

Accelerating the Clean Energy Transition: Review of Solar Energy Potential, Policy Dynamics, and Economic Challenges for Indonesia's Net-Zero 2060 Goals

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ABSTRAK

Indonesia has abundant and well distributed solar energy resources, but solar photovoltaic (PV) deployment remains far below its technical potential. Average daily solar irradiation of about 4.5 to 5.0 kWh/m² could support hundreds of gigawatts of capacity, while installed PV only recently surpassed 1 GW. This paper reviews the current status, potential, and future development of solar energy in Indonesia, focusing on engineering aspects. The analysis covers grid connected and off grid PV applications, including utility scale plants, rooftop systems, floating PV, and rural mini grids. Technical performance indicators such as performance ratio, capacity factor, and specific yield are summarized, along with evidence on project underperformance and lessons from reliable off grid systems. Economic evaluations of levelized cost of electricity are compared with coal and diesel generation to identify conditions where PV is competitive. The paper concludes that rapid scaling of solar PV is technically feasible and increasingly cost effective if grid readiness, policy consistency, and capacity building are strengthened.

Keywords: solar energy, renewable energy, carbon emission

ABSTRAK

Indonesia memiliki sumber daya energi surya yang melimpah dan tersebar luas, tetapi pemanfaatan pembangkit listrik tenaga surya (PLTS) masih jauh di bawah potensi teknisnya. Rata rata iradiasi surya harian sekitar 4,5 sampai 5,0 kWh/m² mendukung potensi kapasitas hingga ratusan gigawatt, sementara kapasitas terpasang PLTS baru melampaui kisaran 1 GW. Artikel ini mengkaji status terkini, potensi, dan arah pengembangan energi surya di Indonesia dengan fokus pada aspek rekayasa. Pembahasan mencakup aplikasi PLTS terhubung jaringan dan di luar jaringan, termasuk PLTS skala utilitas, surya atap, PLTS terapung, dan mini grid pedesaan. Indikator kinerja teknis seperti performance ratio, capacity factor, dan specific yield dirangkum bersama temuan tentang kinerja proyek dan pembelajaran dari sistem off grid yang andal. Kajian ekonomi melalui levelized cost of electricity dibandingkan dengan pembangkitan berbasis batubara dan diesel untuk mengidentifikasi kondisi saat PLTS kompetitif. Artikel menyimpulkan bahwa percepatan skala besar PLTS secara teknis layak dan kian ekonomis apabila kesiapan jaringan, konsistensi kebijakan, dan penguatan kapasitas nasional ditingkatkan.

Kata kunci: energi surya, energi terbarukan, emisi karbon

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PENDAHULUAN

Indonesia is endowed with abundant solar energy resources, yet solar photovoltaic (PV) deployment has lagged behind its potential. Average daily solar irradiation is about 4.8 kWh/m² with low seasonal variability, translating to a theoretical solar capacity exceeding 100,000 GW_p[1]. However, as of 2020 only ~147 MW of PV capacity was utilized[2], a tiny fraction (~0.18%) of the ~207.8 GW technical potential estimated by Indonesia's Ministry of Energy[3]. This article provides a technical and economic overview of both grid-connected and off-grid PV systems in Indonesia, examining system types, performance, costs, and policies. We review the national energy targets and

regulatory framework influencing solar PV growth, including the 23% renewable energy mix goal by 2025[4], feed-in tariff schemes, net metering, and recent policy reforms.

Indonesia is a rapidly growing economy with rising energy demand, primarily met by fossil fuels[5][6]. In 2021, coal, oil, and gas accounted for roughly 85% of power generation[7], with coal alone contributing about 62% of the electricity mix[6]. This heavy reliance on fossil energy has driven up greenhouse gas emissions and prompted the government to pursue a transition to renewable energy. Under the National Energy Plan (RUEN), Indonesia targets 23% of its primary energy to come from renewable sources by 2025 (rising to 31% by 2050)[8][4]. Solar power is expected to play a significant role in meeting these goals given Indonesia's equatorial geography, which endows the country with high solar insolation year-round. Average solar irradiation levels range around 4.5–5.0 kWh/m² per day across much of the archipelago[9]. For example, Bali receives about 5.3 kWh/m²/day of insolation[10], reflecting the strong solar resource available.

Despite this immense resource, the current contribution of solar photovoltaic (PV) to Indonesia's energy mix is minimal. Cumulative installed PV capacity remains under 0.5 GW[3]. According to official statistics, only ~0.37 GW of solar PV was installed by the early 2020s[3], representing a mere 0.18% of Indonesia's estimated ~207.8 GW technical solar potential[3]. Most of the existing installations are small-scale or off-grid systems; indeed, as of 2019, about 64 MW_p out of ~146 MW_p total PV capacity were stand-alone off-grid systems serving remote areas[11]. This reflects Indonesia's historical approach of using solar PV mainly for rural electrification in unelectrified villages, rather than for utility-scale generation. By contrast, grid-connected solar projects and rooftop PV have seen slow uptake, hindered by various economic and regulatory barriers[12][13]. Consequently, renewables (including hydro and geothermal) supplied only 11.5% of Indonesia's electricity in 2021[4], far below the 2025 target. The shortfall of solar PV deployment is often attributed to factors such as the abundance of cheap domestic coal, investment-repelling regulations, and a lack of incentives for solar investors[14][13].

This article examines the current status, potential, and future outlook of solar energy in Indonesia, with an emphasis on energy engineering aspects of PV systems. We first present a technical overview of solar PV system types in Indonesia – from grid-connected power plants and rooftop systems to off-grid and hybrid installations – including typical performance metrics, efficiencies, and the state of local PV technology development. We then analyze economic considerations: the levelized cost of solar electricity in Indonesia, investment trends, and how solar PV costs compare to conventional power generation. The policy and regulatory framework is reviewed, covering national plans (RUEN, RUKN), feed-in tariff policies, net metering schemes, and recent regulatory changes aimed at accelerating solar deployment. Next, we discuss the solar energy potential and regional suitability across Indonesia's diverse geography, including solar irradiance distribution and identification of regions (e.g. eastern Indonesia's rural islands) where off-grid PV can have the greatest impact on electrification. Finally, the challenges to large-scale PV integration – such as grid stability, storage needs, and human resource development – are examined, and prospects for future growth are outlined. The analysis draws on recent peer-reviewed studies and data (2015–2025) to provide an up-to-date perspective on Indonesia's solar energy trajectory and the steps needed to unlock its considerable potential.

Solar Energy Potential in Indonesia

It is noteworthy that solar energy potential is available in various forms: large-scale ground-mounted PV plants (including on arid or unused land), rooftop solar on buildings across the densely populated islands (particularly Java and Bali), and floating solar on water bodies. A recent avenue is *floating solar photovoltaics (FPV)* on reservoirs and lakes, which Indonesia's geography makes attractive – the country has many hydropower reservoirs suitable for FPV installations. Additionally, off-grid and rural applications of solar (such as solar home systems and mini-grids) leverage the resource in remote areas where extending the conventional grid is challenging. In short, the solar resource is abundant and ubiquitous in Indonesia, establishing a strong foundation for solar energy development.

The next sections examine how much of this potential is being realized and what challenges exist in harnessing it.

Global Horizontal Irradiation (GHI) map of Indonesia, showing the solar resource distribution. Much of the country receives 4–6 kWh/m² per day of solar irradiation on average, reflecting a high potential for photovoltaic power generation [1].

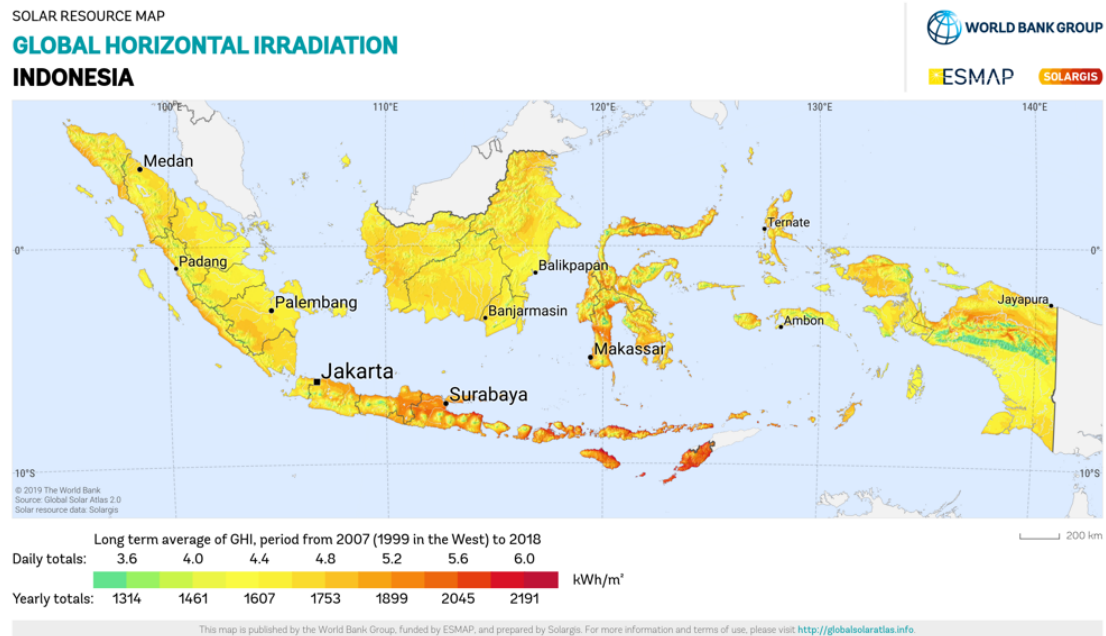


Figure 1: Global Horizontal Irradiation (GHI) map of Indonesia, illustrating the distribution of solar energy resources across the archipelago. Warmer colors indicate regions with higher annual solar irradiation (in kWh/m²). Indonesia's location near the equator ensures strong year-round solar radiation, with many areas receiving over 4–5 kWh/m² per day on average (World Bank)

Current Status of Solar Energy Deployment

Despite its vast potential, solar energy utilization in Indonesia remains in its infancy, though it has grown in the past decade. Until the mid-2010s, grid-connected solar power in Indonesia was virtually negligible – most solar installations were small off-grid systems for rural lighting and telecom towers. Significant growth only began after 2015, and even then progress has been modest compared to neighboring countries. As of 2019, Indonesia's total installed solar PV capacity was on the order of only a few dozen megawatts. An analysis by the Indonesian Renewable Energy Society noted that by late 2019, only 78.5 MW of solar capacity had been installed – a mere 0.04% of the ~207.9 GW technical potential[14]. This indicates that less than one-tenth of one percent of Indonesia's solar resource was being utilized as of 2019, far below the global average (~2.6% of solar potential tapped worldwide) and lagging countries like Germany (~14%)[14]. In 2019, the largest single solar farm in the country was a 15 MW plant in Likupang, North Sulawesi (commissioned in September 2019)[15], highlighting how nascent utility-scale solar was at that time.

Entering the 2020s, solar deployment began to accelerate. According to the Ministry of Energy and Mineral Resources (ESDM), by early 2021 Indonesia had about 154 MW of cumulative installed solar capacity[16]. This figure includes both utility-scale projects and distributed rooftop installations, and it roughly doubled the capacity from just two years prior. By the end of 2021, total installed capacity had reached approximately 190 MW as several new projects came online in late 2021[17]. Notable developments around this period included the completion of multiple medium-scale PV plants across various islands (e.g. PLTS Kupang 5 MW in East Nusa Tenggara and others), as well as growing adoption of rooftop solar PV by industrial and commercial consumers after net-metering regulations were introduced in 2018 (more on policy in later sections). Nonetheless, even

with these additions, solar power still contributed only a tiny fraction (considerably less than 1%) of Indonesia's electricity generation by 2021[2]. For context, Indonesia's electricity system at that time was dominated by over 35 GW of coal-fired capacity, while solar remained under 0.2 GW – highlighting the huge gap between potential and reality.

In the last few years (2022–2025), the solar sector in Indonesia has continued to gain momentum, albeit from a low base. Data from the Directorate General of New Renewable Energy (EBTKE) show that by the end of 2022, solar PV installations had grown to roughly 270 MW nationally (still well below the government's initial plan of ~893 MW by 2022)[18]. A major breakthrough came with the construction of the region's largest floating PV project at the Cirata Reservoir in West Java. In late 2023, the 192 MW Cirata floating solar plant was inaugurated – touted as the largest floating solar installation in Southeast Asia[19]. The Cirata plant, comprising over 300,000 solar panels spread across 250 hectares of reservoir, has become a flagship project symbolizing Indonesia's intent to “go solar”[20]. The project is a joint venture with a UAE company (Masdar) and is noteworthy not just for its size but also as a template for utilizing water surfaces to host solar capacity in land-constrained areas.

Thanks to projects like Cirata and a pipeline of new developments, Indonesia's installed solar capacity has crossed a significant milestone in 2025. By mid-2025, total installed solar PV capacity (utility-scale plus rooftop) surpassed 1 GW (1,000 MW) for the first time[21]. This is a substantial increase from just a few years prior, yet it remains modest relative to Indonesia's targets and relative to other countries in the region. For example, by 2022 Vietnam had installed over 18 GW of solar, and Thailand over 3 GW, whereas Indonesia was around 0.3 GW in that year[22]. As of 2025, solar still constitutes only around 1% of Indonesia's total power generation capacity[23]. Renewable energy (including hydro and geothermal) made up about 12–13% of the electricity mix in 2022, which is far short of the 23% renewable energy share targeted by 2025[3]. In terms of the national energy plan, the government's General Plan of National Energy (RUEN) had set a goal of 6.5 GW of solar capacity by 2025[24], yet the realized capacity by 2025 is only around one-sixth of that goal. This shortfall underscores the challenges that have hindered solar deployment, which will be discussed in later sections.

It is important to break down the current solar capacity by segment: utility-scale PV plants vs. distributed rooftop PV. A significant portion of the recent growth has come from large projects led by independent power producers (IPPs) in partnership with the state utility PLN. Aside from the Cirata 192 MW project, other utility-scale projects built or under development in this period include several 20–50 MW solar farms in Sulawesi, Java, and Kalimantan, as well as two 25 MW plants in Bali[25][26]. On the distributed side, Indonesia launched a “One Million Roofs” initiative aiming for 1,000 MW of rooftop solar by 2020 – a goal that was missed by a wide margin (rooftop PV was only ~16 MW by late 2019)[27]. However, rooftop solar has since gained traction among commercial and industrial users, especially after regulations in 2018–2019 improved net metering terms[28]. By 2021, rooftop solar installations (household, commercial, and industrial combined) reached about 27 MW[29], and continued to grow as businesses adopted solar to reduce electricity bills or meet sustainability goals. Still, rooftop PV remains a small fraction of the total, constrained by policy caps and grid limitations (discussed later). Overall, while Indonesia's solar sector is growing faster than before, it is starting from a very low base. The next sections will explore the technical and economic factors behind this slow start and what is being done to accelerate the adoption of solar power.

Table 1. List of utility-scale solar power plants (PLTS) and major projects installed and operating in Indonesia as of 2025.

No	Name	Location	Capacity (MWp)	Year COD
1	PLTS Terapung Cirata	Waduk Cirata, Kab. Purwakarta & Kab. Bandung Barat, Jawa Barat	192	2023
2	PLTS Likupang (Minut Solar Project)	Desa Wineru, Likupang Timur, Minahasa Utara, Sulawesi Utara	21	2019
3	PLTS Isimu	Isimu, Kab. Gorontalo, Gorontalo	10	2019
4	PLTS Pringgabaya	Pringgabaya, Kab. Lombok Timur, Nusa Tenggara Barat	7	2019
5	PLTS Selong	Selong, Kab. Lombok Timur, Nusa Tenggara Barat	7	2019
6	PLTS Sengkol	Sengkol, Kab. Lombok Tengah, Nusa Tenggara Barat	7	2019
7	PLTS Sambelia	Sambelia, Lombok, Nusa Tenggara Barat	5	2019
8	PLTS Kupang Oelpuah	Oelpuah, Kec. Kupang Tengah, Kab. Kupang, Nusa Tenggara Timur	5	2015
9	PLTS Gorontalo	Kab. Gorontalo Utara, Gorontalo	2	2016
10	PLTS Atambua	Atambua, Kab. Belu, Nusa Tenggara Timur	1	±2019

Technical Overview of Solar PV in Indonesia

System Types and Configurations: Solar PV applications in Indonesia can be broadly categorized into grid-connected systems and off-grid systems. Grid-connected PV includes utility-scale solar farms and rooftop solar installations that tie into the electricity grid. Utility-scale projects (ranging from 1–20 MW or more) feed power to the grid under power purchase agreements, while rooftop PV systems (typically kW-scale) are deployed on residential, commercial, or public buildings with net energy metering. Off-grid PV systems, on the other hand, operate independently of the national grid and are typically used in remote or rural areas. These off-grid systems include solar home systems (small PV with batteries for individual homes), community PV mini-grids supplying a village or island, and hybrid PV-diesel systems that combine solar with generator sets for reliability[15][16]. Historically, off-grid solar has dominated Indonesia’s PV installations – as of the late 2010s, a majority of the country’s cumulative PV capacity was in stand-alone systems powering remote locations[17]. Thousands of solar home systems and communal PV systems have been installed under rural electrification programs, providing basic power (lighting, phone charging, etc.) to unelectrified households. By 2018, over 360,000 solar-powered lighting units had been distributed to communities as part of government efforts to improve rural energy access[18]. In contrast, grid-connected PV has only recently begun to grow, with a handful of notable projects such as the 15 MW Likupang solar plant in North Sulawesi and a 145 MW floating solar project under development in Cirata. Grid-tied rooftop solar is also nascent – the number of rooftop PV customers increased after a 2018 net metering regulation, but the total installed rooftop capacity was only about 0.19 GW (190 MW) by 2024[19].

Performance and Efficiency: The performance of PV systems in Indonesia’s tropical climate is generally good, albeit with some challenges such as high temperatures and humidity. Modern silicon PV modules used in Indonesia have conversion efficiencies in the range of ~15–22%[20]. Monocrystalline silicon panels, which are commonly deployed, tend toward the higher end of this efficiency range and have become the prevalent choice due to their improved energy yield per area[20].

Under real operating conditions, PV system performance is often measured by the performance ratio (PR) and capacity factor. Well-designed grid-connected PV installations in Indonesia can achieve performance ratios on the order of 75–85%, indicating that the system delivers 75–85% of its theoretical energy output after accounting for losses (temperature, wiring, inverter, etc.)[\[21\]\[22\]](#). For instance, a 3 MW_p solar plant in Bali was reported to have a PR around 80%, and a simulated rooftop system in Jakarta yielded a PR of ~79%[\[23\]](#). Correspondingly, annual energy generation in Indonesia per kW of PV installed typically ranges from about 1,200 to 1,500 kWh/kW_p, depending on location and system design[\[24\]](#). An average value of ~1377 kWh/kW_p/year has been used in studies for Indonesia[\[24\]](#), which is higher than many temperate regions due to Indonesia's strong year-round sunlight and minimal seasonal variation. It is notable that Indonesia's equatorial latitude results in relatively uniform solar generation across the year (monthly solar insolation varies by only ~9%)[\[9\]](#), reducing the need for large seasonal energy storage.

However, there have been instances of underperformance in some grid-tied PV projects, often due to maintenance issues or suboptimal system management. Government data indicated that the average capacity factor of grid-connected PV was as low as 2% in some cases[\[11\]](#) – a strikingly low value suggesting that several early PV installations were not producing anywhere near expected output. This could be due to prolonged downtime, shading or soiling issues, or inverter failures that went unaddressed[\[11\]](#). By contrast, many off-grid systems (especially those maintained by local communities or NGOs) have been reliably supplying power; despite forming only 28% of installed PV capacity, off-grid systems produced ~54% of the recorded solar electricity output in 2019[\[11\]](#). This implies that off-grid PV, when properly implemented with battery storage and local maintenance, can effectively meet demand in remote areas with high utilization, whereas some grid-connected installations have faced operational challenges. Improving the performance of grid PV systems through better design (e.g. adequate inverter sizing, cooling, and cleaning schedules) and monitoring (increasingly via IoT-based systems[\[25\]](#)) will be important as the sector grows.

Local Technologies and Innovations: Indonesia has also taken steps to develop local solar PV technology and manufacturing capacity. The government's plans have called for a “vertically integrated domestic PV industry” to be established[\[26\]](#), which includes local production of PV modules and balance-of-system components. To date, a few domestic companies (such as PT LEN and PT Sky Energy) assemble or manufacture PV modules locally, though much of the cell technology is still imported. Research institutions and universities in Indonesia are engaged in solar energy R&D, including studies on improving PV module performance in tropical climates and developing efficient controllers/inverters for off-grid systems[\[27\]\[28\]](#). There have been pilot projects demonstrating innovative applications, such as floating PV systems on reservoirs, agrivoltaic systems, and hybrid PV-battery-diesel systems for isolated grids[\[16\]\[29\]](#). For example, a case study on a hybrid off-grid system for a small island combined PV with wind turbines and battery storage, significantly reducing diesel fuel consumption[\[30\]](#). Another study designed a 200 W_p off-grid PV module for hands-on training to bridge theoretical and practical knowledge gaps in PV technology[\[31\]](#). These local innovations and capacity-building efforts are critical for Indonesia to sustainably expand its solar sector. In summary, from a technical standpoint, Indonesia has access to mature PV technologies capable of delivering clean power effectively, and ongoing improvements in system design and local industry support will further enhance performance and drive costs down.

Economic Considerations

Cost per kWh and LCOE: The economic viability of solar PV in Indonesia has improved markedly in recent years as technology costs decline. The levelized cost of electricity (LCOE) for utility-scale solar PV in Indonesia is now estimated around \$0.10–0.15 per kWh (10–15 US¢/kWh), depending on location and financing assumptions[\[32\]\[33\]](#). Recent feasibility studies indicate LCOE values on the order of \$0.12–\$0.13/kWh for large PV projects under typical conditions[\[32\]](#). For instance, a study of a proposed 3.5 MW solar plant in Nusa Penida (Bali province) calculated an energy production cost of about \$0.124 per kWh (≈2,067 IDR/kWh)[\[32\]\[34\]](#). This is slightly above

Indonesia's average grid electricity generation cost, but approaching competitiveness, especially when considering high-cost diesel generation in remote regions. In fact, in areas with expensive existing generation (e.g. isolated islands relying on diesel fuel at subsidized rates), solar PV can already provide cheaper electricity on a per-kWh basis. The same Nusa Penida analysis showed that when accounting for the cost savings to the state utility PLN from reduced diesel consumption (roughly $\text{\$}0.188/\text{kWh}$ saved), the solar project became highly economical, yielding an internal rate of return $>50\%$ and payback under 4 years[33]. This highlights that PV economics in Indonesia depend strongly on the context – solar is most attractive where it displaces costly generation or where incentives exist (such as carbon credits or tax breaks).

For smaller-scale and off-grid systems, costs per kWh tend to be higher but still reasonable compared to alternatives. Off-grid PV systems with battery storage in Indonesia have an LCOE typically in the range of $\text{\$}0.20\text{--}\text{\$}0.50/\text{kWh}$ (depending on battery life and utilization), which, while higher than grid tariffs, can be lower than the cost of delivering diesel fuel to remote locales[35]. Moreover, off-grid solar provides socio-economic benefits by extending electrification. A 2018 techno-economic analysis of a village solar mini-grid found the solar-battery system produced electricity at around IDR 13,300 per kWh (approx $\text{\$}0.95/\text{kWh}$) with a 4-year payback period[36]. Although nearly $\text{\$}1/\text{kWh}$ seems high, it was competitive when diesel generation and lack of grid access were the alternatives, and costs have fallen since then. Increasingly, hybrid systems (PV + diesel + batteries) are employed to optimize economics: solar handles daytime loads with excess stored, and a generator provides backup during low-sun periods. Such configurations minimize fuel use and often show lower life-cycle costs than diesel-only power for off-grid communities[37].

Investment Trends: Investment in Indonesia's solar sector has historically been sluggish but is now gaining momentum. Throughout the 2010s, annual investment in solar projects was limited, reflecting the small project pipeline. Cumulative installed PV capacity was only ~ 30 MW in 2015 and grew to roughly 150 MW by 2020[2] – a slow growth rate compared to neighboring countries. One reason was that private investors faced uncertain returns under previous regulations, and state-owned utility PLN did not prioritize solar procurement due to concerns over cost and grid management[14][13]. However, as global PV costs declined (module prices fell more than 80% over the past decade) and Indonesia introduced new procurement schemes, interest has risen. By the mid-2020s, several larger projects attracted international investors: for example, a 145 MW floating PV project on the Cirata reservoir is being developed through a joint venture with a UAE company (Masdar), representing one of the first utility-scale solar investments of that magnitude in Indonesia. The government also held solar auctions and assigned quotas for rooftop solar deployment, aiming to spur ~ 900 MW of rooftop installations by 2025[38]. As of 2024, Indonesia planned to add about 5.75 GW of rooftop PV in 2024–2028 through improved regulations and incentives[39], signaling a significant scale-up and corresponding increase in investment.

Cost Competitiveness vs. Other Energy Sources: Solar PV's competitiveness in Indonesia is context-dependent. On the Java-Bali grid (Indonesia's largest grid), coal-fired power remains very cheap (thanks to domestic coal availability and subsidies), with generation costs often below $\text{\$}0.05/\text{kWh}$. In this setting, unsubsidized solar PV at $\text{\$}0.10+$ per kWh struggled to compete in the past[40]. This was evident when a solar feed-in tariff scheme in 2016–2017 offered around $\text{\$}0.145/\text{kWh}$; it attracted limited uptake because PLN's benchmark cost for power in Java was lower, leading the government to later cap solar tariffs at or below the local generation cost (which effectively halted new solar PPAs)[41]. In contrast, in regions like eastern Indonesia where diesel generators produce electricity at $\text{\$}0.20\text{--}\text{\$}0.30/\text{kWh}$ or more, solar is highly competitive and can reduce overall costs for PLN and consumers[33][6]. Solar plus storage is also becoming attractive for commercial/industrial users seeking to reduce reliance on expensive grid tariffs and backup diesel gensets. A recent analysis by Chojkiewicz et al. (2025) demonstrated that for Indonesia's industrial sector, rapidly declining battery costs make solar PV + battery systems economically viable as an alternative to private captive coal or diesel power, especially given Indonesia's consistent solar profile

which allows near-uniform generation year-round. While that study is beyond the scope of this paper, it underlines a trend: the falling cost of PV (now well below $\$800/\text{kW}$ for utility-scale systems) and batteries could enable solar to outcompete fossil options in many applications by the late 2020s.

In summary, the economics of solar in Indonesia have improved to the point where PV is the least-cost option for off-grid electrification and is approaching competitiveness on-grid, particularly in high-cost regions. Achieving further cost reductions (through scale, local manufacturing, and favorable financing) and valuing co-benefits (like avoided fuel costs and emissions) will be key to fully realizing solar's economic potential in Indonesia's energy mix.

Policy and Regulatory Framework

National Targets and Plans: Indonesia's renewable energy policy is guided by high-level plans that set targets and define the energy mix. The National Energy Policy (Government Regulation No. 79/2014) and its derivative RUEN (National Energy General Plan, Presidential Regulation No. 22/2017) establish the goal of 23% renewable energy in the primary energy mix by 2025[8]. In terms of capacity, the state utility's RUPTL (Electricity Supply Business Plan) provides a planning forecast for generation additions; recent RUPTL editions (e.g. 2021–2030) significantly increased the projected solar PV capacity. The RUPTL 2021, for instance, called for *up to* 4.7 GW of new solar PV by 2030 in an “optimistic” scenario, a sharp rise from earlier plans, reflecting a policy shift to emphasize solar[26]. Furthermore, Indonesia's long-term strategy to reach net-zero emissions by 2060 envisions solar PV as the dominant source of electricity by mid-century, potentially supplying one-third or more of all generation with hundreds of GW installed[42]. These targets signal political will to grow solar, but actual implementation has faced obstacles.

Feed-in Tariffs and Auction Policies: A major policy tool to promote renewables has been the feed-in tariff (FiT). Indonesia introduced a solar FiT in 2016, offering fixed purchase prices for PV electricity by region. However, in early 2017 this policy was revised (MEMR Regulation No. 12/2017 and No. 50/2017) to a scheme where tariffs were capped at 85% of the local generation cost (the so-called BPP benchmark)[43]. This effectively meant that in grids with low generation costs (e.g. Java), the solar tariff was capped very low ($\sim \$0.06$ – $\$0.07/\text{kWh}$), deterring investors[44]. Consequently, the FiT regime did not spur the intended solar boom in Indonesia – in contrast to the Philippines where a generous FiT drove rapid solar growth[44]. Recognizing the shortfall, policymakers have started shifting to competitive procurement (auctions) for utility-scale projects, and revising FiT terms. By 2020, Indonesia conducted a few tender rounds for solar projects (e.g. in West Java and Sulawesi) which resulted in winning prices around $\$0.05$ – $\$0.07/\text{kWh}$, indicating improved competitiveness but also reflecting that projects received concessional finance. In addition, Presidential Regulation No. 112/2022 was issued to overhaul renewable pricing and investment: it simplifies pricing (moving away from the 85% cap) and provides a mandate for PLN to retire coal plants early and replace them with renewables[45]. This new regulation is expected to create more room for negotiation of solar tariffs that are attractive to developers while still affordable for PLN.

Net Metering for Rooftop Solar: On the distributed generation side, net energy metering (NEM) policies have been pivotal for rooftop PV uptake. Indonesia's first net metering regulation appeared in 2013, allowing PLN customers to install PV and receive bill credits for excess generation. Initially, credits were given at a 1:1 rate (1 kWh exported nets 1 kWh credit). But in 2018, MEMR Regulation No. 49/2018 adjusted the credit to 1:0.65 (exported power valued at 65% of retail rate), aiming to account for PLN's grid costs. This change was seen as a disincentive by many prospective users, and combined with bureaucratic hurdles to obtain permits, it kept rooftop solar growth modest[13]. In 2021, improvements were made (Regulation No. 26/2021) to simplify applications and slightly better the crediting mechanism, though the 0.65 factor remained. Most recently, MEMR Regulation No. 2/2024 further refined the rooftop solar scheme[46], removing certain capacity limits and eliminating charges that previously penalized larger installations. The government hopes these measures will revive interest and help approach the 3.6 GW rooftop solar target set for 2025[47].

Indeed, provincial programs have emerged – for example, Bali’s governor launched a mandate in 2022 requiring all new public buildings to install PV, and offering incentives for households, aligning with national directives to encourage rooftop solar.

Incentives and Financing: Beyond tariffs and net metering, Indonesia has introduced various incentives to lower the barriers for solar projects. These include tax exemptions (e.g. import duty and VAT exemptions for renewable energy equipment), fiscal incentives for local component manufacturing, and government guarantees for PPAs in some cases to reduce investor risk. Green finance is also being mobilized: Indonesia’s state infrastructure bank and international donors (ADB, World Bank) have set up funds to provide low-interest loans for renewable projects, including PV. Despite these efforts, challenges remain – securing land for solar farms can be complicated, and permitting can involve numerous agencies leading to long lead times[14][48]. There have been cases where solar IPP (Independent Power Producer) projects were delayed due to difficulties in land acquisition and lengthy PPA negotiations with PLN. The government is addressing some of these in a new Renewable Energy Bill (under discussion as of 2025) which aims to streamline licensing and possibly introduce direct subsidy mechanisms for renewables.

Utility and Grid Integration Policy: A critical regulatory aspect is how PLN, the state utility, accommodates solar. Historically, PLN has shown reluctance toward rapid solar deployment, citing grid stability concerns and contractual issues with oversupply of baseload power[13]. The utility’s financial model, which relies on government-subsidized coal and guaranteed returns on existing plants, provided little incentive to purchase intermittent solar generation. However, policies are evolving. PLN’s latest RUPTL is branded as the “green RUPTL” with a higher share of renewables planned than ever before. Furthermore, PLN is experimenting with floating PV on its reservoirs, leasing water surface to IPPs, which avoids land use conflicts and might expedite permits. On grid integration, the government (with donor support) is investing in grid upgrades, such as battery energy storage systems (BESS) and improved grid control, to enable more solar. The Sustainable Energy for Remote Indonesian Grids (SERIG) initiative, for example, emphasizes on-grid solutions including solar-diesel hybrid systems for isolated grids[49]. Additionally, the national electricity regulator has issued grid codes and standards for connecting large-scale solar and requires PLN to prioritize dispatch of renewable energy when available (as long as grid security is maintained).

In summary, Indonesia’s policy framework for solar is in a state of transition: lofty targets and recent reforms signal strong intent, but inconsistent past policies and implementation challenges have slowed progress. The success of upcoming measures – such as improved FiTs/auctions and net metering incentives – will determine whether Indonesia can create a conducive market environment to significantly scale up solar PV investment in the coming years.

Challenges and Future Development

Moving from the current modest deployment of solar PV to a high-penetration solar future in Indonesia entails overcoming several technical, economic, and institutional challenges. At the same time, it opens opportunities for innovation, capacity building, and international collaboration. This section discusses the key challenges and outlines pathways for future development of solar energy in Indonesia.

Grid Integration and Reliability: A high share of solar PV poses challenges for Indonesia’s grid, which was historically designed around large centralized coal and gas plants. Solar power is intermittent and variable – output drops in cloudy weather and disappears at night – requiring flexibility in grid operations. Currently, PLN’s grid has limited flexibility to balance such intermittency[40]. Issues include a lack of fast-ramping backup plants, minimal frequency regulation reserves, and transmission constraints between regions. For instance, Java’s grid could technically absorb several GW of midday solar, but without storage or load shifting, PV output fluctuations might force some conventional plants offline and strain grid stability. Recognizing this, PLN and policymakers are investing in grid upgrades and energy storage. Battery energy storage systems (BESS)

are planned for deployment in several locations to help smooth solar output and provide frequency support. Pumped hydro storage is also being explored (e.g. a proposed pumped-storage plant in West Java) to store excess solar power for evening peak use. Strengthening interconnections – such as linking Sumatra’s grid more strongly with Java – can allow regions with surplus solar to export power to others, thus easing integration. Technical standards are being updated so that large PV plants are required to have features like ramp-rate control and ride-through capabilities to support the grid. Despite these efforts, integration remains a learning process. Studies suggest that beyond ~20% penetration of solar (by energy) on a given grid, curtailment might be needed without significant storage or demand-side management[40]. Thus, a future with, say, 50–100 GW of solar in Indonesia will almost certainly require a smarter grid – one that uses advanced forecasting, automated control, and possibly regional power trading to manage variability.

Energy Storage Development: Increased R&D and deployment of storage technologies are critical for Indonesia’s solar expansion. Lithium-ion battery prices have fallen rapidly, and Indonesia (as a major nickel producer) is keenly interested in battery manufacturing. In the coming years, we expect to see pilot projects of utility-scale BESS paired with solar farms (some are already in procurement, e.g. a plan to install 500 MWh of batteries in Java by 2025). These will help demonstrate how to maintain stable power supply after sunset. On smaller grids and off-grid systems, batteries are already commonplace. The challenge is improving their longevity in tropical conditions (high heat can shorten battery life) and recycling them sustainably. Beyond batteries, Indonesia is exploring alternative storage: green hydrogen production from excess solar is mentioned in the national roadmap (with an eye on using it for industrial fuel or power generation later)[59][60], though this remains nascent. Pumped hydro is a proven storage method and Indonesia’s terrain offers some suitable sites in Java and Sulawesi. The government’s strategy documents (e.g. Presidential Reg. 112/2022) explicitly call for accelerating storage solutions to enable renewables[45]. In sum, expanding solar will go hand-in-hand with advancing energy storage capabilities in Indonesia.

Policy and Regulatory Challenges: While policies are improving, investors still cite regulatory uncertainty and bureaucratic hurdles as major challenges. Frequent changes in rules (for instance, net metering conditions changed multiple times in a few years) create uncertainty for businesses and consumers considering solar. Streamlining the permit process for solar projects is a high priority – ideally a one-stop service that handles land use, environmental clearance, and grid interconnection approvals. The government is working on simplifying licensing via omnibus legislation (e.g. the 2021 Job Creation Law included clauses to ease renewable project permits)[61]. Another ongoing challenge is the bankability of solar projects: PLN’s financial health and subsidized electricity tariffs sometimes raise concerns about timely payments to IPPs. Government guarantees or support from multilateral banks have been used to alleviate this in initial projects, but establishing a track record of successful PPAs will boost confidence. There is also the matter of subsidies and pricing – Indonesia’s electricity tariffs for consumers are kept artificially low for social reasons, meaning PLN must be subsidized for any high-cost generation it buys. This has historically made PLN favor cheap coal over “expensive” solar. However, with global climate commitments and the rising cost of coal externalities, the economic calculus is shifting. The government will need to reconcile short-term subsidy burdens with long-term gains from cleaner energy. Implementing carbon pricing or renewable portfolio standards could internalize the environmental benefits of solar, making its case stronger.

Human Capital and Workforce: Developing a skilled workforce is fundamental for the future solar industry. Indonesia will need thousands of trained engineers, technicians, and installers to deploy and maintain solar PV systems at scale. Currently, many installations rely on a small pool of experts often concentrated in Java. Expanding training programs in vocational schools and universities can build local capacity across provinces. Some initiatives are underway – for example, the Ministry of Energy has supported training centers for solar technicians, and international partnerships (like German aid agency GIZ programs) have provided technical training in solar PV design and maintenance. Workforce development also ties into local manufacturing: if solar module or

component production grows domestically, there will be demand for skilled labor in those factories. Ensuring quality and safety standards in installations is another aspect; as the industry booms, oversight and certification (of products and installers) will be essential to maintain performance and avoid failures that could undermine public confidence.

Research and Development Needs: While solar PV is a mature technology globally, certain R&D areas are particularly relevant for Indonesia. One is PV performance in tropical climates – high temperatures and humidity can affect panels, so research on materials (e.g. coatings to reduce degradation, or panel designs that dissipate heat) could yield gains. Another area is off-grid system optimization: developing smarter controllers and mini-grid management systems that can handle variable solar and load conditions will improve reliability for remote systems. Integration of solar with other renewables (like combining PV with biomass or hydro in hybrid systems) also warrants study to maximize renewable penetration. Furthermore, floating solar PV has unique considerations (water cooling can improve efficiency, but biofouling and anchoring need attention) which local researchers are examining, given Indonesia's large water bodies. Collaboration between Indonesian universities and international research institutions is increasing, as evidenced by a growth in publications on these topics in recent years[62][63]. Continued R&D investment will help adapt global solar innovations to Indonesia's context, driving costs down and performance up.

Overcoming Institutional Barriers: One cannot ignore the institutional and political economy factors. The state utility PLN historically had an effective monopoly and was cautious of disruptive change. Reports have documented instances of “active resistance” from PLN toward distributed solar initiatives[13]. Overcoming this requires aligning PLN's incentives with renewable energy goals – recent moves to restructure PLN and create a division specifically for renewables procurement is a positive sign. Additionally, engaging local communities and governments is key. Large solar farms will need local buy-in, which can be facilitated by offering community development programs or revenue-sharing for regions hosting renewable projects. Early solar projects sometimes faced NIMBY-style resistance or skepticism; continuous public education about the benefits of solar (clean air, job creation, improved access) can build broader support. The successful examples of community-based solar (like in Sumba) serve as showcases that can be replicated.

Looking ahead, the future development of solar energy in Indonesia appears poised for acceleration. With supportive policies now largely in place, the coming decade (2025–2035) is likely to witness a rapid rise in solar capacity – potentially into the tens of gigawatts – if the challenges discussed are managed. The confluence of declining technology costs, international climate finance, and Indonesia's own commitment to reducing emissions (as stated in its Enhanced NDC and net-zero pledge) creates a favorable environment. By focusing on grid readiness, stable policy, and human capital, Indonesia can transform its power sector. In a scenario where these issues are addressed, studies have envisioned Indonesia reaching upwards of 420 GW of solar PV by 2060[42], supplying a large share of a decarbonized grid. While such figures are ambitious, they underscore the scale of opportunity. Even in the nearer term, achieving the 2025 target of 23% renewables (which implies several gigawatts of solar) will be a meaningful step that tests Indonesia's ability to integrate and benefit from solar energy on a large scale.

CONCLUSION

Indonesia stands at a pivotal moment in its energy transition as vast solar resources contrast with still modest deployment. Installed solar PV capacity remains tiny compared with the country's technical potential of hundreds of gigawatts, yet existing projects already demonstrate the feasibility and benefits of both grid connected and off grid applications. Solar mini grids and home systems have expanded electricity access in remote areas, while utility scale and rooftop plants supply clean power to growing urban and industrial loads. Economically, declining technology costs and rising fuel prices are making solar increasingly competitive, especially where it displaces diesel or supports constrained grids, although upfront investment and financing barriers persist. Policy frameworks have evolved

toward clearer renewable targets, improved net metering, and early steps to phase down coal, but challenges remain in grid integration, regulatory complexity, and institutional resistance.

Strengthening storage and smart grid solutions, streamlining permitting, ensuring bankable power purchase agreements, and expanding technical human resources will be critical to unlock larger investment flows. If these issues are addressed, Indonesia can accelerate solar deployment in multiple forms, from large ground mounted and floating plants to widespread rooftop and rural off grid systems, creating green jobs, enhancing energy security, and cutting greenhouse gas emissions. Solar PV, once marginal in the power system, can become a central pillar of a resilient, affordable, and low carbon electricity mix that aligns national development with global climate goals. Such a pathway would position Indonesia as a regional leader in clean energy deployment and innovation.

REFERENCES

- Putra, A. E., Hasan, A., & Bow, Y. (2025). Performance evaluation of 119.88 kWp IoT based on grid solar system at Admin Building Grissik. *EKSAKTA: Journal of Sciences and Data Analysis*, 6(2), 124-134. <https://doi.org/10.20885/EKSAKTA.vol6.iss2.art8> [1] [20] [22] [25]
- Prahastono, I., Paradongan, H. T., Aditya, I. A., Banjarnahor, K. M., & Sinisuka, N. I. (2023). Photovoltaic power plant feasibility study based on Indonesia's renewable energy tariffs: A study of Nusa Penida solar power plant. *International Journal of Energy Economics and Policy*, 13(5), 221-228. <https://doi.org/10.32479/ijecp.14659> [2] [4] [6] [16] [32] [33] [34] [65]
- Aditya, I. A., Wijayanto, T., & Hakam, D. F. (2025). Advancing renewable energy in Indonesia: A comprehensive analysis of challenges, opportunities, and strategic solutions. *Sustainability*, 17(5), 2216. <https://doi.org/10.3390/su17052216> [3] [42] [45] [46] [59] [60] [61] [62] [64]
- Langer, J., Quist, J., & Blok, K. (2021). Review of renewable energy potentials in Indonesia and their contribution to a 100 percent renewable electricity system. *Energies*, 14(21), 7033. <https://doi.org/10.3390/en14217033> [5] [7] [8] [11] [12] [13] [14] [18] [24] [26] [40] [48] [50] [51] [52] [53] [54] [63] [68] [69]
- Handayani, K., Krozer, Y., & Filatova, T. (2017). Renewable energy potentials in Indonesia: Optimal investment and deployment strategies. *Energy Policy*, 109, 577-589. <https://doi.org/10.1016/j.enpol.2017.07.036> [8] [68]
- Hafizan, M. R., Zakri, A. A., Hanafi, D., & Ali, U. (2024). Implementation of solar power plant as a backup power source in apartment buildings. *International Journal of Electrical, Energy and Power System Engineering*, 7(3), 175-189. [9] [21] [23]
- Syanalia, A., & Winata, F. (2018). Decarbonizing energy in Bali with solar photovoltaic: GIS based evaluation on grid connected system. *Indonesian Journal of Energy*, 1(2), 5-20. <https://doi.org/10.33116/ije.v1i2.22> [10] [55] [56]
- Wantira, A. D., Sugiharto, M. I., & Setiabudi, B. R. (2023). Utilization off grid solar powered cold storage for economy improvement of fishermen in Mangur Island. *International Journal of Multicultural and Multireligious Understanding*, 10(6), 125-134. <https://doi.org/10.18415/ijmmu.v10i6.4852> [15] [58]
- Eko Utylizacja. (2019). There are several locations for photovoltaic sites in Indonesia. *Eko Utylizacja*. <https://eko-utylizacja.pl/Fri-15-Mar-2019-9320.html> [17]
- EnergyTrend. (2024, July 4). Indonesia issues new quota for rooftop solar system development. *EnergyTrend*. <https://www.energytrend.com/news/20240704-47769.html> [19]
- Subarkah, R., Heryana, G., & Widiawaty, C. (2019). The development of photovoltaic application in Indonesia: A review. In *Proceedings of the 8th Annual Southeast Asian International Seminar (ASAIS 2019)* (pp. 108-113). SCITEPRESS. <https://doi.org/10.5220/0009906100002905> [27] [28] [29] [36] [57] [66] [67]

- A sustainable hybrid off grid system design for isolated island considering techno economic and frequency stability analysis. (2024). *Journal of Applied Engineering and Technological Science*, 5(1). <https://doi.org/10.55670/jaets.v5i1.464> [30] [37]
- Sitorus, N., Ginting, B. B., Panjaitan, B. P., & Simanjuntak, B. E. (2025). Design and performance evaluation of a 200 Wp off grid solar photovoltaic module for renewable energy in Indonesia. *Journal of Geoscience, Engineering, Environment and Technology*, 10(3), 408. [31]
- Institute for Essential Services Reform. (2020). *Levelized cost of electricity in Indonesia: Renewable energy technologies*. Institute for Essential Services Reform. [32]
- TNO. (n.d.). *Scoping paper: Promoting off grid renewable energy in Indonesia*. TNO. <https://publications.tno.nl/publication/34632237/30CQV8/o14017.pdf> [35]
- Trisnawati, M. (2022, May 13). Pessimistic observer 3.6 GW rooftop solar power plant capacity target reached in 2025. *VOI*. <https://voi.id/en/economy/167020> [38] [47]
- Yuen, S. (2024, June 11). Indonesia to add 5.75 GW rooftop solar PV between 2024 and 2028. *PV Tech*. <https://www.pv-tech.org/indonesia-to-add-5-75gw-rooftop-solar-pv-between-2024-and-2028/> [39]
- Institute for Energy Economics and Financial Analysis. (2019). *Indonesia's solar policies: Designed to fail?* Institute for Energy Economics and Financial Analysis. https://ieefa.org/wp-content/uploads/2019/02/Indonesias-Solar-Policies_February-2019.pdf [41]
- Development Policy Centre. (2019, September 4). How not to design energy feed in tariffs: A look at Indonesia and the Philippines. *Devpolicy Blog*. <https://devpolicy.org/how-not-to-design-energy-feed-in-tariffs-a-look-at-indonesia-and-the-philippines-20190904/> [43]
- Feed in tariffs and the politics of renewable energy in Indonesia and the Philippines. (n.d.). [Manuscript]. Retrieved from https://www.researchgate.net/publication/335446097_Feed-in-tariffs_and_the_politics_of_renewable_energy_in_Indonesia_and_the_Philippines [44]
- National Renewable Energy Laboratory. (2017). *Sustainable energy for remote Indonesian grids: Strategies toward developing deployment roadmaps* (NREL/TP-6A20-66548). National Renewable Energy Laboratory. <https://docs.nrel.gov/docs/fy17osti/66548.pdf> [49]
- Retnanestri, M., Outhred, H., & Healy, S. (2017). Off grid photovoltaic applications in Indonesia: An analysis of preliminary field findings. *Energy Procedia*, 110, 294-299. [66] [67]
- International Renewable Energy Agency. (2017). *Renewable energy prospects: Indonesia (REmap 2030 analysis)*. International Renewable Energy Agency. [69]