major implications for solar and renewables sectors in general. The first major implication is that, in the longer term, Indonesia could make room for more renewables in the power system planning. Currently, PLN only plans to add 4.7 GW of solar capacity in RUPTL 2021–2030, due to overcapacity condition, among other considerations. However, recent analyses showed that solar could play a larger role not only in achieving the 2025 target but also for long-term decarbonization. IEA analyzed that 2.5 GW of non-committed planned capacity in RUPTL 2021 (mainly geothermal[9], hydro[9], and some biomass co-firing[10] capacity) could be replaced with 17.7 GW of utility-scale solar (in Java–Bali and Sumatra systems) to achieve the 23% RE target in 2025. IEA also found that Java–Bali and Sumatra systems are capable of accommodating a 10% share of solar electricity by 2025 using flexibility[11] means in the system.

- Another major implication is that the clause will open up the opportunity for PPA contract renegotiation of thermal power plants, especially coal, to be operated flexibility, moving away from base load into flexible generation. Flexible generation of conventional power plants, during transition times, is one of best sources of power system flexibility to accommodate VRE's variability, allowing for higher VRE penetration. To do this, however, there should be contract renegotiation from the currently high guaranteed offtake obligation (80–85%) of coal-fired power plants, as stipulated in the rigid take-or-pay (ToP) clause, into compensating and incentivizing the fleet for flexible operation (operating at minimum load during certain times, especially when VRE generation is high). Renegotiation could also consider encouraging the producer into ancillary services and capacity markets to cover the loss from the lowered ToP scheme (IESR, 2022).

Box 2. Improving solar economics

Electricity generation cost comparison between new (LCOE) and running (SRMC) CFPP with stand-alone or battery-paired solar PV



Source: IESR analysis. Notes: LCOE refers to levelized cost of energy, a unit cost per energy metric used to compare new-build electricity generation. SRMC refers to short-run marginal cost, often associated with the cost of running a power plant (fuel cost).

- IESR analysis shows that it will be cheaper to build new solar than new coal (LCOE) in 2023 and that solar will undercut the cost of running coal (SRMC) before 2040 (assuming the protectionary DMO price of $70/ton). It is important to note that solar is already cheaper than running a coal-fired power plant today if real market price is used (coal price has reached more than $300/ton in 2022).

- New solar with energy storage sized at 25% capacity will be more competitive than new coal by 2025 and even becomes more competitive than running coal equipped with CCS, which is currently being proposed as one of false solutions to reach NZE, by 2025. Solar, therefore, will become the cheapest option to catalyze early coal phase-out in Indonesia, and, hence, a more ambitious solar planning must be considered in the power sector roadmap.

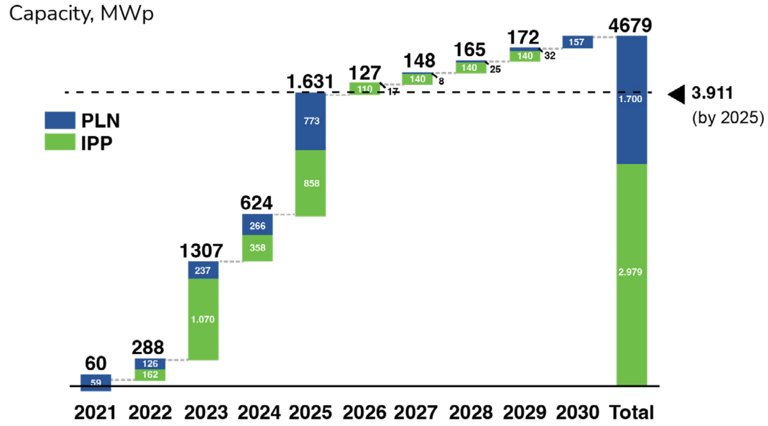
[9]Due to long lead times and [10]feedstock sustainability concern.
[11]While the existing assets are technically capable of delivering the flexibility needs, the IEA stressed that the main barrier to accommodating higher variable renewables penetration in Indonesia is the contractual inflexibility, that is, the take-or-pay obligations (with minimum offtake) in coal IPPs' PPAs and in fuel supply contracts for gas generators, which reduces the incentives for thermal units to be operated flexibility.

Ultimately, auction scheduling and auction design will be pivotal in realizing the many good potential of the presidential regulation

- When it comes to the actual implementation of planning in RUPTL, auction scheduling becomes ever more crucial. Since 2017, utility-scale (IPP) solar auctions have been procured sporadically without a regular auction schedule, often using one-off standalone auction (IESR, 2021). This has been a rather poor translation of the RUPTL from planning to implementation for years. Under the current RUPTL, PLN plans to add 4.7 GW of solar by 2030 where at least 2.9 GW (63%) will be procured using IPP scheme. However, PLN has not—or rather, never—released an auction schedule for the implementation of RUPTL. Releasing an auction schedule will be the first requisite for a sustained deployment and more competitive solar auctions as it sends clear market signals.

- Another equally important enabler is the design of the auction. The presidential regulation stated that it will use a capacity quota offering for solar project auction. This is already a good sign since auction volume will reflect the size of the demand to market participants. The government and PLN should also consider several key auction design elements (IRENA, 2015):

Solar capacity addition plan in RUPTL 2021–2030



Source: PLN, IESR analysis.

  - *Qualification requirements*: Essentially, balancing the trade-offs between participation and competition (by lowering the barrier to entry) and the risk of underbidding that might lead to project delays, even incompletion, when companies try to bid below their technical and financial means. Theoretically, increasing participation should lead to more competition and, hence, will give the most competitive results. This, however, will depend on the kind on the technical experience and financial capabilities of the bidding companies. In certain cases, it might make sense to make a tiering requirement for larger scale projects (>100 MWp) and smaller ones (≤20 MWp).

  - *Winner selection process:* As the heart of the auction itself, involves what bidding procedure is used, how the winner is determined, and how the contract is awarded. In Indonesia, PLN's bidding has traditionally followed a sealed-bid process, using a one-stage: two-envelope bidding (one for administrative and technical proposal, the other for price proposal). The criteria to determine the winner is often the lowest price, but could also include multiple criteria especially when a specific policy is considered (for example, linking bidding scoring with building domestic PV manufacturing). The eventual PPA price is usually determined according to the bids (pay-as-bid), although traditionally it has been done using further negotiation (which is undesired as it is non-transparent and takes more time). And lastly, should ideally have a well-balanced risk allocation in the PPA, where a standardized bankable PPA would certainly help send a positive signal to the market.

  - Beyond auction design elements, another important element is *pre-project development*: the government could support pre-developing sites to reduce sunk costs risks for developers as they are only reimbursed if the project is awarded, which has been one of the major barriers for unsolicited proposal-based tenders in the past years (IESR, 2021). The government could also provide support on pre-project development such as access to grid, permitting, conducting pre-feasibility studies as and environmental and social impact assessments. A quick win for this could be to pre-develop sites for floating solar projects at dams and lakes, which has been 22 gaining traction in the past two years.

Solar electricity export projects hit a wall as the govt mulls plan to ban clean power exports

- In October 2021, Singapore announced its plan to import 4 GW of low-carbon electricity by 2035. By April 2022, Singapore has received a total of 20 proposals from Indonesia, Laos, Malaysia, and Thailand, of which at least five consortiums plans to develop export-oriented solar projects from Indonesia, specifically in Riau Islands. By the following month, however, the projects were faced with uncertainty as the Indonesian government mulls plan to ban clean power exports.

- The ban was floated by the Indonesian Minister of Investment, ostensibly at the instruction of President Joko Widodo, over domestic priorities concerns. This is despite the fact that the energy ministry had previously signed an MoU with Singapore's trade and industry ministry in January 2022 on energy cooperation that includes renewable energy development such as solar power and green hydrogen, cross-border electricity interconnection, energy trading, and human resources capacity building. At the time of writing, however, the Indonesian government has not officially released the ban yet (nor has it granted any electricity export permits).

- Consortiums will still have to secure at least three main licenses to export electricity from Indonesia should the ban is not imposed: an electricity business concession (*Wilayah Usaha*), an electricity supply business license (IUPLTU), and cross-border electricity sales and/or interconnection permit(s). Obtaining a *Wilayah Usaha* will be the most difficult as it can only be done when there is an existing holder that is unable to (or no longer qualified to) provide electricity in the area and have its license revoked—which is quite unlikely in Riau Islands' case. An alternative scheme does exist; that is, to use a (power) wheeling agreement with an existing *Wilayah Usaha* holder.

Consortiums with plans from Indonesia

No.	Consortium	Capacity (PV, BESS)	Phase	Location	Notes
1.	PacificLight Power, Medco Power Indonesia, Gallant Venture	670 MWp (100 MWac)	Pilot, RFP1	Bulan Island, Batam, Riau Islands	Has been granted in-principle approval by the EMA for the pilot import project of 100 MW equivalent of non-intermittent electricity (on a separate RFP from RFP1)
2.	Sembcorp Industries, PLN Batam, Trisurya Mitra Bersama (Suryagen)	1 GWp + BESS*	RFP1	Batam, Bintang, dan Karimun, Riau Islands	
3.	EDF Renewables, Indonesia Power, Tuas Power, Masdar	1.2 GWp + BESS*	RFP1	Undisclosed	
4.	Sunseap, Mustika Combol Indah, Agung Sedayu, Sumitomo Corp., Samsung C&T Corp., Oriens Asset Management, Durapower	7 GWp, 12 GWh	RFP1	Batam, Combol, Citlim, Riau Islands	Including the 2.2 GWp (+4 GWh) floating solar project in Duriangkang Reservoir, Batam
5.	ib vogt, Quantum Power Asia, Union Power	3,5 GWp, 12 GWh	RFP1	Riau Islands	

*Source: Company press releases, IESR analysis. Notes: BESS = Battery energy storage system, *capacity undisclosed*

If the export projects could be realized, it may unlock the opportunity toward realizing the ASEAN Power Grid

- In the broader context, the success of the export projects could open up the path toward realizing the ASEAN Power Grid (APG), a regional supergrid that allows multilateral electricity trading between the ten ASEAN member states. Originally conceptualized in 1997, the APG has been a long-standing goal of ASEAN. To date, however, regional power trading has been limited to a series of uncoordinated bilateral cross-border arrangements, despite its multiple benefits such as reduced system costs, increased energy security, and the ability to provide system flexibility for higher variable renewable energy integration.

- In June 2022, Singapore finally began importing hydroelectricity from Laos through Thailand and Malaysia in a project (LTMS PIP[12]) that serves as a pathfinder toward realizing the APG. While marking a historic milestone as the first multilateral cross-border electricity trade involving four ASEAN countries, it took eight years to finally transfer power across borders. With the recent renewable energy export ban of Indonesia and Malaysia, it further signifies that while the APG has been discussed for a long time (25 years), the APG remains difficult to realize not necessarily only because of technical and commercial reasons, but primarily because of political considerations, domestically and internationally.

- With ASEAN countries now racing to go net zero, a regional collaboration could help accelerate the energy transition and alleviate the climate impacts. While prioritizing domestic use may be obvious for countries, sharing resources could still be approached with a system net benefit mindset. If done correctly, all countries may benefit from the interconnectedness of the APG, especially in the effort toward cutting emissions.

The ASEAN Power Grid

Source: IEA (2019). Note: Existing transmission lines as of April 2019.

[12]*LTMS: Laos–Thailand–Malaysia–Singapore Power Integration Project*

Distributed Solar

- Rooftop solar market and policy development

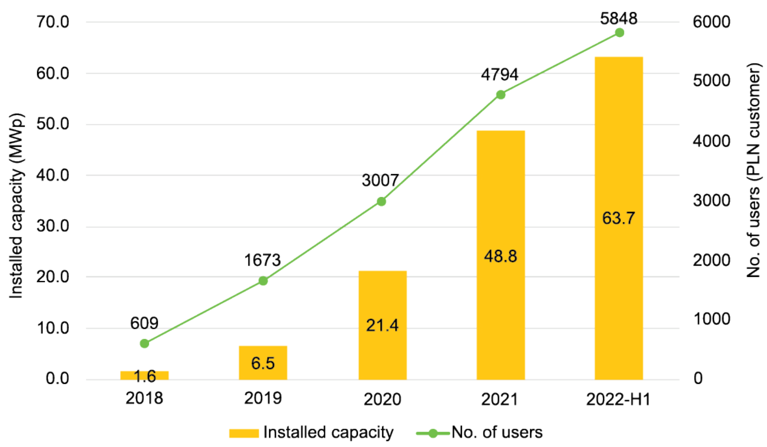
Distributed solar offers alternative, faster adoption compared to utility-scale solar. Its deployment, however, is hampered by the recent maximum capacity limitation

- Distributed solar, particularly rooftop solar, has enjoyed modest growth since the release of MEMR 49/2018 that allows net metering in PLN's system. Since 2019, the sector has added about 1,300 users on average every year, adding about an average of 15 MWp annually. As of H1 2022, total installed rooftop solar capacity (from PLN customers only) reached 63.7 MWp with a total of 5,848 users.

- Despite decent progress over the years, this year's growth has been hampered by PLN-imposed restriction[13] started in March 2022 that limits rooftop solar maximum capacity installation to only 10–15% of the customer's installed power connection (from originally 100%) due to concerns over further overcapacity condition, primarily in Java–Madura–Bali (Jamali) system, and potential revenue loss. This is also on top of the fact that MEMR 26/2021, which revises net metering policy to 1:1 (from 1:0.65), was just formally enacted[14] a month prior, which is still pending implementation until the time of this writing.

- Hosting capacity studies conducted separately by Universitas Gadjah Mada and Udayana University found that while there is a limitation in solar penetration to the Jamali system (until it becomes necessary to add more grid flexibility to the system), it exists at system-level, not at individual customer's connection. According to Udayana University, Jamali system can host as much as 15% of solar penetration without the need of flexibility and should be interpreted as 15% from power transformers' capacity rather than from the customer's individual power connection.

Rooftop solar installed capacity and user growth (PLN customer only), 2018-2022 H1



Source: MEMR, IESR analysis

- As much as 2.3 GWp of project pipeline from 31 declarators at the Indonesia Solar Summit 2022 could be in limbo because of the limitation. Relatedly, the government's 3.6 GWp by 2025 rooftop solar target may potentially remain off-target if the limitation persists.

[13]According to PLN's internal circular, the restriction arises due to concerns over further overcapacity condition in Java–Madura–Bali (Jamali) system as there will be 8.3 GW of capacity addition in 2022, all the while blaming MEMR 26/2021's lack of technical details in ensuring the system's reliability. While PLN did mention that the current "service strategy" is temporary, it is unclear when PLN will remove the restriction.

[14]MEMR 26/2021 was originally stipulated in August 13, 2021 and enacted in August 20, 2021 but its "official enactment" was postponed until February 7, 2022 due to requiring approval from the President 26 (following Presidential Regulation 68/2021). In the process there were additional studies on the impact of the implementation to subsidies and compensation on the state budget.

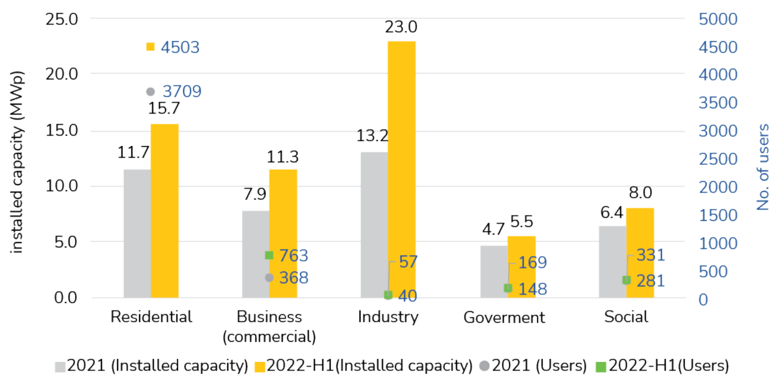
Lost opportunities: the 10–15% maximum capacity limitation is a major impediment to rooftop solar growth and is affecting different segments differently

- The restriction affects different segments differently as they are playing under different economics and business model. The C&I sector, for example, might still be able to find a good business case under the 10–15% max. capacity limitation[15]. Assuming a 10 MVA power connection, a 10% max. capacity limitation could still allow a 1~1.5 MWp project that might give an attractive economic case, though may not be most optimum. However, it is important to highlight that the C&I sector contributed to over half of the total installed rooftop solar capacity by H1 2022 and is expected to become a major driver to come. Putting a maximum capacity limitation also means cutting down the largest driver of growth in the sector.

- For the residential sector, the limitation necessarily prohibits households to have a sound business case for adopting rooftop solar. Under the limitation, assuming a typical 2200 VA installed power connection for regular house, households can only install a single panel (300~400 Wp), which is not optimum for cost savings and the return on investment. This is quite unfortunate since the residential sector is the largest driver for rooftop solar user growth.

- Other sectors such as the government and social (tariff groups) sectors are also similarly impacted by the max. capacity limitation, although the sectors are driven by different enabling factors to begin with (such as state budgeting, for instance). Altogether, the max. capacity limitation has also hindered the effectiveness of the one-year Sustainable Energy Fund (SEF) grant that provides incentives for rooftop solar users (using a voucher cashback).

Rooftop solar growth by segment, 2021-2022-H1



Source: MEMR, IESR analysis. Notes: 2021 data breakdown is as of Nov 2021. Data from special service tariff group excluded for graph clarity

[15]*The capacity limitation is based on the inverters power rating (AC), not the solar panel power rating (DC)*

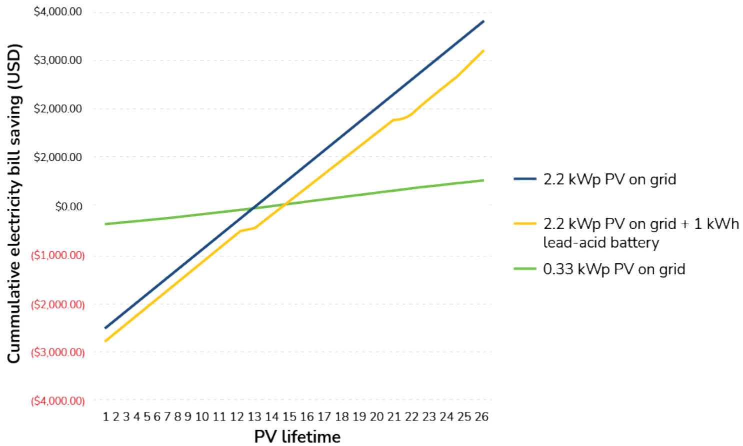
Much lower bill savings potential due to capacity limitations would discourage the prosumers' interest in PV despite declining installation costs cutting the payback time to around 10 years

- In Indonesia, the cost to install rooftop PV has fallen to 15-17 million rupiah (per kWp). As a result, for example, if there is a 2200 VA PLN customer who wants and is allowed to install 100% (from installed power subscriptions) of PV capacity, the installer has the potential to reduce electricity bills approximately 56 million rupiahs within the PV lifetime. Additional savings can further be obtained, through the SEF program, to prospective PV installers.

- In addition to the benefits of electricity bill savings in a grid-tied PV system, adding a battery today would give a property electrical supply security in case of a utility power outage at only a small additional cost. It should be noted that the national SAIDI[16] and SAIFI[17] in 2021 are 9 hours and 7 times, respectively, and historically occurred longer and more often to consumers who live outside the Java utility system (PLN, 2022). Small battery packs can meet the technical requirement as a backup appliance. A typical commercial 1 kWh battery sold in the Indonesian marketplace for <$200/kWh could sufficiently back up the house power outage for 2-4 hours[18] when it is fully charged. IESR estimates a trade-off to equip a 2.2 kWp rooftop PV with a battery would be a slight increase of initial capital cost of around 7% for every kWh storage capacity, depending on the battery type.

- Although the capital to install rooftop PV is now much more affordable, the capacity limitation set by PLN without a definite period heavily discourages the interest of potential PV adopters. Even with the upper limit of 15%, the electricity cost savings for residential customers (2200-3500 VA) practically will be less than 5% (of 100% capacity limit). Any form of regulation (e.g., renewal of net metering) or incentives such as installation subsidies, therefore, can also be counterproductive as long as capacity restrictions are in place.

Potential bill savings from installation of rooftop PV with different capacity limit



Electricity source	NPC	Initial Capital	LCOE ($/kWh)	IRR	ROI	Payback (years)	Discounted Payback (years)
Grid($0.97/kWh)	$5,945	$0	0.097				
2.2 kWp PV on grid	$4,718	$2,503	0.058	8.7	5.9	10.05	13.61
2.2 kWp PV + 1 kWh Lead-acid battery on grid	$5,153	$2,680	0.063	7.1	4.7	11.7	16.43
0.33 kWp PV on gird	$5,761	$380	0.094	8.7	5.9	10.05	13.61

Source: IESR analysis. Note: Assumes a discount rate of 6%.

[16]SAIDI: System Average Interruption Duration Index; [17]SAIFI: System Average Interruption Frequency Index
[18]Assuming 2200 VA household daily electricity consumptions of 6-12 kWh in Indonesia (Abdurohman. K. O, et at, 2020

The Indonesian government should, instead, start fostering rooftop solar uptake to the point of self-sufficiency

- What Indonesian policymakers should aim to do instead—all the while aligning progress toward deep and rapid decarbonization—is to stimulate early market development to the point of self-sufficiency, that is, by providing stable policy environment for stable growth and industry development. While *utility push-back*[19] is common when it comes to distributed solar adoption anywhere in the world, Indonesia must carefully consider its policy design to align incentives for both PLN and the adopters.

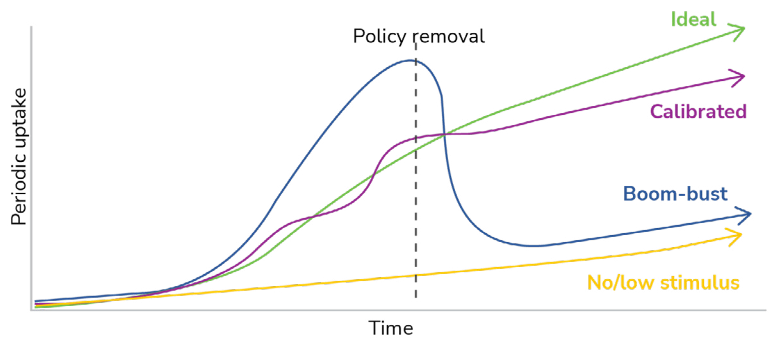
- The government could consider the following uptake profiles when considering a policy design:

  - A decade ago, policymakers have used production-based incentives such as feed-in tariffs, capital subsidies, or tax benefits to kickstart distributed solar adoption at a time when the cost of a solar panel was still very expensive (85% more expensive than today's). With the falling cost of solar panels today, less and less subsidies are required to make a distributed solar system cost-competitive, hence the "policy removal" after a self-sustaining market is achieved ("**ideal**" profile).

  - Historically, though, policymakers found it difficult to ignite the market takeoff without an unsustainable boom. Markets such as the Europe, Japan, Australia, and more recently Vietnam have offered generous feed-in tariffs that led to a **boom–bust** uptake when the policy support was removed (BloombergNEF & Scheinder, 2021). While it is sometimes inevitable to do so (driven by political will), not all countries are able to do the same due to fiscal space and budgetary constraints.

  - In contrast, the other end of the uptake profile is the "**no/low stimulus**", where countries do little to support market adoption using financial incentives, much like in Indonesia with its net metering policy that hinges entirely on consumer's intrinsic motivation. While it is generally less attractive than premium feed-in tariffs scheme, net metering can still foster development granted that it has a stable policy environment (not prone to regulatory changes, restriction, export tariff limitation, etc.).

Illustrative policy-driven distributed solar uptake profiles



Source: BloombergNEF & Schneider (2022).

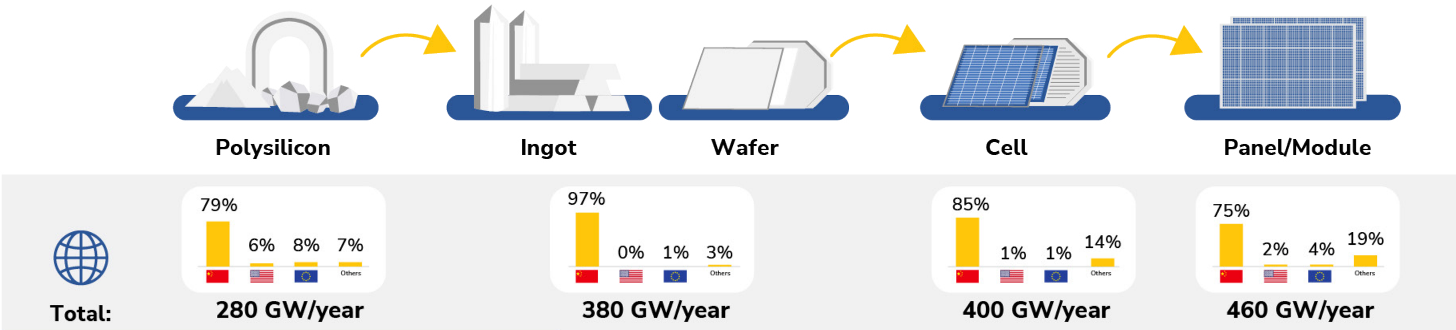
- Ultimately, the realistic sweet spot of all is the "**calibrated**" uptake profile, where policymakers can drive customer interest without unsustainable boom by aligning incentives to market dynamics and adjusting policy support based on desired adoption level. For instance, the Indonesian government could support (or further incentivize) early adoption with the net metering (1:1) without the capacity limitation until a certain adoption level and market sufficiency are reached before calibrating (dialing back on) the policy, rather than disincentivizing it at such an early development stage.

[19]Utility push-back is when utilities demonstrate reluctance in supporting distributed solar adoption. It generally happens when there is a lack of incentive for utilities to encourage the deployment with which the reasons may vary from revenue loss, system stability and reliability perspective, etc. Utility push-back may come in the form of onerous permitting rules, penalties and charges; and export limits are common that make solar more difficult to install, more expensive and less attractive (BloombergNEF & Scheinder, 2021)

PV Manufacturing and Supply Chain

- Global PV manufacturing
- Indonesia PV manufacturing and policy development

Global solar PV manufacturing capacity has been increasingly concentrated in China over the last decade, posing a potential risk of supply chain disruption in the future



Global PV industry production capacities, H1 2022

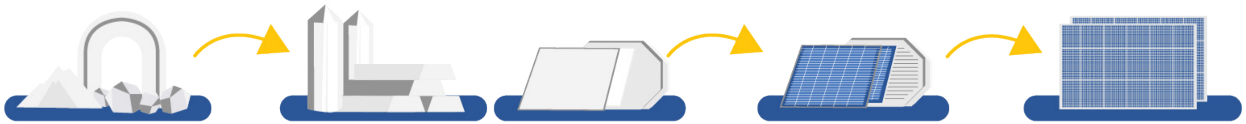
Source: Ministry of Industry, APAMSI, BloombergNEF. IESR analysis. Notes: Production capacities include plants that have been commissioned, are under construction, or have been announced.

- Global solar PV manufacturing has been dominated by China in recent years. By the end 2021, more than 80% of each key manufacturing stages of solar panels are dominated by China. As trade is important to provide the material and components to the final market, the supply chain is vulnerable to the trade restrictions (especially imposed to China) and will affect to the deployment of the solar PV. Along with that, the concentration of production capacity also poses vulnerability. For instance, a 2020 explosion at a polysilicon facility in China put 8% of global polysilicon production capacity out of operation. It led to an estimated 4% decline in annual production in an already-tight polysilicon market, contributing to the near tripling of prices between 2020 and 2021. The availability of polysilicon also affected by the Covid-19 crisis which pushed polysilicon prices tripled at the beginning of 2021 towards the end of that year.

- Recent disruptions have raised important supply chain questions. The Covid-19 crisis, record commodity prices, and Russia's invasion of Ukraine have all focused attention on the high reliance of many countries on imports of energy, raw materials, and manufacturing goods that are key to their supply security. Countries can improve resilience by investing to diversify their manufacturing and imports. And with the expectation of annual additions of solar PV capacity to electricity systems around the world, policymakers and stakeholders across the world have already paid more attention to solar PV manufacturing supply chains.

- Market consolidation occurs especially the higher up the value chain (polysilicon and ingot & wafers). This is due to a high technical (energy-related) and economic hurdles for plants that make polysilicon, ingot, and wafers. The market for solar cells is much less consolidated. In 2019, the top 10 cell producers supplied only 59% of the market. Outside China, there is 50-60 GWdc of cell manufacturing capacity, based on projects that have been announced or under construction, mainly in Vietnam and Malaysia. The investment trend outside China, is due to United States and Europe announced anti-dumping and anti-subsidy against China, leading to higher tariffs on solar import.

PV manufacturing in Indonesia is still limited to only module assembly stage; technical and economic hurdles make investments on the higher value chain not feasible



	Polysilicon	Ingot	Wafer	Cell	Panel/Module
	N/A	N/A		(+1 GWp)	1644 MWp (+1 GWp)

Indonesia's PV industry production capacities, H1 2022

Source: Ministry of Industry, APAMSI, BloombergNEF. IESR analysis. Notes: Production capacities include plants that have been commissioned, are under construction, or have been announced.

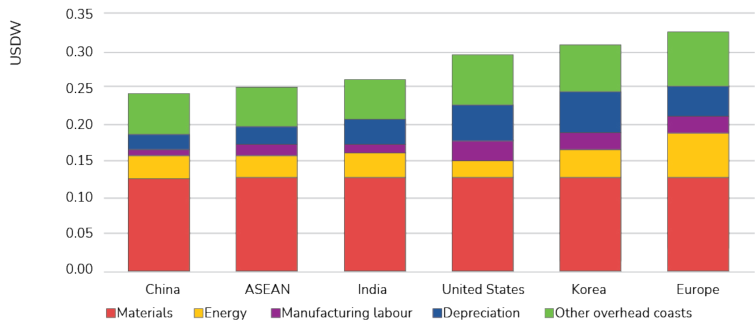
- Indonesia's PV manufacturing is so far only limited to module assembly (using imported cells), with a total annual production capacity of 1,644 MWp from 21 manufacturers. Out of the 21 manufacturers, three manufacturers located in Batam alone accounted for 50% of the total production capacity and are oriented for trade export. In terms of quality, that is efficiency and module size, local PV modules are still below imported Tier-1 ones and with higher prices (30–45%). This has led to the low utilization of the local PV module manufacturing, that is less than 10% of its annual production capacity.

- MEMR announced a roadmap to achieve NZE by 2060 that led to additional PV capacity of 420 GW. Furthermore, more ambitious target to achieve NZE by 2050 require 1,500 GW of additional PV capacity. Hence, all the targets need a significant deployment of PV for the upcoming years which led to readiness of domestic PV supply chain of Indonesia. Heavy reliance on import led to bad implication regarding the supply. More localised production would provide greater security against disruptions. However, Indonesia should consider multiple factors such as investment requirements, electricity prices, and manufacturing costs before deciding to expand their capacity production of PV key manufacturing.

- As previously mentioned, building PV manufacturing industry is difficult, especially the higher the value chain. However, building a solar cell factory with a competitive production capacity is still feasible. For cells and modules, minimum investment requirements are low compared with the energy-intensive part of the PV supply chain. Cell and module-manufacturing plants could be as small as 100 MW, requiring very low minimum investments of around a few million US dollars. PT Len industri announced that there's a plan to build a solar cell manufacturing with them as Partner Technologies and Investment.

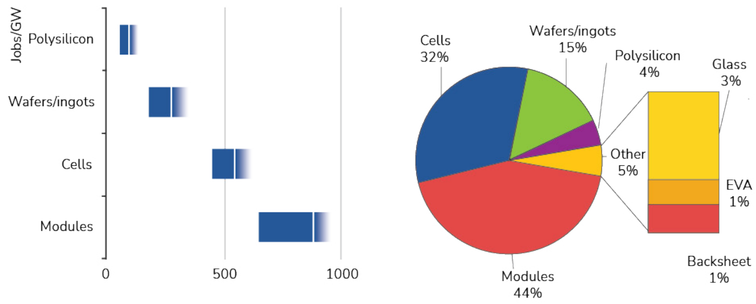
Net-zero emissions target consequently demands the development of an integrated domestic solar manufacturing

Total production costs mono PERC c-Si solar components by input, 2022



Source: IEA

Jobs per GW of manufacturing capacity and share of jobs per supply chain segment



Source: IEA

- Relatively low energy prices, material costs and inexpensive labour make China the most cost-competitive location to manufacture all components of the solar PV supply chain. In the ASEAN region, total module-manufacturing costs can be around 5% more than in China, mainly due to slightly higher overhead and labour costs. Indonesia's relatively low electricity prices, below USD 80/MWh (although helped by the DMO policy for the coal), present opportunities for cost-competitive solar PV manufacturing. However, today Indonesia has emissions intensities for manufacturing that exceed the global average due to high shares of coal in their power mixes should also got an attention. Other factor to consider is the economic of scale for the integrated solar pv industry from polysilicon to module plants to make the cost of product cost competitive with the imported ones.

- To expanding manufacturing capacity, job creation is one factor that should be considered. IEA estimated that producing 1 GW of c-Si solar module capacity per year could create 1300 full-time manufacturing jobs. The most labor intensive segments along the manufacturing process are module production and cell manufacturing, which stands on 44% and 32% respectively. Hence, a workforce training should be included by policy makers in the strategy to scale up domestic production.

- Governments and employers should introduced coordinated training programmes for new employees to provide the amount of labour needed to secure investment in local manufacturing facilities. Such policy implementation which led to positive implication can be found in Malaysia. Policies that already implemented are: Integrating practical knowledge regarding renewable energy in the curriculum, developing centre of research and development in universities, and give incentive program of certification which aligned with industry needed. Good quality of Malaysian human resources is one of the factors that attract investment foreign investment.

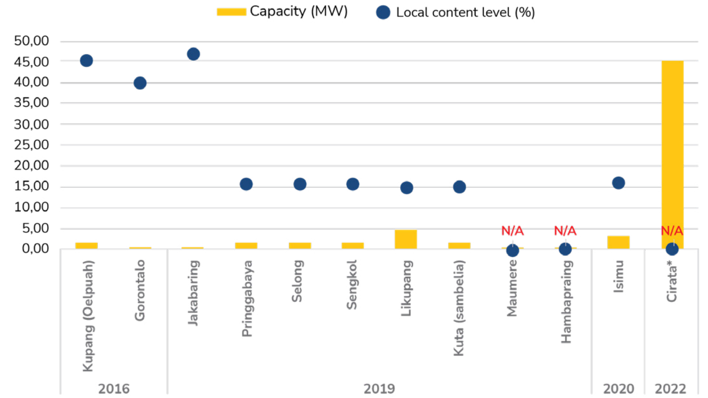
LCR policy, implemented to support the development of domestic PV production, is still a big hurdle for PV deployment

- LCR policy (MoI 5/2017) to support the development of domestic PV production, oblige the development of solar PV module using 60% domestic product by 2019. According to MoI's roadmap by the end of 2025, LCR for the solar PV module should reach a minimum of 90% with the support of the establishment of solar grade silicon, ingot, and metallurgical grade silicon factory. However, there's still no announced plan regarding those factory projects. Hence, the target is not feasible to be achieved.

- For now, LCR policy has been a significant hurdle discouraging the development of solar PV projects in Indonesia. LCR policy applied to PV module components is hard to fulfil, even for the 40% obligation, given the none single PV module chain supplier with more than 150 MWp production/ year, has a lower quality and 30-45% more expensive than the imported ones. The low quality and the prices of the PV module has implications for the financing of the projects.

- EBTKE imposes a more feasible roadmap. With the support of local module and cell manufacturers, the LCR is targeted to reach 40% by 2024. The critical target is the availability of Tier-1 local solar PV manufacturers to provide the "bankability" (see Box 3). One of the requirements to achieve that standard is local manufacturers should provide for at least six different projects. Hence, it's crucial to increase the number of solar PV projects by the government.

Local content of several solar projects in Indonesia



Source: MEMR, IESR analysis. Notes: Year represents COD (For Cirata is the expected COD date)

Box 3. BloombergNEF PV Module Tier 1

BloombergNEF has developed a tiering system for PV module products based on bankability, to create a transparent differentiation between the hundreds of manufacturers of solar modules on the market. 'Bankability'—whether projects using the solar products are likely to be offered non-recourse debt financing by banks—is the key criterion for tiering. Banks, and their technical due diligence providers, are extremely unwilling to disclose their whitelists of acceptable products. BloombergNEF therefore bases its criteria in what deals have been closed in the past.

- Increasing number of solar PV projects while maintaining LCR policy is a challenge considering the given domestic PV industry. In India case, to achieve the best of both worlds, they imposed two categories of project. Developers can participate in LCR segment, need to provide modules and cells locally, or "open" category, the LCR policy did not apply. This rules gave the developers flexibility while keep the domestic production high. In terms of installed solar generating capacity, the country had 43.6 GW of operating PV as of November 2020. While local-content rules spurred growth in India solar manufacturing. The country today has a significant presence in the production of finished PV modules and, to a lesser degree, in the manufacturing of PV cells.

Solar Environmental Impacts

- Life-cycle GHG emissions
- PV waste and recyclability
- Land use requirements

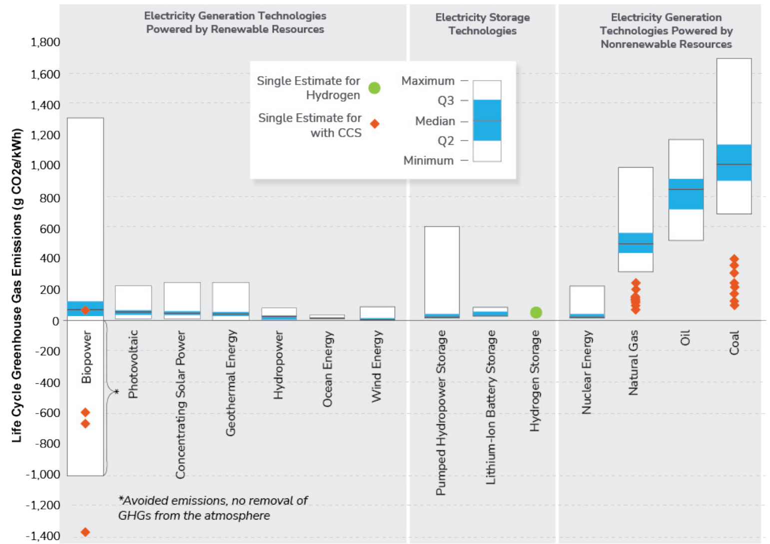
Solar PV offers an alternative low-emissions electricity, although from a life-cycle perspective it still produces one-time emissions from its manufacturing

- Solar PV technology has multiple environmental advantages compared to fossil fuel. For instance, GHG emissions of power production from solar PV is significantly less than fossil fuel technology, which the emissions come from the grid. From cradle to grave, coal-fired electricity delivers about 20 times more GHGs per kilowatt-hour than solar, while natural gas produces about 10 times more (NREL,2021).

- However, emissions are still come from PV production. The life cycle inventories' scopes of PV includes infrastructure, site preparation and occupation, operation and maintenance; decommissioning (energy inputs and waste production); and connection to grid (UNECE, 2021). About two third of solar PV life cycle GHG emissions come from the upstream process, which includes resource extraction, material and component manufacturing, and construction.

- Lifecycle GHG emissions of silicon PV ranges between 23–83 g CO_2 eq./kWh depending on the region. The high regional variation is due to different raw material origin, energy mix used for production, transportation, etc. (UNECE, 2021). Currently, most of silicon PV panels are produced in China, which has the share of coal and gas in power generation for more than 70% (Bloomberg, 2022). As Indonesia moves toward deep decarbonization, which require building its own domestic PV manufacturing, Indonesia could lower life-cycle emissions along with its transition through the increasing share of renewable energy mix.

Life cycle greenhouse gas emission estimates for selected electricity generation and storage technologies



	Biopower	Photovoltaic	Concentrating Solar Power	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Pumped Hydropower Storage	Lithium-Ion Battery Storage	Hydrogen Storage	Nuclear Energy	Natural Gas	Oil	Coal
Estimates	276 (+4)	46	36	35	149	10	186	16	29	1	99	80(+13)	24	164 (+11)
Refrences	57 (+2)	17	10	15	22	5	69	4	3	1	27	47 (+11)	10	53 (+9)

Source: NREL (2021). Notes: NREL estimates GHG emissions from hundreds of life cycle assessments worldwide.

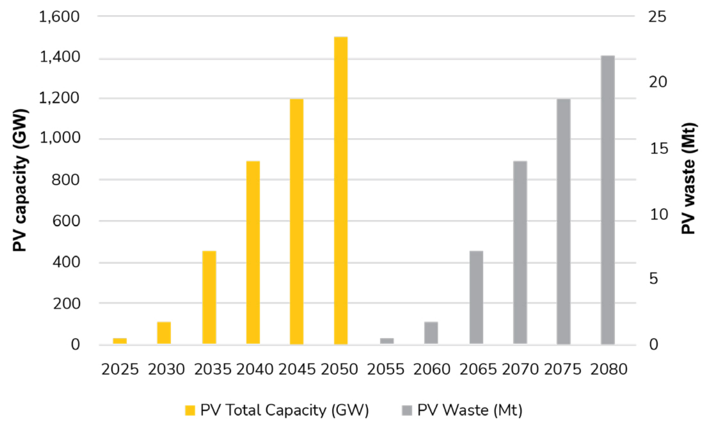
The value creation of Indonesia's solar PV waste could reach $400 million in 2060. However, a comprehensive and sound policy framework is crucial in realizing the opportunity

- To achieve the 1.5 °C scenario, waste from global cumulative solar PV projects would increase from 0.2 Megatonne (Mt) in 2021 to 4 Mt in 2030 and more than 200 Mt in 2050 (IRENA, 2021). Meanwhile, to achieve zero emissions target by 2050, Indonesia would need to install 100 GW of solar PV up to 2030 (IESR, 2021). Considering 30 years of PV life span, it could potentially bring more than 1.5 million tonnes of PV waste in 2060.

- Crystalline silicon (c-Si) PV panel is built with 76% glass (panel surface), 10% polymer (encapsulant and backsheet foil), 8% aluminium (mostly the frame), 5% silicon (solar cells), 1% copper (interconnectors) and less than 0.1% silver (contact lines) and other metals (mostly tin and lead) (IRENA, 2016). More than 80% of solar PV panels can be recycled and reused (Kearney, 2017). Furthermore, the recycling industry of glass, which composes most of the weight, is already well-established. In addition, waste from end-of-life solar panels create jobs through recycling and offers opportunities to recover valuable materials (EPA, 2022). The value creation from raw material recovery, new industries and employment can reach almost USD 400 million from 1.5 million tonnes of potential PV waste.

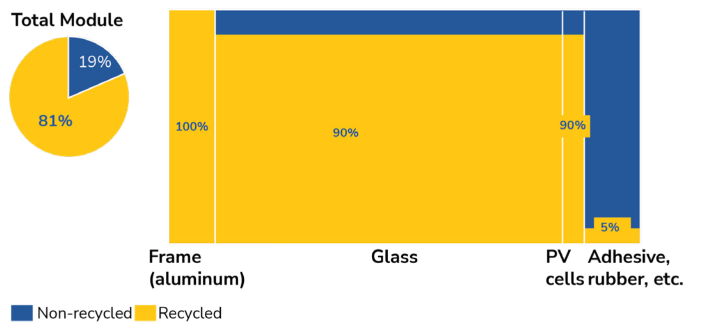
- A comprehensive and sound policy framework to unlocking the full potential of solar PV recycling must be carried out immediately. The policy framework should consist regulations based on clearly defined recycling responsibility, standardisation and certification; data collection and reporting systems; financial and fiscal policies; research, development and demonstration of recycling technologies; and public awareness-raising (IRENA, 2021).

Indonesia solar PV capacity and waste projection



Source: IESR analysis

Recyclability of a typical Crystalline PV Module



Source: Kearney (2017)

Land use is often regarded as one of the main challenges when adopting solar. However, only 2.5% of Indonesia's land area are required for Indonesia to reach deep decarbonization; alternatives that do not require land use competition such as floating solar and agrivoltaics also exist

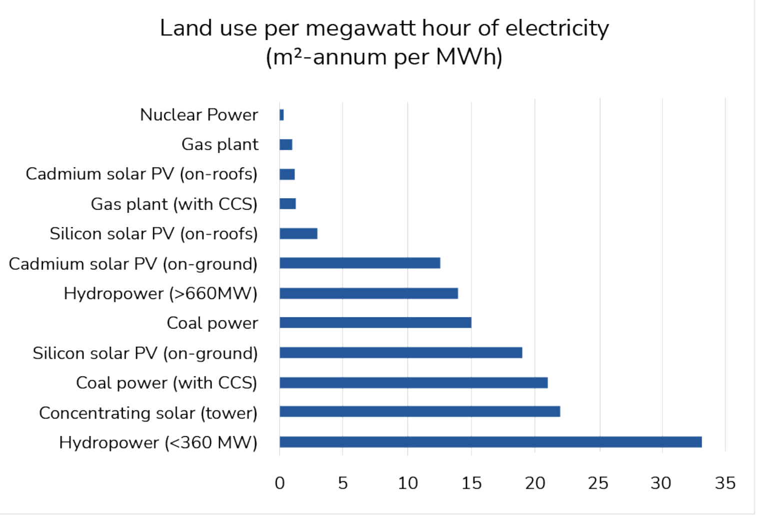
- Land use required for ground-mounted silicon solar PV is the fourth highest amongst other power generation technologies, with land use of 19 m^2 per MWh of electricity. While the area of land needed for rooftop solar PV, although minimum, is not zero since mining materials used to produce the panels are still requires some land (OWID, 2022).

- As the primary source of Indonesia electricity generation in 2050, the projected amount of 1,492 GW of solar PV installed capacity requires only 2.5% (excluding forest and water) of land area in the country (IESR, 2021). However, there are some obstacles in acquiring the land for ground-mounted solar PV such as competition with agricultural land. Alternative ways to avoid such hindrance is through agrivoltaic systems or floating solar.

- In agrivoltaic systems, the land underneath solar panels can be used for other purposes such as farming. Under particular conditions, the yield can even increase compared with conventional crops due to water balance, evapotranspiration, and reduced temperatures (OWID, 2022). Meanwhile, floating solar is expected to continue leading utility-scale solar development within PLN's capacity addition plan. In addition, pairing floating solar with hydro could bring several co-benefits.

- The government should start implementing presidential decree 112/2022 to provide land for renewable energy expansion, especially solar PV. According to the decree, local government facilitates permits, incentives, and land use for renewable energy development. The decree also sets purchase price of electricity from solar PV whose land is provided by government.

Land use of energy sources per unit of electricity



Source: Our World in Data (2022)

2023 Outlook & Way Forward

Outlook and way forward

- In 2022, Indonesia's commitment to achieving net-zero emissions by 2060 has helped shape the country's discussion on which pathway it needs to take. While it has not been formalized, solar has made its way into a bigger role in Indonesia's net-zero pathways, projected to become one of the primary sources of Indonesia's electricity generation by 2060 or mid-century—thanks to its improving cost-competitiveness. The unexpected twist of Presidential Regulation 112/2022, originally only to include RE tariff pricing policy, further bolstered Indonesia's commitment to stop building new coal-fired power plants and to plan for its early closure by the 2050s (or 2040s with international support). These positive developments will certainly carry on to shape more climate-friendly policies throughout this decade.

- In 2023, however, Indonesia must start taking implementation more seriously, else it will risk not meeting even the 23% RE target by 2025, let alone the decarbonization requirements. In the utility-scale solar sector, with the new tariff pricing policy finalized, PLN must start designing and releasing its auction schedule in 2023 if PLN was to meet its planned solar capacity addition plan in RUPTL 2021. In RUPTL 2021, PLN plans to add 3.9 GW of solar by 2025 where 2.45 GW will be procured using IPP scheme and 1.45 GW to be procured directly by PLN. However, as of Q3 2022, there are only eight utility-scale projects totaling 585 MWp in the pipeline (have been auctioned). These include Cirata 145 MWac FPV project, Bangka 10 MWp & Bali 2x25 MWp ground-mounted solar projects, and projects from Indonesia Power's Hijaunesia equity partner auction; two of them are Saguling 60 MWac and Singkarak 50 MWac floating solar projects. Given the short time frame, PLN risks not meeting its planned capacity addition plan that also means not meeting the 23% RE target.

- While the new ceiling price-based pricing provides more room for developers to gain more margin than the previous BPP-based pricing, the imposition of high LCR (60%) for PV modules—with sub-par efficiency and higher cost than imported Tier-1 PV modules—will likely still become a hurdle in solar auctions. Rethinking of the LCR policy along with domestic PV manufacturing readiness, therefore, will be key in realizing competitive solar projects for the short term (by 2025). For the longer term, however, Indonesia must start to prepare its long-term industrial policy strategy on PV manufacturing as the country will require massive deployment of solar PV to decarbonize its energy system.

- On the distributed solar side, the implementation of MEMR 26/2021 is expected to keep being stalled by the maximum capacity limitation, although MEMR and PLN are said to be working on a technical instruction on how to determine the capacity limitation that will be formalized into a ministerial decision by the end of 2022. Should a strict capacity limitation persist, however, the government's 3.6 GW by 2025 PSN target will be at risk of not being met. On the other hand, distributed solar implementation outside PLN's wilayah usaha is expected to keep growing especially in the metals and mining (i.e., nickel and EV-related) sector, as there are increasing carbon footprint concerns in the sector.

- Solar power export projects to neighboring country Singapore are likely to continue, although not without uncertainty. That being said, a government-to-government resolution is to be expected as Indonesia and Singapore signed an MoU for energy cooperation in early 2022. This could include demands to ensure local electricity demand is met first and commitment to invest in Indonesia's domestic PV manufacturing. As a matter of fact, in October 2022, a consortium signed an MoU to build a domestic PV module manufacturing (1 GWp annual production capacity) to support their project while also investing in domestic PV manufacturing in the Karimun Special Economic Zone, the Riau Islands. If the study deemed feasible, the manufacturing will start production in 2025.

- Finally, following COP27 and Indonesia's G20 presidency in 2022, Indonesia must continue carrying on its political will and leadership domestically and internationally to decarbonize its energy system, to not stop from creating supportive policies toward climate action but also to start implementing it effectively.

References

References

The role of solar energy in the mitigation of climate change and in the energy transition

IEA. (2021a). Net Zero by 2050: A Roadmap for the Global Energy Sector. URL.
IEA. (2021b). Global Energy Review 2021. URL.
IEA. (2022). An Energy Sector Roadmap to Net Zero Emissions in Indonesia. URL.
IEA PVPS. (2022). Snapshot of Global PV Markets 2022. URL.
IESR, Agora Energiewende, LUT University. (2021). Deep decarbonization of Indonesia's energy system: A pathway to zero emissions by 2050. URL.
IFC. (2015). Utility-Scale Solar Photovoltaic Power Plants: A Project Developer's Guide. URL.
IPCC. (2019). Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. URL.
IPCC. (2022). Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. URL.
IRENA. (2022). World Energy Transitions Outlook: 1.5°C Pathway. URL.

Utility-scale solar

BloombergNEF & IESR. (2021). Scaling Up Solar in Indonesia. URL.
EMA. (n.d.). Electricity Imports. URL.
IEA. (2019). ASEAN Renewable Energy Integration Analysis. URL.
IEA. (2022). Enhancing Indonesia's Power System: Pathways to meet the renewables targets in 2025 and beyond. URL.
IESR. (2021). Hitting Record-Low Solar Electricity Prices in Indonesia. URL.
IESR, Agora Energiewende, LUT University. (2021). Deep decarbonization of Indonesia's energy system: A pathway to zero emissions by 2050. URL.
PLN. (2021). RUPTL 2021–2030. URL.

Distributed solar

Abdurohman, K. O., et al., (2020). Household energy usage pattern in 2200 VA. URL.
BloombergNEF & Schneider Electric. (2021). Realizing the Potential of Customer-Sited Solar. URL.
MEMR. (2022). Rooftop solar installed capacity update, H1 2022. Webinar.
PLN. (2022). Statistik PLN 2021. URL.

Solar manufacturing and supply chain

APAMSI. (2021). Production Capacity Status. Webinar.
Bloomberg. (2021). Secrecy and abuse claims haunt China's solar factories in Xinjiang. URL.
BloombergNEF. (2021a). Clean Energy Trade Policy Case Study: India. URL.
BloombergNEF. (2021b). Solar PV Trade and Manufacturing. URL.
BPPT. (2018). Indonesia Photovoltaic Industry Roadmap.
IEA. (2022). Solar PV Global Supply Chains. URL.
MEMR. (2022). Evaluation of the Indonesian Solar PV Module Industry. FGD.

Solar environmental impacts

Bloomberg. (2022). China Remains as Reliant as Ever on Fossil Fuels. URL.
EPA (2022). Solar Panel Recycling. URL.
IESR. (2021). Deep decarbonization of Indonesia's energy system: A Pathway to zero emissions by 2050. URL.
IRENA. (2016). End-of-life management: Solar Photovoltaic Panels. URL.
IRENA. (2021). World Energy Transitions Outlook: 1.5°C Pathway. URL.
Kearney. (2017). Solar Photovoltaic Fact Book. URL.
NREL. (2021). Life Cycle Greenhouse Gas Emissions from Electricity Generation: Update. URL.
Our World In Data. (2022). How does the land use of different electricity sources compare? URL.
UNECE. (2021). Life Cycle Assessment of Electricity Generation Options. URL.

IESR
Institute for
Essential Services
Reform

Jalan Tebet Barat Dalam VIII No. 20
Jakarta Selatan 12810 | Indonesia
T: +62 21 2232 3069
F: +62 21 8317 073

iesr.id iesr
www.iesr.or.id