Global Environmental Institute
北京市朝阳区永续全球环境研究所

Solar-powered business:
Technical and financial analysis of industrial and tourism zone in Indonesia

Authors: Global Environmental Institute, Institute for Essential Services Reform, Guangzhou Institute of Energy Conversion.

Acknowledgments

This report is one of a series of works conducted in Southeast Asian countries under the Global Climate Action Initiative (GCAI). We would like to give special thanks to the Children's Investment Fund Foundation (CIFF), Natural Resources Defense Council (NRDC), OAK Foundation, Rockefeller Brothers Fund (RBF), and Tsinghua University Education Foundation for their financial support for this research project. We are grateful to Mr. Fabby Tumiwa (Executive Director of IESR) and Dr. Marlistya Citraningrum (Programme Manager, Sustainable Energy Access) for their guidance and support. We would also like to thank Daniel Kurniawan (Researcher on Solar Photovoltaic and Material Technology) and Dr Handriyanti Diah Puspitarini (Senior Researcher on Renewable Energy) for the reviewing; and Ms. Icmi Safitri (Programme Officer, Sustainable Energy Access) and Rizqi Prasetyo (Local Project Officer, Sustainable Energy Access of IESR) for their valuable assistance through the whole process. We would also like to thank Mme Jiaman JIN (Executive Director of GEI) and Ms. Lin JI (Programme Director) for their guidance and support; and Ms. Huiling ZHU (Programme Officer), Ms. Yu LIU (Project Consultant), and Ms. Sirui Huang (Programme Intern), for their hard work throughout the project.

We owe a particular debt of gratitude to our partners, Dr. Jianhua LIU, Beijing University of Civil Engineering & Architecture (BCEA); Ms. Pengcheng Xie and Ms. Xiaoquan Gao, Guangzhou Institute of Energy Conversion (GIEC); and the Center for Climate Strategies (CCS), for their tremendous contribution and support.

Executive Summary

Under the framework of the Global Climate Action Initiative (GCAI), the Global Environmental Institute (GEI) is collaborating with Indonesian energy and climate think-tank partner, the Institute for Essential Services Reform (IESR), to accelerate the development of rooftop solar photovoltaic (PV) systems in commercial buildings and industrial zones in Indonesia. This report is the second part of the Indonesian solar PV potential assessment project, following the first report released in 2021, Beyond 207 Gigawatts: Unleashing Indonesia's solar potential, which estimated the national solar resources. The current report conducts a policy analysis of rooftop solar PV. It adopts the Renewable Energy Implementation (REI) toolkit to complete the technical potential assessment for the commercial area, the Nusa Dua Bali Tourism area, and 11 industrial zones located in Banten, East Java, West Java, and Central Sulawesi (Morowali); including two industrial zones with investment from Chinese enterprises. In addition, this report takes the medium-size (625 kWp) rooftop solar PV project in Nusa Dua Bali tourism area as an example of commercial buildings, and a large-size (2.5 MWp) rooftop solar PV project in Jababeka Industrial Estate as an example of industrial zones, to examine their financial performance under the baseline scenario.

Through analysis of the current policy, we find that the Indonesian government is dedicated to solar energy development. To mitigate climate change, Indonesia has committed to reduce greenhouse gas (GHG) emissions by at least 29%, or by 41% with international support, compared to the business as usual (BaU) scenario; it has also agreed to increase the share of renewable energy in the energy mix, to

23% and 31% by 2025 and 2050 respectively. To achieve the commitment, the National Energy Policy is aimimg for 6.5 GW of cumulative solar by 2025. Moreover, a national strategic programme spots 3.6 GW rooftop solar PV. However, the domestic fiscal instrument is insufficient to promote solar energy development, especially for rooftop solar PV. There are several tax facilities and incentives for renewable energy in general, and specifically for solar energy, but they have yet to be effective in accelerating development. International grants are currently available for rooftop solar through the Sustainable Energy Fund managed by the Indonesia Environment Fund (BPDLH).

The technical potential assessment shows that rooftops in the Nusa Dua Bali tourism area and the 11 industrial zones have great potential to produce green electricity and generate social and environmental benefits. The results show that the Nusa Dua Bali tourism area has 2,356 rooftops, with an available rooftop area of around 876,348 m^2. Its potential installed capacity of rooftop solar is 104,12 MW, with the electricity generation potential of about 141.77 GWh; this means it can reduce of coal equivalent by 63,794 tons, and carbon dioxide equivalent by 119,083 tonnes annually. Regarding the 11 industrial zones, there are 7,683 rooftops, with an available rooftop area of around 22,334,248 m^2. The potential installed capacity of rooftop solar is around 2.63 GW, with the electricity generation potential of approximately 3 TWh; this has the potential to reduce coal by 1.3 million tons and carbon dioxide equivalent by 2.5 million tonnes annually.

In the financial potential assessment, we analysed the economic performance of the solar PV projects in the Nusa Dua Bali tourism area and Jababeka Industrial Estate, under the baseline scenario. The result shows that the levelized cost of electricity (LCOE) for rooftop solar PV is 0.057 USD/kWh in the Nusa Dua Bali tourism area and 0.065 USD/kWh in Jababeka industrial area; both of which are lower than the benchmarking traditional coal LCOE (0.0726 USD/kWh). Under the baseline scenario, the rooftop solar PV project in the Nusa Dua Bali tourism area has an internal rate of return (IRR) of 12.4%, with a payback period (PBP) of between seven years, and the ROI (Return on Investment) is 45.0%. For the Jababeka Industrial Estate, under the baseline scenario, the IRR is 6.8%, with PBPs being 11 years, and the ROI is 26.5%. Based on these findings, this report observes that investing in the Nusa Dua Bali tourism area is profitable; whereas Jababeka Industrial Estate is not profitable, as its IRR is lower than the minimum acceptable rate of return (MARR) and the payback period is longer than the loan years. Compared to the case of Nusa Dua Bali, the Jababeka Industrial Estate is not profitable due to the lower capacity factor and the large installed capacity leading to the high implementation cost.

Apart from the benefits, there are also investment-related challenges and risks that must be properly managed. We map several pertinent risks for rooftop solar investment in Indonesia, as follows:

1. Policy and Regulatory Risk

As Indonesian rooftop solar policies are still in a relatively nascent stage, regulatory uncertainty exists on many levels, including for business processes and permitting. This may have an insignificant impact, but is likely to deter investment to some extent. Such policy and regulatory risk should become the primary consideration when considering a project development and investment.

2. Capital Risk

Risk of default on financing sources is common; this risk can be controlled through effective legal guarantees and the increased enthusiasm of project developers.

3. Operational Risk

Risk associated with the operation of solar power plants is affected by several variables, including

the factory performance factor, power load capacity, electricity price, unit investment cost, and fixed operation and maintenance costs. It is necessary to ensure proper planning, design, standards, and business plans, including for power purchase agreements (PPAs).

To conclude our technical potential calculation for rooftop solar in several areas of Indonesia, and its corresponding financial analysis, we provide several recommendations as follows:

1. Remove regulatory uncertainty

In the current policy landscape, the changing dynamics of policies and their implementation discourage business players and potential users. Thus, the government should swiftly remove the uncertainty that hampers rooftop solar development, and ensure the coherent implementation of policies.

2. Strengthen planning and coordination

Strengthening planning and coordination at all government levels is also paramount. For example, subnational governments could set other utilization ratios for rooftop solar in buildings, which are integrated with development planning, and promote low-carbon development plans. They can also initiate pilot projects with innovative financing.

3. Improve solar's quality infrastructure system

It is important to align and adopt Indonesia's solar quality infrastructure systems according to internationally accepted standards, in order to foster the domestic solar industry's quality and competitiveness. It is also necessary to improve the standardization of licensing and permitting.

4. Improve the investment climate for solar

The government should also focus on improving the investment climate for solar, including good policy design and incentives, and facilitating long-term cooperation with international counterparts.

Table of Contents

List of Abbreviations

AC: Alternating current

Ar: Rooftop area

BAPPENAS: National Development and Planning Ministry

BaU: Business as usual

C&I: Commercial and industrial

CCS: Center for Climate Strategies

DC: Direct current

DCF: Discounted cash flow

Eu: Power production

FOM: Fixed operation and maintenance cost

GCAI: Global Climate Action Initiative

GDP: Gross domestic product

GEI: Global Environmental Institute

GHG: Greenhouse gas emissions

GIEC: Guangzhou Institute of Energy Conversion

GW: Gigawatt

GWdc: Gigawatt of direct current

GWh: Gigawatt hour

GWp: Gigawatt peak

ha: Hectare

IEA: International Energy Agency

IESR: Institute for Essential Services Reform

IRR: Internal rate of return

KEN: National energy policy

KIEC: Krakatau Industrial Estate Cilegon

KW: Kilowatt

KWdc: Kilowatt of direct current

KWp: Kilowatt peak

LCOE: Levelized cost of electricity

MARR: Minimum acceptable rate of return

MEMR: Ministry of Energy and Mineral Resources

MW: Megawatt

MWp: Megawatt peak

N/A: Not available

NDC: Nationally Determined Contribution

NEP: National energy policy

NPV: Net present value

NREL: National Renewable Energy Laboratory

PBP: Payback period

PLN: State electricity enterprise

PPA: Power purchase agreement

PSN: National Strategic Program

PV: Photovoltaic

RCR: Roof cover ratio

RE: Renewable energy

REI: Renewable energy implementation

ROI: Return on investment

RPJMN: National Medium-Term Development Plan

RUEN: National General Energy Plan

RUPTL: National Electricity Supply Business Plan

TWh: Terrawatt hour

TWp: Terrawatt peak

UNDP: United Nations Development Programme

UNFCCC: United Nations Framework Convention on Climate Change

VOM: Variable operation and maintenance cost

W: Watt

Wdc: Watt of direct current

List of Figures

List of Tables

1 Introduction

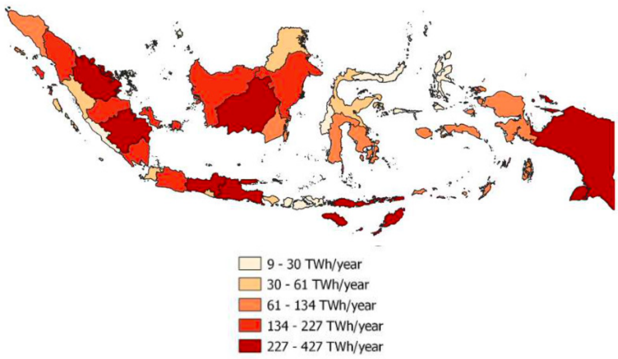
1.1 Background

Indonesia is a diverse archipelagic nation of more than 300 ethnic groups and home to 275 million people (World Bank, 2022). Not only is Indonesia the world's fourth most populous country, it is also the world's 10th largest economy in terms of purchasing power parity—with a steady 5% annual growth rate during pre-COVID years—and Southeast Asia's largest economy and energy consumer (World Bank, n.d.). The International Energy Agency (IEA) (2022), estimated that Indonesia contributed as much as 35% of the region's energy demand. Several institutions projected that the Indonesian economy would become the world's 7th largest by 2030 and 4th largest by 2050, whilst the Indonesian government envisioned its economy to be the 5th largest by 2045—commemorating its 100th year since foundation (Bappenas, 2019; McKinsey & Company, 2012; PwC, 2017). This means that Indonesia's energy demand will grow at an unprecedented rate. That being said, Indonesia's total primary energy supply is still very much dominated by fossil fuels (88% in 2021) (MEMR, 2022).

To meet the increasing energy demand and mitigate the adverse impact of climate change, Indonesia has recently made a bold pledge to reach net-zero emissions by 2060 or sooner (IESR, 2021b). This is an extension to Indonesia's Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) that aims to unconditionally reduce 29% of greenhouse gas emissions (GHG) or conditionally reduce 41% of GHG emissions with international support against its business-as-usual projection scenario (Government of Indonesia, 2021b). Moreover, the energy ministry has also separately formulated a net-zero roadmap for the energy sector that aims to achieve net-zero emissions by 2060 (for the energy sector only), where 100% of the supplied electricity by that year should come from clean energy. Solar solar PVs (PV), in particular, is projected to be the primary clean power generation technology in the net-zero scenario, accounting for 62% of total power generation capacity by 2060 (IESR, 2021b).

Solar PVs are prioritized by the government (also as modeling outcome) largely due to its abundant resources, increasing cost-competitiveness, as well as the recent political momentum to transition to clean energy. According to a report released in 2021 by the Global Environmental Institute (GEI) and the Institute for Essential Services Reform (IESR) (as shown in Figure 1), Indonesia's technical solar power potential can range between 3–20 TWp, or about 16 to 95 times higher than the government's estimate at the time (207 GWp) (IESR & GEI, 2021). Solar PV has also seen a major improvement in terms of costs over the past decade. Between 2010 to 2019, solar PV module costs have fallen by 90%, making solar PV cost-competitive in two-third of the world's population today (BloombergNEF, 2020).

Figure 1. Indonesia's national technical potential assessment. Source: IESR & GEI (2021)



As a consequence of that, there has been a change in the attitude toward solar energy development by the Indonesian government. In Indonesia's latest power development plan (PLN's RUPTL 2021–2030), PLN plans to add 4.7 GW of solar capacity by 2030, a fivefold increase compared to the previous RUPTL 2019–2028. On another front, the government also set a target for rooftop solar installation of 3.6 GWp by 2025. Subnational governments such as Jakarta, Central Java, Bali, and others have also issued policy instruments and allocated budgets to support rooftop solar deployment on government buildings (IESR, 2021b). Commercial and industrial (C&I) sectors in particular, which make up half of the power demand in 2019, are becoming hotspots for rooftop solar installations due to high interest in operational efficiency, corporate sustainability targets, as well as the increasing international (trade) pressure to greening the supply chain (BloombergNEF & IESR, 2021).

With all the potential and development, however, renewable energy is still largely underdeveloped in Indonesia. Data from the energy ministry shows that renewable energy only accounts for 11.2% in the primary energy mix in 2021 (IESR, 2021b). This means that Indonesia needs to double the number by 2025 to achieve their 23% renewable energy target. Solar PV utilization is much worse in that sense. By the end of 2021, Indonesia had only installed ~200 MWp, that is 0.001% of Indonesia's upper-limit solar technical potential (IESR, 2021b). In order to facilitate solar PV development and mobilize investment in Indonesia, therefore, GEI collaborates with IESR to conduct a study on rooftop solar technical potential and financial assessment in Nusa Dua Bali (tourism area) and 11 industrial zones in Banten, East Java, West Java and Morowali.

1.2 Report Structure

This report is structured in the following:

- **Chapter 1** provides a context and background of the study.
- **Chapter 2** follows with an overview of the methodology and the introduction of the Renewable Energy Implementation (REI) toolkit.
- **Chapter 3** further provides an overview of Indonesia's country overview, energy demand and supply projection, renewable energy development, and particularly solar energy development
- **Chapter 4** discusses the results for the technical potential assessment on rooftop solar in Nusa Dua, Bali and 11 industrial zones in Banten, East Java, West Java and Morowali. The chapter also includes fossil fuel and emission reduction potential from the rooftop solar potential.
- **Chapter 5** further provides a more in-depth financial assessment on the rooftop solar potential. Followed by risk assessment in Chapter 6.
- **Chapter 7** finally concludes the report with conclusion and policy recommendations on the findings.

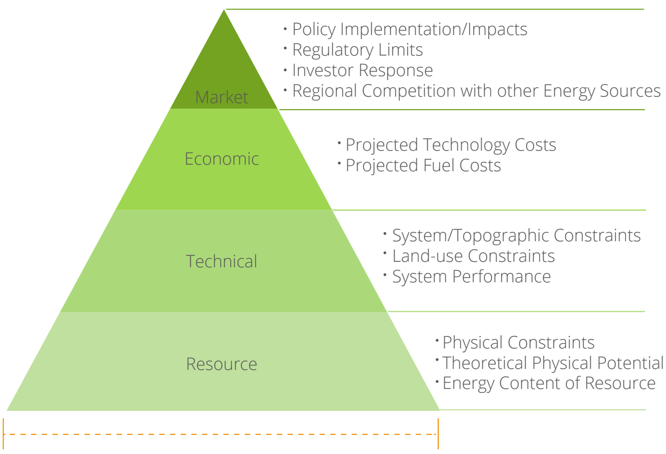
2 Methods

2.1 Introduction of Renewable Energy Implementation (REI)

The Global Environmental Institute (GEI), together with the Center for Climate Strategies (CCS) and the Guangzhou Institute of Energy Conversion (GIEC) of the Chinese Academy of Science, have developed the Renewable Energy Implementation (REI) Toolkit.

The research logic of the REI Toolkit is based on the Renewable Energy Technical Potential theory proposed by the National Renewable Energy Laboratory (NREL) (see Figure 1). The four levels of energy potential are resource, technical, economic, and market. The "resource" is the theoretical natural potential, which is the total amount of the specific energy resource. The "technical" is the available potential of techniques with the considerations of technical implementation. The "economic" is the available potential to generate profit after evaluating the economic feasibility. The "market" is the resource potential that is competitive in the market and groundable with the consideration of the market preference. Each level of energy potential is based on the underlying potential and is further reduced.

Figure 2. Renewable energy technical potential definition by NREL



Based on the demand consultation with IESR, this report focuses on the technical and financial potential and environmental benefits assessments of rooftop solar PV projects in the commercial buildings and industrial zones.

The REI Toolkit includes Microsoft Excel-based workbooks, document templates and guidance documents to assist different levels of jurisdictions (including cities, provinces/states and countries) in the evaluation, implementation and scale-up of renewable energy (RE) projects and programs. To complete the above-mentioned assessments, The following tools of REI toolkits are developed and applied:

1. Artificial Intelligent Recognition: to identify the number and area of the available rooftops. The parameters of the satellite images are demonstrated in (see Section 4.1).
2. Technical Potential Calculation Tool: to calculate the potential installed capacity and annual electricity production (see Section 4.1).
3. Environmental Benefit Estimation: to calculate fossil fuel reduction and carbon dioxide reduction, based on the annual electricity production, Indonesian standard coal consumption rate for generation, and Java–Bali grid emission factor (see 5.1).
4. Financial Risk and Return Assessment Tool: to evaluate key financial performance by collecting system cost data, project description data, and financing data to estimate financial performance (see Section 5.1).

3 Overview of Indonesia's Solar Energy Development

3.1 Country Overview

Indonesia is located off the coast of mainland Southeast Asia, lying between the Indian Ocean and the Pacific Ocean. With an area of 1,904,569 km², Indonesia is the largest country in Southeast Asia consisting of 17,508 islands (Statistics Indonesia, 2022). It is also the world's fourth most populated nation and the most populous Muslim-majority country (World Bank, 2022). The population of Indonesia reached about 278 million in 2021 and it is projected to reach 306 million in 2050 at an annual growth rate of 5.0% (Trading Economics, 2022; Worldometer, 2022).

As the largest economy in Southeast Asia and the world's 10th largest economy in terms of purchasing power parity, Indonesia is a significant player in the global economy (World Bank, 2022). It has made enormous gains in poverty reduction, cutting the poverty rate by more than half since 1999, to just under 10 percent in 2020. The average annual growth rate of GDP in Indonesia is 4.86 percent from 2000 until 2021 (Trading Economics, 2022).

It is expected that Indonesia would be the most vulnerable country in Asia to coastal flooding which would affect 5.9 million people every year by 2100 (Øverland et al., 2017). Meanwhile, it is among the top ten countries with the largest GHG emissions with projected emissions that continue to increase, especially in the energy sector which will be the main contributor to GHG emissions in 2030 (IESR, 2021b).

3.2 Energy Demand and Supply

3.2.1 Energy Demand

Indonesia is the largest energy consumer in Southeast Asia, accounting for around 35% of the region's total energy demand (IEA, 2022). It is predicted that the consumption of domestic energy will triple from 2010 to 2030 in Indonesia while the electricity demand will grow by 4.9% annually (Sharvini et al., 2018). As shown in Figure 3 and Figure 4, transportation is the largest energy consumer. Meanwhile, it is also the largest contributor to the increase in energy consumption. From 2011 to 2021, the share of the transport sector in total energy consumption increased from 32% to 43%. The industry is the second-largest energy consumer, with a share of around 35% of the total energy consumption in recent years.

Figure 3. Total final energy consumption by sector in Indonesia from 2011 to 2021. Source:)

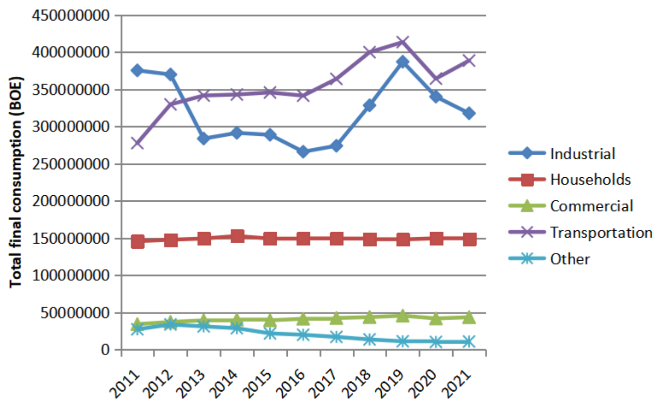
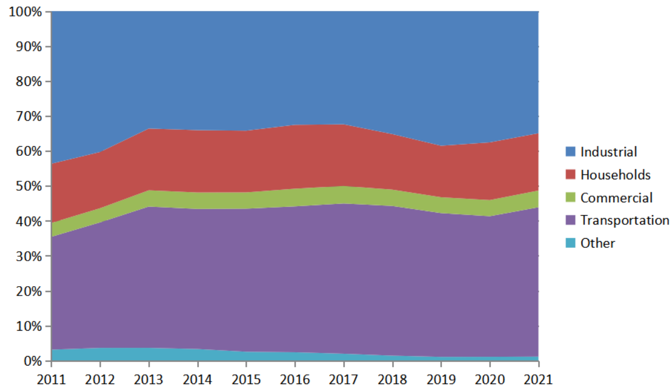


Figure 4. Share of final energy consumption by sector in Indonesia from 2011 to 2021. Source:)



3.2.2 Energy Supply

As shown in Figure 4 and Figure 5, Indonesia's energy supply is dominated by fossil fuels while the share of fossil fuels in the total energy supply steadily increases from 2000 to 2019, accounting for around 76% of the total energy supply in 2019. It reflects Indonesia's natural abundance of hydrocarbons (PwC, 2016). Indonesia is the world's fourth-largest producer of coal and Southeast Asia's biggest gas supplier (IEA, n.d.-b).

Oil is the main energy supply source in Indonesia—which was primarily used for the transportation sector—and it occupies around 35% of the total energy supply. However, the deployment of oil lagged behind that of coal due to the depletion of domestic oil resources in recent years and thus the supply of coal increases dramatically in the past 20 years, accounting for 29% of the total energy supply in 2019 while only 8% in 2000 (ICLEI, 2020; PwC, 2016). Natural gas is the third-largest energy supply source in Indonesia, accounting for around 16% of the total energy supply in 2019. As for renewable energy, its share of total supply decreases from 38% to 24% from 2000 to 2019. It indicates that the deployment of fossil fuel surpasses that of renewable energy.

Figure 5. Total energy supply by source in Indonesia from 2000 to 2019. Source: IEA, (n.d.-a)

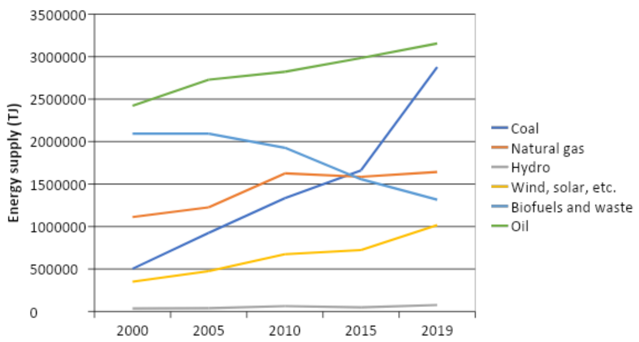
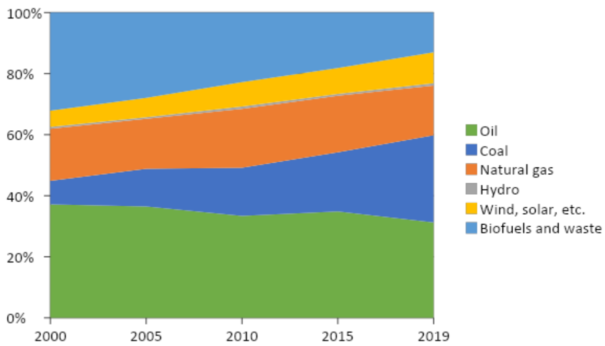


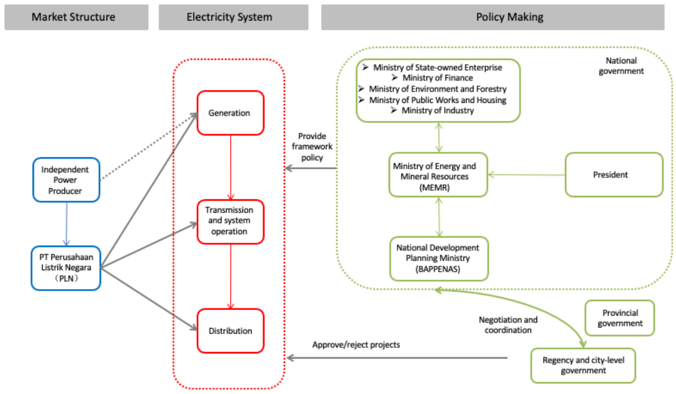
Figure 6. Share of energy supply by source in Indonesia from 2000 to 2019. Source: IEA, (n.d.-a)



3.3 Energy Sector Governance

In Indonesia, the Ministry of Energy and Mineral Resources (MEMR), under the supervision of the President, is the primary government institution in charge of policy and decision-making to supervise Indonesia's energy sources and assets at the national level (Figure 6) (ICLEI, 2020). It is responsible for preparing the National Energy Policy (NEP) (PwC, 2016). It also regulates the renewable energy sector through the Directorate General of New and Renewable Energy and Energy Conservation, and the Directorate General of Electricity (Ashurst, 2022). After the national legislature approves of NEP, MEMR further develops National General Energy Plan (RUEN) in coordination with relevant technical ministries and institutions, including the Ministry of Finance, Ministry of Environment and Forestry, and Ministry of Public Works and Housing, and Ministry of Industry (Ashurst, 2022). Meanwhile, the National Development and Planning Ministry (BAPPENAS) ensures that the energy programs developed by the MEMR are accommodated and incorporated into the National Medium-Term Development Plan (RPJMN) (ADB, 2016).

Figure 7. Governance structure of the energy sector in Indonesia. Source: Marquart (2014)



Indonesia has a multi-level governance structure in the energy sector (Figure 6) and local governments play significant roles in energy governance since energy projects cannot be implemented without the local governments' support, especially when public land acquisition is involved. Local governments are responsible for issues related to energy, including renewable energy planning and development, project implementation, and provision of permits and licenses. Meanwhile, provincial governments only facilitate the coordination and communication between national and local governments, especially when more than one local government is involved (Marquardt, 2014). It is reported that this complex political structure, including complex corruption and lack of coordination, have the major influence on renewable energy support in Indonesia (Marquardt, 2014; Sharvini et al., 2018)

As for market structure, PT Perusahaan Listrik Negara (PLN) is the state-owned company that bundles the country's electricity transmission and distribution system and 85% of Indonesia's power generation (Marquardt, 2014). Independent power producers are permitted to generate electricity (Norton Rose Fulbright, 2019). However, PLN is the sole off-taker and party that has the right to sell electricity to end consumers except for limited Business Areas, where private participants can sell electricity (ADB, 2016).

3.4 Renewable Energy Sector Status and Trend

MEMR estimated that Indonesia has an abundant renewable energy potential of 418 GW (REN21, 2019). As shown in Figure 7, the total installed capacity of renewable energy in Indonesia is around 10.3 GW in 2019, which is only 2.3% of the potential. Moreover, the deployment of renewable energy in Indonesia lagged behind its neighboring countries. The total capacity of renewable energy in Indonesia increased by 22% from 2014 to 2019, while those of Vietnam and Thailand increased around 55% during the same period (IRENA, 2021). As for renewable energy mix, hydro, geothermal, and bioenergy have accounted for most of the country's installed capacity, with a minimal presence of solar and wind (Figure 8). This is contrary to the global trend that shows an increasing adoption of solar and wind for power generation.

Figure 8. Installed capacities of renewable energy sources in Indonesia from 2011 to 2020. Source: IRENA (2021)

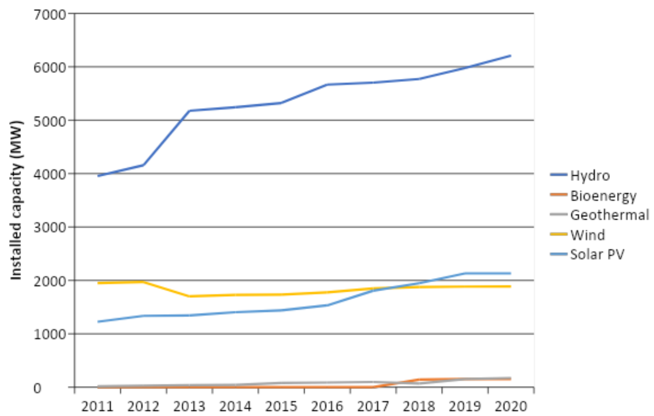
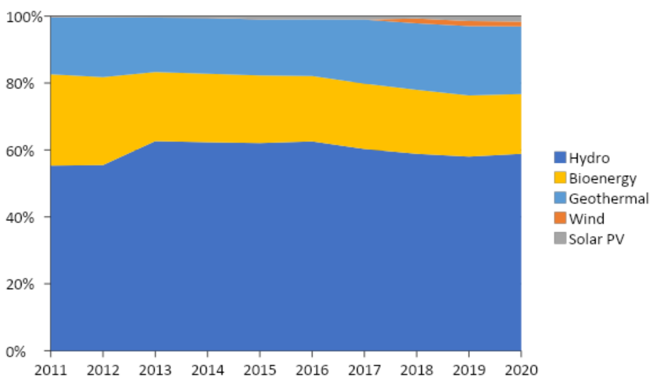


Figure 9. Share of installed capacity of renewable energy by sources in Indonesia from 2011 to 2020. Source: IRENA (2021)



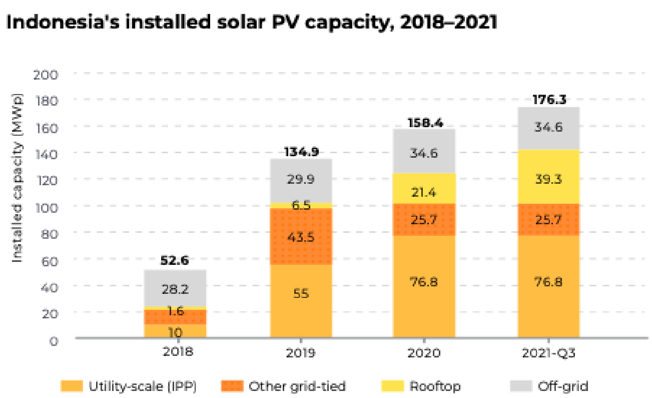
3.5 Solar PV Development

3.5.1 Installation status and trend

Situated near the equator line, Indonesia has a stable daily solar energy throughout most of the year, with little monthly variation of 9-10% (Handayani & Ariyanti, 2012; Hasan et al., 2012). According to MEMR's 2017 estimate, which utilized a specific irradiation cut-off, Indonesia's solar power technical potential totals 207 GWp (Government of Indonesia, 2017). It was later found that, through IESR and GEI's joint report "Beyond 207 Gigawatts: Unleashing Indonesia's solar potential", Indonesia's solar technical potential could reach 3,400 up to 20,000 GWp (IESR & GEI, 2021). Soon after, the MEMR updated the solar technical potential data to 3,295 GWp (MEMR, 2021). Despite the very vast potential of solar energy across Indonesia, the sector has remained relatively untapped.

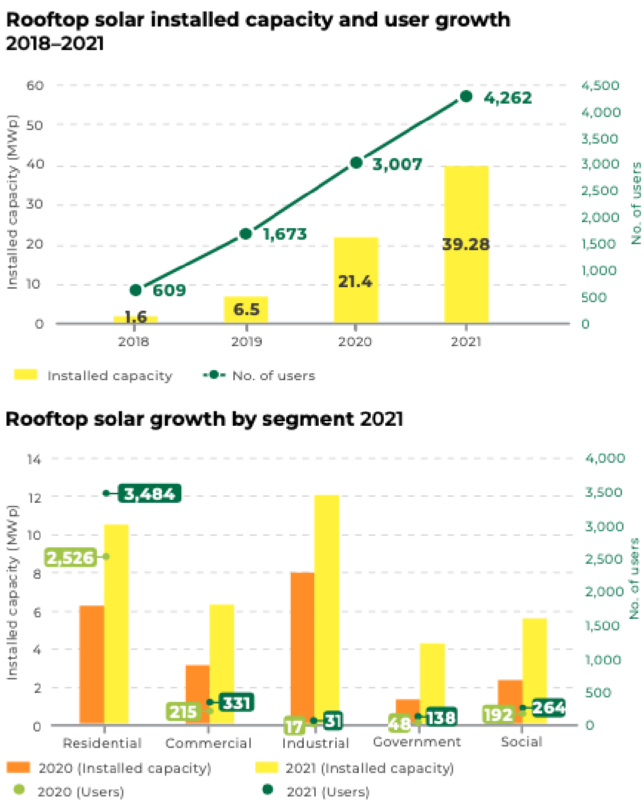
Specific regulations that supported solar energy deployment have been around since at least 2013 (IESR, 2021a). These include rooftop solar net metering regulation through PLN Director's Regulation 0733.K/DIR/2013 and Indonesia's first capacity quota offering for utility-scale solar through MEMR Reg. 17/2013. However, it was only until 2018 that capacity installations started to increase significantly, albeit still at a slow pace. By the end of 2021, Indonesia had only installed slightly less than 200 MWp (see Figure 9). That is only 0.001% of the upper-limit of Indonesia's solar technical potential that is 20,000 GWp (IESR, 2021b).

Figure 10. Indonesia's installed solar PV capacity. Source: IESR (2021b)



Rooftop solar, in particular, has been growing significantly over the last four years. By the end of 2021, Indonesia has 4,262 users with a total installed rooftop solar capacity of 39.28 MW, compared to only 609 users with a total installed capacity of 1.6 MW by the end of 2018 (Figure 10). By 2021, the industrial sector installed 31 rooftop solar PV systems, among which the Coca Cola rooftop solar PV project at Cikarang is the largest in ASEAN with an installed capacity of 7.2 MW (Figure 10) (MEMR, n.d.). Although the number of rooftop solar PV systems in the industrial sector is not large compared to other sectors, its installed capacity of 12.15 MW by 2021 is the highest among the sectors due to the large size of the systems.

Figure 11. a) Installed rooftop solar capacity and user growth, 2018-2021; b) Rooftop solar growth by PLN's customer segment. Source: IESR (2021b)



3.5.2 Policies and regulatory development

In this section, key policies and regulatory development on solar PV development, especially on rooftop solar, in Indonesia will be discussed (see Table 1 for summary of key policies). A full list of key policies on solar energy in Indonesia are listed in Appendix 1.

Table 1. Overview of key policies, targets, policy instruments and incentives on solar PV development in Indonesia.

		National policies
Targets	Renewable energy target	The share of renewable energy in the energy mix should achieve 23% and 31% by 2025 and 2050 respectively (National Energy Policy or "KEN")
	Solar energy target	Total capacity addition of solar PV of 4680 MW by 2030 (RUPTL PLN 2021–2030)
	Rooftop solar energy target	3.6 GW of rooftop solar PV by 2025 (Govt's National Strategic Program or "PSN")
	Nationally Determined Contribution	Emission reduction of up to 29% by its effort and up to 41% with international support by 2030
Policy instrument	Net metering scheme	1:0.65 under MEMR 49/2018 (now 1:1 under MEMR 26/2021, although implementation stalls)
Tax facility and incentives	Investment or production tax credits/tax breaks/ customs duty exemptions	Tax and duty allowances, tax holiday, investment tax deduction, VAT exemption on imported goods, and import duty exemption for greenfield investment in renewable energy (ADB, 2020)
Other	International grants	Sustainable Energy Fund

Underlying drivers

Primary drivers for Indonesia to develop solar energy are its climate commitments that are to reduce emissions, decarbonize its economy, and to achieve net-zero emissions by 2060 (or sooner). Coinciding with that is also Indonesia's energy policy to develop (local) renewable energy and to improve energy security (removes dependence from other countries). From a global market perspective, the falling cost of solar modules over the past decade also became an important driver for Indonesia to start developing solar power to decarbonize, given that solar is already cost-competitive in two-thirds of the world's population (BloombergNEF, 2021). From an industry perspective, increasing international trade pressure (for low carbon footprint) has also pushed businesses to reduce their carbon footprint, making demand from corporates particularly high (BloombergNEF & IESR, 2021).

Targets

In supporting climate change mitigation and the Paris Agreement, Indonesia has committed to reducing 29% of its greenhouse gas emissions by 2030 unconditionally, or 41% by 2030 conditionally with international support in its Nationally Determined Contribution (NDC) (Government of Indonesia, 2021b). More recently, Indonesia has also committed to achieving net-zero emissions by 2060 (or sooner) when Indonesia submitted its Long-Term Strategy for Low Carbon and Climate Resilience 2050 (LTS LCCR, 2050) to the United Nations Framework Convention on Climate Change (UNFCCC) (Government of Indonesia, 2021a)

Another key policy on solar energy development is the National Energy Policy (Kebijakan Energi Nasional or "KEN"), which targets 23% renewable energy share in the primary energy mix by 2025 and 31% by 2050 (Government of Indonesia, 2014). While the specific target for solar is largely unspecified, KEN's derivative RUEN (National Energy General Plan) did mention 6.5 GW of projected installed capacity in the modeling, although this number has been considered obsolete since the economic and electricity demand growth assumptions were too overoptimistic (IESR, 2020). Besides the National Energy Policy, solar development as a climate change mitigation strategy is also mentioned in Indonesia's NDC (Government of Indonesia, 2021b).

In a more implementation-level, solar energy development is also targeted by the state-owned utility PLN's electricity supply business plan, otherwise known as the RUPTL (Rencana Usaha Penyediaan Tenaga Listrik). In the latest RUPTL (2021–2030), PLN aims to add 4.68 GW of solar capacity by 2030, a fivefold increase compared to the previous RUPTL 2019–2028 of only 0.9 GW (IESR, 2021b). However, it is important to note that capacity additions from RUPTL only accounts for utility-scale solar, i.e. large, traditional, centralized solar projects that supplies electricity to the grid traditionally (in one direction toward the transmission and distribution system), typically under a power purchase agreement (PPA) with an independent power producers but could also be built, operated, and owned by PLN themselves (IESR, 2021a).

Rooftop solar development, on the other hand, is regulated under the MEMR Regulation 49/2018 that allows PLN's customers to install rooftop solar under a net metering scheme with an import and export ratio of 1:0.65. The regulation has been revised three times now to MEMR Regulation 26/2021 that increases the net metering ratio to 1:1 and widened the scope to outside PLN's business concession (to private power utilities, or electricity supply business license holders)—although the regulation's implementation is pending due to PLN's objection to the revision due to coal overcapacity issue (and potential revenue loss implication). Prior to the objection, the MEMR has also stated its development target for rooftop solar of 3.6 GWp of installed capacity by 2025 (CNBC Indonesia, n.d.).

4 Technical Potential Assessment of Rooftop Solar PV in Pilot Areas

4.1 Method

(1) The available rooftop areas (Ar) and number are identified by manual identification through ArcGIS. Satellite image information is as follows:

- Data source: Google Earth Level 19
- Spatial resolution: 0.54m
- Band: R, G, B
- Pixel depth: 24
- Coordinate system: GCS_WGS_1984
- Datum: D_WGS_1984

(2) System size means the potential installed capacity; this report applies the same method as described in the Handbook for Rooftop Solar Development in Asia, produced by ADB in 2014.

To calculate the potential installed capacity of the rooftop solar PV system, C_u, in kilowatt-peak per square metres (kWp/m2), we use the following equation:

$$C_u = (C_M/A_M) \times (RCR/1000)$$

where:

C_M is the individual model rate capacity in Wp,

A_M is the area of one module in square metres (m^2),

RCR is the roof cover ratio, which is the fraction of roof area covered by the solar PV modules.

As many different solar PV modules are available, here we select one module, 'Tallmax' from the Trina Company, with 330 Wp, 1.944 m^2 and efficiency of 18%. Using the module with C_M=330 Wp, A_M=1.944 m^2 and the assumption of RCR=0.7, we get:

$$C_u = 0.11881 \text{ kWp/m}^2$$

Corresponding to different roof areas, we obtain the system size (C_R) of each rooftop by

$$C_R = A_R \times C_u$$

(3) For power production (E_u) in kilowatt-hour per square metres in direct current (DC), we use the following equation:

$$E_u = C_u \times PV_{OUT}$$

where:

C_u is the potential installed capacity of the solar PV system per m^2,

PV_{OUT} is the solar PV electricity output in kWh/kWp.

In this equation of power production, we use PV_{OUT} instead of GHI, the global horizontal irradiation, as explained in the ADB handbook in 2014. The values of PV_{OUT} are geographically variable, and the values of each industrial zone are derived from the Global Solar Atlas (https://globalsolaratlas.info/map).

The annual power generation can be calculated by the following equation:

$$E_R = E_u \times A_R \times D$$

where:

D is the factor for converting direct current (DC) to alternating current (AC). The DC/AC ratio in Indonesia is 1.25, therefore D = 0.80 (1.25/1 ≡ 1:0.8),

A_R is the area of the rooftop available for the installation of solar PV modules in m^2.

(4) Fossil fuel consumption reduction is calculated following the formulation below:

Fossil fuel consumption reduction = Annual Electricity Generation* Coal Consumption Rate

Coal consumption rate: 0.45 kg coal equivalent/kWh.

(5) Greenhouse gas emissions reduction potential is calculated using the formulation below:

GHG emissions reduction potential = Annual Electricity Generation* Emission Factor

Emission factor: 0.84 tonnes of CO_2 equivalent per MWh (Java–Bali grid emission factor) (MEMR, 2019)

4.2 Technical Potential Assessment and Results for Nusa Dua Bali Tourism Area

4.2.1 Overview of Nusa Dua Bali Tourism Area

In 2019, 23.26% of the gross regional domestic product came from the tourism sector, while it shrank to 18.37% in 2020 under the influence of the COVID-19 pandemic (Statistics Indonesia, 2020). Bali's electricity consumption reached 5.7 TWh in 2019 and declined to 4.9 TWh in 2020 due to COVID-19; most of the electricity supply came entirely from thermal power plants (944 MW) or a subsea cable connection (400 MW) to Java's power system (PLN, 2021). Bali's electricity demand is projected to grow by 6.51% (10-year average) annually from 2021–2030. The biggest energy consumer in Bali is the business sector, accounting for 50% because its economy depends on the tourist industry (PLN, 2019).

Although the actual total installed capacity of solar energy is only 7 MWp as of Quarter 1 of 2022, as IESR and GEI's analysis suggests, Bali has great solar energy potential, given that the regional solar technical potential reaches 26 GWp, with an electricity generation potential of 40.5 TWh per year across its nine regions. Indeed, the provincial government actively supports rooftop solar PV development. In 2019, The 'Bali Clean Energy' regulation, issued by the regional government, stated that at least 20% of the total roof areas in Bali should install rooftop solar PV. Also, the Bali government has set the target of installing 7.5 MWp of rooftop solar PV by 2025 (Provincial Government of Bali, 2021). In March 2022, the Bali government issued a circular letter that aims to accelerate rooftop solar PV development by focusing on opening-up business opportunities, investment, and mobilization of funding for rooftop solar PV. The letter orders public buildings and commercial, industrial, social, and residential buildings with more than 500 square metres of floor area to install rooftop solar as a minimum of 20% of installed electrical capacity.

Nusa Dua Bali, as a world-renowned tourism area, is one of the backbones of the Bali province's economy; it is also the key contributor to electricity consumption and regional economic growth. This area is thus occupied by many commercial buildings, which can provide an opportunity to utilize rooftop solar PV. The rich natural solar energy resources and regional government support can benefit the deployment of rooftop solar PV in Nusa Dua.

This section investigates the technical potential of commercial buildings in Nusa Dua Bali tourism area and presents the results, including the number and area of the available rooftops, the potential installed capacity, and annual electricity production.

4.2.2 Available Rooftops and Solar Technical Potential

Figure 12 presents the AI recognition results for Nusa Dua Bali. In total, the Nusa Dua Bali tourism area has 2,356 rooftops, with an available rooftop area of around 876,348 m^2. The result of the technical potential analysis shows that the potential installed capacity of rooftop solar is about 104.12 MWp, with a potential annual electricity production of around 141.77 GWh.

Figure 12. AI recognition results for Nusa Dua Bali

4.2.3 Social and Environment Benefits of Rooftop Solar PV Projects in Nusa Dua Bali

The project team investigated the energy demand of Bali Province, finding that the total electricity consumption was 4.9 TWh in 2020. According to the evaluation results, if the capacity factor reaches 19%, the annual electricity generation of Nusa Dua can reach about 141.77 GWh. Thus, the annual rooftop solar PV production from the Nusa Dua tourism area can replace around 2.8% of the total electricity consumption of the Bali Province.

The annual total technical potential power generation of rooftop solar PV in Nusa Dua Bali is 141.77 GWh, which is equivalent to reducing fossil energy consumption by 63,794 tonnes of coal equivalent per year. In terms of greenhouse gas emissions reduction potential, it could offset as much as 119,083 metric tons of CO_2 equivalent per year (using Java–Bali's grid emission factor of 0.84 tonnes per MWh) (see 5.1 for the detailed method).

Table 2. Summary of rooftop solar technical potential (capacity and generation), fossil fuel consumption reduction, and GHG emissions reduction potential of commercial buildings in Nusa Dua, Bali

Project Location	Number of Rooftop Aareas	Rooftop Area (m^2)	Potential Installed Capacity (MWp)	Annual Electricity Production (GWh)	Fossil Fuel Consump-tion Reduction (tonnes of coal eq.)	GHG Emissions Reduction Potential (tonnes of CO_2 eq.)
Nusa Dua tourism area, Bali	2,356	876,348	104.12	141.77	63,794	119,083

4.3 Assessment and Results for Industrial Zones

4.3.1 Overview of the Industrial Zones

In Indonesia, 11 industrial zones were analysed, i.e., one in Banten province, one in East Java province, seven in West Java province, and two with Chinese capital investment (Table 3 and Table 4).

Table 3. Industrial parks analysed in this study in Banten, East Java and West Java provinces in Indonesia

Province	Name	Total Planned Area (ha)	Companies
Banten	Krakatau Industrial Estate Cilegon (KIEC)	625	Around 70 international and national companies (e.g. Krakatau Steel). Steel, chemical and petrochemical industries
East Java	Sidoarjo Rangkah Industrial Area	307	N/A
West Java	Bekasi International Industrial Estate	200	Korean manufacturers. 104 companies including 26 Korean corporations
	Greenland International Industrial Center	1,458	Auto and auto-related (70%), logistics, consumers and others (30%)
	MM2100	2,500	Mixed. More than 300 companies
	Jababeka Industrial Estate	5,600	Mixed. More than 1,650 local and multinational corporations from 30 countries, such as the US, Japan, France, UK, the Netherlands, Australia, Korea, Singapore, Taiwan, Malaysia, and numerous others
	Lippo Cikarang	3,000	N/A
	Hyundai Inti Development	200	N/A
	East Jakarta Industrial Park	320	N/A

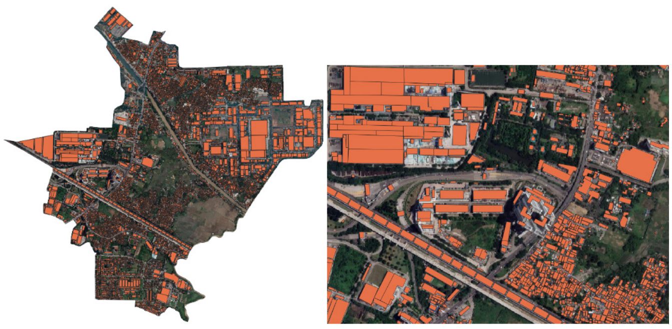
Table 4. Industrial zones with Chinese capital investment in Indonesia

Province	Name (English)	Name (Chinese)	Total Area (ha)	Priority Industry
Central Sulawesi	Indonesia Morowali Industrial Park	中国印尼综合产业园区青山园区	2,000	Iron and nickel
West Java	PT Kawasan Industri Terpadu Indonesia China	中国 • 印尼经贸合作区	429	Machinery manufacturing, infrastructure building materials, logistics and warehousing, food processing

4.3.2 Technical Potential of the Industrial Zones

In total, the 11 industrial zones have 7,683 available rooftops with a total area of 22,334,248 m^2. The result of the technical potential analysis shows that the potential installed capacity of all rooftops solar PV is 2.63 GWdc, with the potential annual electricity production of 3 TWh/year. Table 5 presents the rooftop number, rooftop areas, solar PV potential installed capacity, and the yearly solar PV power generation of the 11 industrial zones.

Figure 13. Example of AI recognition results for Jababeka Industrial Estate



4.3.3 Social and Environmental Benefits of the 11 Industrial Zones

The annual total technical potential power generation of rooftop solar PV in the 11 industrial zones is 3 TWh/year, equivalent to reducing fossil energy consumption by 1.3 million tonnes of coal per year. In terms of greenhouse gas emissions reduction, it could potentially offset 2.5 million metric tons of CO_2 equivalent per year (using Java–Bali's grid emission factor of 0.84 tonnes per MWh) (see 5.1 for detailed method).

Table 5. Summary of rooftop solar technical potential (capacity and generation), fossil fuel reduction, and GHG emissions reduction potential of the 11 selected industrial zones in Indonesia

Province	Name	Rooftop Number	Rooftop Areas (m^2)	Potential Installed Capacity (MWp)	Annual Production (GWh)	Fossil Fuel Consumption Reduction (tonnes of coal eq.)	GHG Emissions Reduction Potential (tonnes of CO_2e)
Banten	Krakatau Industrial Estate Cilegon (KIEC)	397	903,298	107.3	120.8	54,359.1	101,470
East Java	Sidoarjo Rangkah Industrial Area	106	435,629	51.8	67.4	30,314.5	56,587
West Java	Bekasi International Industrial Estate	344	920,638	109.4	123.8	55,717.5	104,006
	Greenland International Industrial Center	667	2,200,090	216.4	297.9	134,091.7	250,305
	MM2100	1411	4,871,244	578.7	630.1	283,559.8	529,312
	Jababeka Industrial Estate	1381	5,010,404	595.2	691.9	311,375.9	581,235
	Lippo Cikarang	1303	3,711,230	440.9	495.6	223,018.5	416,301
	Hyundai Inti Development	270	729,380	86.66	98.1	44,142.5	82,399
	East Jakarta Industrial Park	921	1,224,378	145.5	162.9	73,314.5	136,854
	PT. Kawasan Industri Terpadu Indonesia China	200	839,830	99.8	113.4	51,006.6	95,212
Central Sulawesi	Indonesia Morowali Industrial Park	683	1,488,127	176.8	205.4	92,417.3	172,512
Total		7,683	22,334,248	2,635.5	3,007.3	1,353,318	2,526,194

Note: Sums may not equal total due to rounding

5 Financial Potential Assessment and Results for Rooftop Solar PV in Pilot Areas

The project's financial evaluation covers costs, benefits, related impacts, and also financial risks. The three types of related financial risks are market risk, policy risk and credit risk. Market risk refers to the risk that the project owners and lenders need to take due to changes in the market environment that affect the feasibility of technology application. Policy risk considers that changes in government policy may have a significant impact on the financial feasibility and bankability of the project (similarly, on project owners and creditors). For solar PV power generation projects, potential policy risk includes the government's adjustments to the production subsidy or sales price. Credit risk is the risk incurred by the lender due to the expansion of the credit scale to the borrower, and the lender bears the risk that the borrower cannot repay the loan.

The project team took a medium-size (625 kWp) rooftop solar PV project in the Nusa Dua Bali tourism area as an example of commercial buildings and a large-size (2.5 MWp) rooftop solar PV project in Jababeka Industrial Zone to represent industrial zones projects for the financial assessment. The introduction of the indicators, the financial model and the result are presented below.

5.1 Introduction to Financial Analysis Indicators

The relevant indicators of the project's financial evaluation include basic reimbursement, discounted principal repayment, investment payback period, and discounted cash flow. Other lendings institution-related financial indicators are the internal rate of return and return on investment.

Discounted Cash Flow (DCF): The discounted present value of the sum of all future planned costs and revenues.

$$DCF = \sum_{t=0}^{N} \frac{FV_t}{(1+r)^t}$$

Where: DPV is the discounted present value of future cash flows,

FV is the nominal value of cash flows in the following year,

r is the discount rate,

t is the number of years in the future,

N is the upper limit of the summation.

Internal rate of return (IRR) refers to a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis. It represents the maximum annual interest rate at which a project owner can afford to borrow money to invest in a project.

$$NPV = CF_0 + \frac{CF_1}{(1+IRR)^1} + \frac{CF_2}{(1+IRR)^2} + \cdots + \frac{CF_n}{(1+IRR)^n} = 0$$

Return on investment (ROI) and risk-adjusted ROI: this shows the ratio of the net benefit to total cost of the project.

ROI = (Total Benefit - Total Cost) /Total Cost

Risk-adjusted ROI (discounted benefits and costs) is favoured, as it provides a more conservative ratio, i.e., benefits are commonly higher than costs in the remaining years, and risk-adjusted ROI applies the time value of money to calculate discounted benefits and costs over a period of time, with the discounted benefits and the calculated rate at a relatively lower level.

Discounted payback period: The time required to recover the accumulated investment in the project.

Discounted Payback Period = Investment Cost/(Projected) Annual Net Cash Flow

Discounted payback period is used for comparison with other investments available to borrowers. The discounted payback period discounts future net cash flows, since there are time horizons for costs and benefits; it also takes into account the lost opportunity to invest cash elsewhere (usually set at a level equal to the company's cost of capital) and the relative measurement of project risk (cost of capital + discount rate at which risk is generated). For projects with a longer payback period, the discounted payback period provides a more conservative assessment than undiscounted payback (due to the consideration of time value of money).

In the financial analysis of specific solar PV system projects, the following cost indicators are mainly considered:

Levelized cost of electricity (LCOE): Several formulas are required to convert various units into unit representing the levelized cost ($/MWh). The following is a brief introduction to the formulas:

• **Initial investment cost (IIC):** According to the following formula, the expected plant operational costs are annualized and expressed in units of year/MWh:

$$\text{Annual IIC} = \text{IIC} * \text{FCF} * 1{,}000 / (8{,}760 * C_f)$$

Where:

IIC is the initial investment cost, including the capital cost of land and equipment and any other initial costs of planning, engineering and construction ($/kW),

FCF is the fixed cost factor, 1,000 is the conversion from $/kW to $/MW, 8,760 is the number of hours per year, and C_f is the capacity factor (%)

• **Fixed operation and maintenance cost (FOM):** According to the following formula, the annual cost of operating a system can be estimated in units of $/MWh:

$$\text{Annual FOM} = \text{FOM} * 1{,}000 / (8{,}760 * C_f)$$

Where:

FOM is fixed operations and maintenance cost ($/KW year), subjected to an annual growth rate equal to or higher than the rate of inflation; 1,000 is the conversion from $/kW to $/MW; 8,760 is the number of hours per year, and C_f is a capacity factor (%).

• **Variable operation and maintenance cost (VOM):** The formula is similar to FOM, but it considers the total cost of operation and maintenance activities, which is already provided in $/MWh.

• **Discounted cost:** All annual costs estimated above are discounted as follows:

$$\text{Discounted Annual Cost} = [PV_{GEN} * DR * (1+DR)^t] / [(1 + DR)^t - 1]$$

Where:

PV_{GEN} is the present value of the sum of all power-generating costs based on the sum of annual IIC, FOM, VOM, and fixed cost ($/MWh, annual cost over the system life cycle), and DR is the discount rate.

Finally, the value of the discounted annualized cost flow is levelized throughout the system life cycle:

$$\text{LCOE} = \text{Sum of Costs of PL} / \text{Sum of Electricity Production of PL}$$

Where:

LCOE (levelized cost of electricity) is in $/MWh, and PL is plant life in a year.

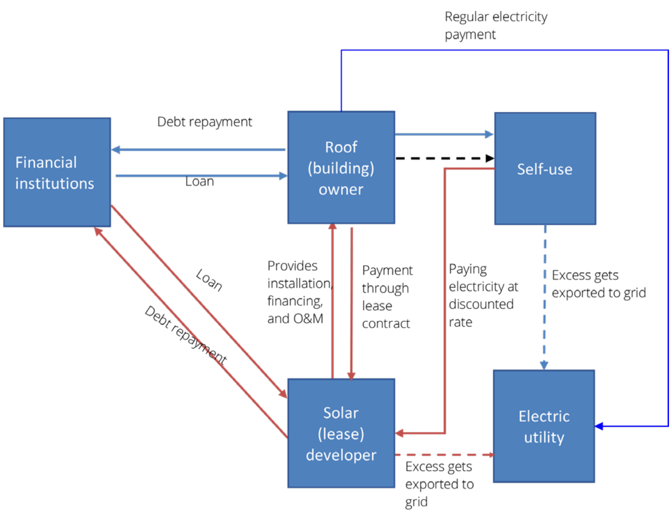
5.2 Financial Analysis Methods

The research team conducted a financial evaluation of rooftop solar PV power generation potential by using Microsoft Excel tools for discounted cash flow analysis. In addition, it analysed the uncertainties affecting financial indicators and the sensitivity of various financial parameters by using Argo, a Monte Carlo simulation add-in for Microsoft Excel.

Before conducting the financial evaluation of rooftop solar PV power generation, the project's business model should be determined first. There are at least three basic configuration modes for rooftop solar PV power generation systems. The first configuration mode is self-use with surplus feed-in electricity. The second configuration mode is independent or 'off-grid' systems. A third configuration mode can be considered a hybrid system, such as a gas turbine or diesel engine with an electric generator and/or the introduction of grid power as a supplement. The first mode is adopted for the commercial and industrial rooftop solar projects assessed here.

Potential financing sources for industrial and commercial rooftop projects include funds provided by roof owners (equity), bank financing (debt), financial support mechanisms such as government subsidies, and/or funds from carbon trading systems. Different financing types can be combined, with the two most likely financing combinations shown as follows:

Figure 14. Financing models of rooftop solar PV power generation projects



In Financing Model 1 (orange), a solar developer bears all the risk of developing a rooftop solar project at a building owner's site. The solar developer may receive a loan from financial institutions to provide the building owner with full installation, financing, and operations and maintenance services for using a rooftop solar system. The building owner then pays a monthly electricity fee to the developer, usually at a discounted rate (lower than the utility company's), using a type of lease contract or a long-term power purchase agreement – although the latter is not allowed in Indonesia's electricity law.

In Financing Model 2 (blue), a building owner may or may not obtain a loan and invest in a rooftop solar system on its own. The building owner then benefits from the electricity cost saving from self-generated solar electricity, while the excess will be exported to the grid (and compensated by the utility company, assuming that its exporting capability is utilized). In this assessment, the second financing mode is carried out.

5.3 Input of Financial Analysis

The specific data and sources of key input values of cost are shown in the following table (note that all $ units are in United States dollars unless otherwise stated):

Table 6. Key input values of cost for evaluating solar PV power generation systems

System component cost	Value	Unit	Notes	Data source
Equipment cost				
Inverter for medium system	0.07	$/W		Alibaba
Inverter for large system	0.05	$/W		Alibaba
Crystalline silicon component for medium system	0.235	$/W		Alibaba
Crystalline silicon component forlarge system	0.230	$/W		
Medium system: Architecture	0.019	$/W		Alibaba
Large systems: Architecture	0.016	$/W		
Equipment overhead cost				
Medium system	13%	Percentage of total equipment cost	Equipment supplier's overhead, storage, shipping and handling costs and expenses, plus 2% developer's commission	IESR
Large system	13%	Percentage of total equipment cost		
Medium system	0.042	$/W	Totaling above costs	
Large system	0.041	$/W	Totaling above costs	
Tax				
Medium system	11%	Percentage of total equipment cost	VAT	PwC, 2022
Large system	11%	Percentage of total equipment cost	VAT	

System component cost	Value	Unit	Notes	Data source
Medium system	0.016	$/W	Calculated by percentage and equipment cost	
Large system	0.016	$/W		
Installation cost				
Medium system	0.075	$/W		IESR
Large system	0.080	$/W		
Wiring, testing, on-grid charges				
Medium system	0.110	$/W		NREL, 2021
Large system	0.110	$/W		
Accidental cost				
Medium system	4.0%	Percentage of total equipment cost	The share of construction cost in the project implementation	NREL, 2020
Large system	4.0%	Percentage of total equipment cost	The share of construction cost in the project implementation	
Medium system	0.018	$/W	Calculated by percentage and equipment cost	
Large system	0.018	$/W		
Total cost of system				
Medium system	0.57	$/W	Calculated by percentage and equipment cost	
Large system	0.57	$/W		
Other input				
DC-AC inversion loss (DC/AC ratio = 1:0.8)				
Medium system	20	%	Estimated value	IESR
Large system	20	%	Estimated value	

Note: All $ units are in United States Dollar (USD) unless otherwise stated.

Table 7. Key project parameters and assumptions for pooftop solar PV system in Nusa Dua, Bali tourism area

Parameter	Value	Unit	Notes and references
Analysis of the first year	2022	Year	
Power plant's expected lifetime	25	Year	Assumptions; based on warranty period
DC capacity	625	kWp	A 625 kWp (500 kWac) rooftop solar system is taken as a representative commercial building in Nusa Dua tourism area, Bali
AC capacity	500	kWac	DC/AC ratio of 1.25
Project installation cost	0.57	$/Wdc	See Table 6, solar PV power generation system and system cost table
Grid connection of power station	0	$	Included in the total project cost

Parameter	Value	Unit	Notes and references
Total project cost	356,250.00	$	Including equipment, construction, permits, and all other costs associated with initial construction and start-up, as shown in Table 6
Subsidy	0	$	All subsidies are not applicable to the project
Power station capacity factor	0.194	unitless	Calculated
Rooftop rental fee	0	$/MW year	Not applicable to this project
Fluctuation rate of rooftop rental fee	0	%	Not applicable to this project
Net generating capacity: the first year	849,720.00	kWh/ year	Calculated, considering the construction duration of the project (the number of months left in the year after the system starts operation)
Output performance degradation rate of solar PV power generation system	0.5	%/year	PV module manufacturer's datasheet
Other variable operation and maintenance cost	0.00	$/kWh	Set to 0
Self-used power generation	70	%	IESR
Fixed operation and maintenance cost	19	$/kW year	IESR
Fluctuation rate of operation and maintenance cost	2.0	%/year	According to the rate of inflation
Levelized cost of electricity benchmark	0.0726	$/kWh	LCOE of thermal power generation in Indonesia. Data source: IESR

Note: All $ units are in United States dollars (USD) unless otherwise stated.

Table 8. Key costs and financing input values for rooftop solar PV system in Nusa Dua, Bali tourism area

Parameter	Value	Unit	Notes and references
Input ratio of power station owner's principal	30	%	Assumed according to the minimum value of the range (30–70%) required by lending institutions
Electricity sale price	0.08	$/kWh	PLN
Value of self-used electricity	0.08	$/kWh	PLN
Annual growth rate: value of electricity generation	0.03	%/year	IESR
Carbon neutrality subsidy	0	$/t$CO_2$e	Not applicable to this analysis
State subsidy	0	$/kWh	Not applicable to this analysis
City subsidy	0	$/kWh	Not applicable to this analysis
Inflation rate	2.80	%	IESR
Project construction time	0.5	Year	Assumption; this value means that the project is in the middle of the first year when it is commissioned

Parameter	Value	Unit	Notes and references
Corporate income tax: Phase 1	12.50	%	IESR
Corporate income tax: Phase 2	20	%	
Corporate income tax: Phase 3	25	%	
Discount rate (nominal)	5.0	%/year	Assumptions; one of the metrics used in financial analysis is the weighted average cost of capital (WACC); this varies from business to business and depends on its cost of equity capital, cost of debt, market value of business liabilities and equity, and corporate income tax. Assume that the discount rate for this analysis is in the range of 3.0–10%
Interest rate	8.17	%/year	IESR
Loan period	10	Years	The range is 8–15 years
Capital recovery factor (CRF)	0.15	None	Calculated based on interest rate and loan period
Residual value	-	$	Not applicable to this analysis

Note: All $ units are in United States dollars (USD) unless otherwise stated.

Table 9. Key project parameters and assumptions for rooftop solar PV system in Jababeka Industrial Estate

Parameter	Value	Unit	Notes and references
Analysis of the first year	2022	Year	
Power plant's expected lifetime	25	Year	Assumptions; based on warranty period
DC capacity	2,500	kWp	A 2,500 kWp (2,000 kWac) rooftop solar system is taken as a representative industrial building in Jababeka Industrial Estate
AC capacity	2,500	kWac	DC/AC ratio: 1.25
Project installation cost	0.57	$/Wdc	See Table 6: solar PV power generation system and system cost table
Grid connection of power station	0	$	Included in the total project cost
Total project cost	1,425,000	$	Including equipment, construction, permits, and all other costs associated with initial construction and start-up, as shown in Table 6
Subsidy	0	$	All subsidies are not applicable to the project
Power station capacity factor	0.166	unitless	Calculated
Rooftop rental fee	0	$/MW year	Not applicable to this project
Fluctuation rate of rooftop rental fee	0	%	Not applicable to this project
Net generating capacity: the first year	2,908,320	kWh/year	Calculated, considering the construction duration of the project (the number of months left in the year after the system starts operation)
Output performance degradation rate of solar PV power generation system	0.5	%/year	PV module manufacturer's datasheet
Other variable operation and maintenance cost	0.00	$/kWh	Set to 0
Self-used power generation	70	%	IESR

Parameter	Value	Unit	Notes and references
Fixed operation and maintenance cost	19	$/kW year	IESR
Fluctuation rate of operation and maintenance cost	2.0	%/year	According to the rate of inflation
Levelized cost of electricity benchmark	0.0726	$/kWh	LCOE of thermal power generation in Indonesia. Data source: IESR

Note: All $ units are in United States dollars (USD) unless otherwise stated.

Table 10. Key costs and financing input values for rooftop solar PV system in Jababeka Industrial Estate

Parameter	Value	Unit	Notes and references
Input ration of power station owner's principal	30	%	Assumed according to the minimum value of the range (30–70%) required by lending institutions
Electricity price	0.08	$/kWh	PLN
Value of self-used electricity	0.08	$/kWh	PLN
Annual growth rate: value of electricity generation	0.03	%/year	IESR
Carbon neutrality subsidy	0	$/t$CO_2$e	Not applicable to this analysis
State subsidy	0	$/kWh	Not applicable to this analysis
City subsidy	0	$/kWh	Not applicable to this analysis
Inflation rate	2.80	%	IESR
Project construction time	0.5	Year	Assumption; this value means that the project is in the middle of the first year when it is commissioned.
Corporate income tax: Phase 1	12.50	%	IESR
Corporate income tax: Phase 2	20	%	
Corporate income tax: Phase 3	25	%	
Discount rate (nominal)	5.0	%/year	Assumptions; one of the metrics used in financial analysis is the weighted average cost of capital (WACC); this varies from business to business, depending on its cost of equity capital, cost of debt, market value of business liabilities and equity, and corporate income tax. Assume that the discount rate for this analysis is in the range of 3.0–10%
Interest rate	8.17	%/year	IESR
Loan period	10	Years	The range is 8–15 years
Capital recovery factor (CRF)	0.15	None	Calculated based on interest rate and loan period
Residual value	-	$	Not applicable to this analysis

Note: All $ units are in United States dollars (USD) unless otherwise stated.

5.4 Financial Analysis Results

5.4.1 Cost and Benefit Result for Nusa Dua Bali

A cost-benefit analysis was conducted based on the current policy support and investment environment in Indonesia.

The expected return on investment for the rooftop solar PV project in Nusa Dua Bali tourism area is shown in the table below:

Table 11. Cost-benefit analysis results for rooftop solar PV project in the Tourism area under the baseline scenario

Total initial investment ($)	$356,250	Rooftop solar solar PV power generation system; including cost of equipment, installation and grid connection
Discounted net cash flow (NCF) ($-2022)	$283,411	2022–2046; owners' net income
Internal rate of return (IRR) (%)	12.4%	2022–2046; should be greater than the cost of capital
Minimum acceptable rate of return (MARR) (%)	8.2%	Cost of capital
Return on Investment (ROI) (%)	45.0%	2022–2046
Payback period (PBP) (year)	7.89	Recovery based on underlying equity
Discounted payback period (PBP) (year)	10.64	Recovery based on risk-adjusted underlying equity
Cost-benefit ratio	1.45	2022–2046 discounted
Levelized cost of electricity ($/kWh)	0.057	Undiscounted; benchmark is traditional coal cost of 0.0726 $/kWh
Net present value of implementation cost	$629,170	2022–2046; shareholders' equity, principal and interest repayment, operation and maintenance

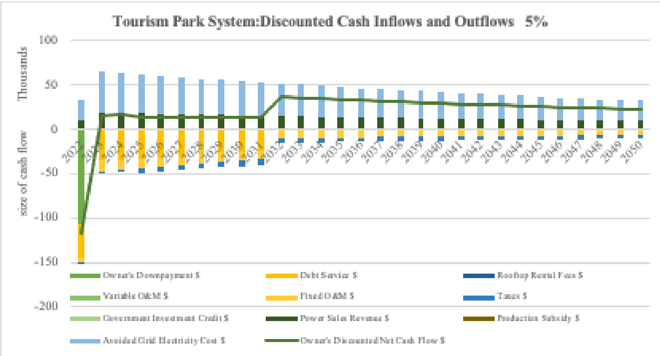
In this analysis, a 625 kWp commercial rooftop solar project in Nusa Dua Bali is simulated using a crystalline silicon module fixed array, 80% output guarantee for 25 years, 70% of electricity for own use, and no battery storage. The surplus electricity is sold to the grid operator, without paying rooftop rental fees.

In the first 25 years of the project, the project owner's net income can reach $283,411. From the results, we can notice that the internal rate of return (IRR) is 12.4%, which is higher than the cost of investment (MARR) of 8.2%, meaning that the remaining 4.2% is the project owner's profit margin and can meet the investment requirement. Internal rate of return (IRR) refers to the maximum currency depreciation ratio that a project can withstand in terms of profit margin and anti-risk ability; it can represent the maximum annual interest rate at which a project owner can afford to borrow money to invest in a project. The overall ROI is 45.0%. The LCOE of this project is 0.057 $/kWh, which is lower than that of traditional coal (0.0726 $/kWh).

The payback period (PBP) is between 7.89 and 6 years, which can be compared with the 'cut-off investment period' to measure the investment return of the project. 'Cut-off investment period' is the expected value of the project owner's investment recovery, and discounted net cash flow and discounted payback period are the analysis results adjusted according to the risk of currency value. The cut-off investment period will depend on the valuation of the project owner.

The net present value of implementation cost indicates the project's total cost, including the owner's initial input, financing, and operation and maintenance. The net current value of this project's implementation cost is $629,170.

Figure 15. Discounted cash flow of the solar PV system in the Nusa Dua Bali tourism area (discount rate 5%)



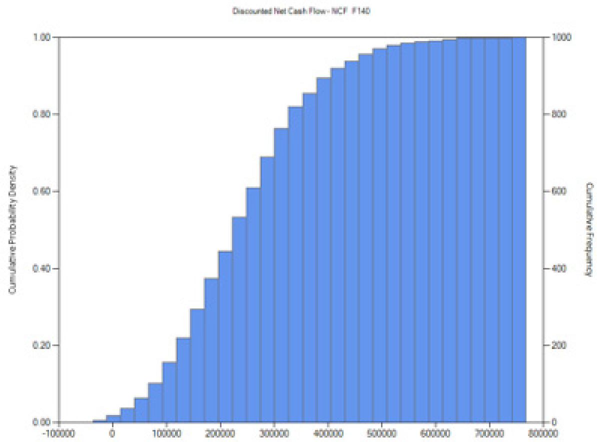
5.4.1.1 Uncertainty and Sensitivity Analysis of Rooftop Solar PV Projects

To promote the project's implementation, this research further explored the essential factors affecting its planning and execution. The share of self-consumption, the time that PV is used for the owner's self-consumption installed coefficient, discount rate, and fixed operation and maintenance costs are often important factors affecting the project's financial performance. Thus, the project team conducted a sensitivity analysis of the variable factors. The primary process of study consists of three steps, i.e., determining the numerical variation range of variable factors, the calculation based on Monte Carlo simulation, and the chart analysis of simulation results – including a spider chart to analyse the impact of variable values on the net cash flow, and a tornado chart to detail the impacts.

According to the different probabilities of variable factor values, variables can exhibit uniform or triangular distribution. Specifically, if the likelihood of a variable's values falling at a given value within the interval is the same, it is assumed to be a uniform distribution; if they are most likely to fall in the centre, it is considered a triangular distribution. Based on the inputs shown in Tables 6 and 7 in section 5.3, variable factors are divided into two categories: Category A includes value for self-use, city subsidy, discount rate, interest rate, loan period, electricity price, and power station capacity factor, and self-used power generation. The values of these factors are usually concentrated near a specific value, which indicates triangular distribution. Category B includes the power station owner's principal input and the fixed operation and maintenance cost, whose values have equal probabilities in a small range, thus demonstrating uniform distribution.

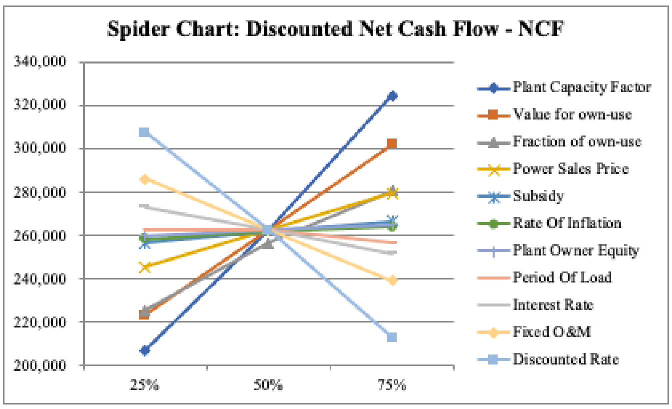
The Monte Carlo simulation repeats the permutations and combinations of these variable factors, calculates 1,000 times, outputs the corresponding results, and finally obtains the probability distribution of the project's net cash flow value. Based on the results of those tests' summary statistical data for the constructed distribution, the project's average discounted net cash flow is about $248,300, the maximum is $738,000, and the minimum is -$69,500. Figure 19 shows the cumulative probability density chart based on the Monte Carlo simulation of net cash flow; the possibility that the discounted net cash flow is more than $0 is greater than 98.8%.

Figure 16. Cumulative discounted net cash flow probability density



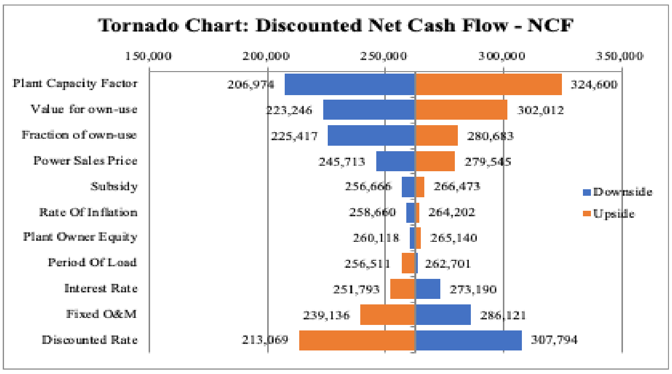
Sensitivity analysis can help to determine what factors increase the uncertainty of net cash flow valuation and their impact on the upward and downward risks to net cash flow. Figure 17 shows the spider chart of the sensitivity analysis, and Figure 18 shows the tornado chart. The input and output values of the sensitivity analysis are presented in Appendix 2.

Figure 17. Spider chart of net cash flow sensitivity analysis



In Figure 17, the X-axis represents the variable values of the sensitivity analysis. For example, 50% is the median of each variable, and 25% is the value corresponding to the 25th percentile. A variable with a positive slope has a greater upward effect than a downward effect, and a variable with a negative slope has a more downward than upward effect. Among them, the plant capacity factor, fraction of own use, and the electricity price for self-use (retail electricity cost offset by PV systems) are the critical variables that have a greater upward than downward effect. The variables with a larger downward than upward effect include discount rate and the fixed operation and maintenance fee. Appendix 2 and Figure 17 show that the self-use fraction and the self-use value are more sensitive variables to the estimated discounted net cash flow (as indicated by the slope in Figure 17). A downward variable refers to a variable that drives the result down when the variable rises, while an upward variable moves the result up when it rises. Lending institutions and project owners may be more concerned about downward risk variables. For example, a sharp drop in cash flow indicates that a lender faces an increased risk of non-repayment of a loan.

Figure 18. Tornado chart of net cash flow sensitivity analysis



As for the upward variables in the upper part of Figure 18, the increase in their values makes the net cash flow higher, while the rise of the downward variables in the lower part makes the net cash flow lower. Important downward risk variables are the period of the loan, interest rate, discount rate, and fixed O&M cost.

Without relying on the subsidy for electricity, project owners are encouraged to compare the price of electricity sold and the price of electricity for their own use and balance their own demand for electricity use with the share of electricity sold to achieve better overall economic benefits and lower net cash flow sensitivity. According to the analysis results, it is a profitable business model to increase the self-use ratio and sell electric power to the grid. It is also important to choose when to offset electricity purchases with self-use, as this affects the benefits gained from avoiding the grid electricity cost. Because of the difference in peak/valley electricity prices, using project-generated electricity to meet the needs of self-use in the peak period will also result in a better performance of the financial indicators.

Fixed O&M cost is also one of the downward risk variables in the analysis of net cash flow. If the project can reduce fixed operation and maintenance costs, the financial indicators will be improved. In their loan application, project owners should pay sufficient attention to the operation and maintenance methods and try to choose the plans with lower maintenance costs throughout the project.

5.4.2 Cost and Benefits Results for Jababeka Industrial Estate

The project team took Jababeka Industrial Estate as an example to conduct the investment and financing analysis of rooftop solar PV projects in Indonesian industrial zones. A cost-benefit research was conducted based on Indonesia's current policy support and investment environment. The expected return on investment for rooftop solar PV projects is demonstrated below.

Table 12. Cost-benefit analysis results for industrial rooftop solar PV projects

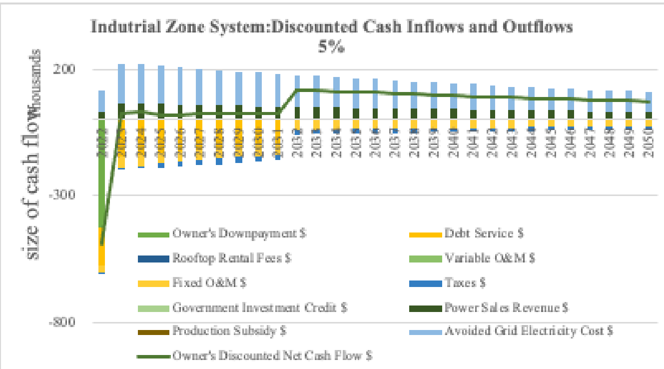
Jababeka Industrial Estate		
Total initial investment	$1,425,000	Rooftop solar solar PV power generation system; including cost of equipment, installation and grid connection
Discounted net cash flow	$654,510	2022–2046; owner's net income
Internal rate of return (IRR) (%)	6.8%	2022–2046; should be greater than the cost of capital
Minimum acceptable rate of return (MARR) (%)	8.2%	Cost of capital
Return on Investment (ROI) (%)	26.5%	2022–2046; some projects may require 100% or more
Payback period (PBP) (year)	11.02	Recovery based on underlying equity

Jababeka Industrial Estate		
Discounted payback period (year)	13.44	Recovery based on risk-adjusted underlying equity
Cost-benefit ratio	1.27	2022–2046 discounted
Levelized cost of electricity ($/kWh)	0.065	Undiscounted; benchmark is traditional coal cost of $0.0726/kWh
Net present value of implementation cost	$2,468,964	2022–2046; shareholders' equity, principal and interest repayment, operation and maintenance

In this project, the Jababeka Industrial Park in Indonesia has a calculated potential 2.5 MWp rooftop solar PV system, with a crystalline silicon module fixed array, 80% output guarantee for 25 years, and 70% electricity for own use, and no battery storage. The surplus electricity is sold to the grid operator without paying rooftop rental fees.

In the first 25 years of the project, the project owner's net income can reach $654,510. From the results, we can notice that the internal rate of return (IRR) is 6.8 %, which is lower than the cost of investment (MARR), 8.2%. In contrast to the Nusa Dua tourism case, the Jababeka Industrial Park is not profitable due to the lower capacity factor (16..6%) and also the large installed capacity. The lower irradiation in Jababeka Industrial Park leads to the low capacity factor and becomes one of the determining factors for the project's viability. Also, the more extensive system size (2.5 MWp) could be a contributing factor to the unprofitable results (in the model). Calculations related to capacity, especially O&M, might be higher, too, leading to higher construction and O&M cost. The payback period is 11 years, and the overall ROI is 49.6%. The LCOE of this project is 0.065 $/kWh, which is lower than traditional coal's LCOE of 0.0726 $/kWh.

Figure 19. Net cash flow at a discount rate of 5% in Jababeka

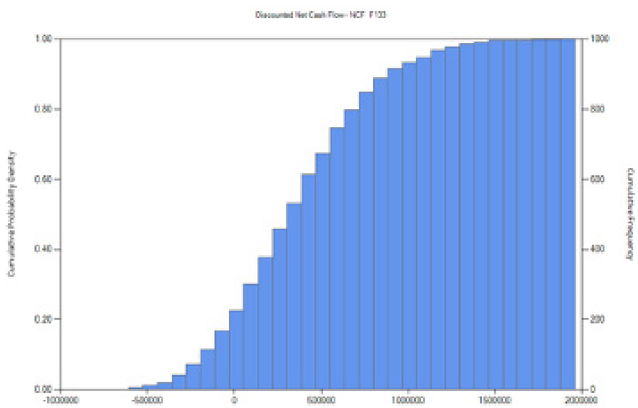


5.4.2.1 Uncertainty and Sensitivity Analysis of Rooftop Solar PV Projects

Jababeka sub-park is an example to explore further the important factors affecting project planning and implementation. The share of self-consumption, the time that PV is used for the owner, installed coefficient, discount rate, and fixed operation and maintenance cost are important factors affecting the project's financial performance. The variable factor classification and selection principles refer to those relevant to the tourism zone, and the range of values is based on the inputs shown in Tables 6 and 8 in section 5.3.

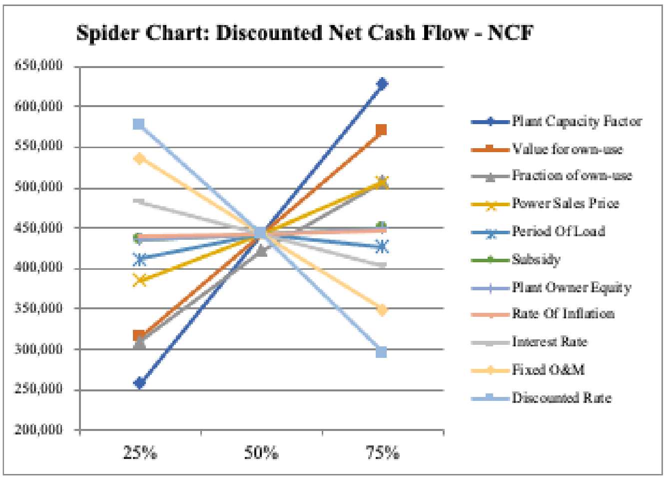
In this research, the Monte Carlo simulation of discounted net cash flow was conducted. Based on the 1,000-test summary statistical data of the constructed distribution, the project's average discounted net cash flow is about $364,500, the maximum is $1,800,000, and the minimum is -$660,000. Figure 19 shows the cumulative probability density chart based on the Monte Carlo simulation of net cash flow; the possibility that the discounted net cash flow is more than $0 is greater than 77.8%.

Figure 20. Cumulative discounted net cash flow probability density



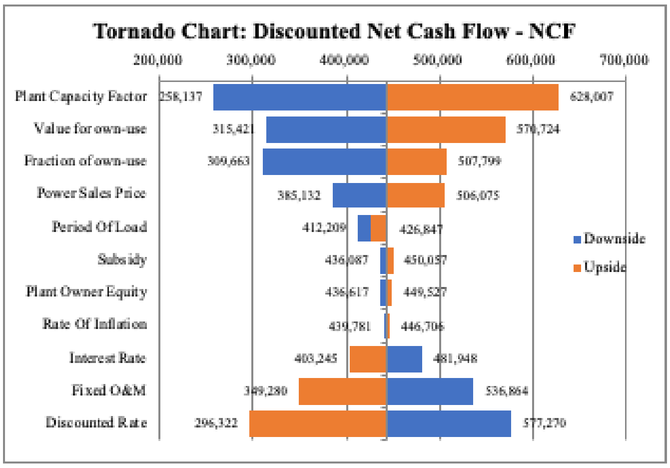
Sensitivity analysis can help to identify what factors increase the uncertainty of net cash flow valuation and their impact on the upward and downward risks to net cash flow. Figure 20 shows the spider chart of the sensitivity analysis, and Figure 21 shows the tornado chart. The input and output values of the sensitivity analysis are provided in Appendix 2.

Figure 21. Spider chart of net cash flow sensitivity analysis



Important upward variables include the plant capacity factor, the fraction of self-use, and the value for self-use (retail electricity cost offset by PV systems). The variables that play a more downward than upward role include interest rate, discount rate, and fixed O&M (operation and maintenance) cost. The variables with a larger downward than upward effect include discount rate and fixed O&M cost. Appendix 2 and Figure 20 show that the fraction of self-use and the value for self-use are more sensitive variables to the estimated discounted net cash flow (as demonstrated by the slope in Figure 20).

Figure 22. Tornado chart of net cash flow sensitivity analysis



For the upward variables in the upper part of Figure 21, the increase in their values makes the net cash flow higher, while the rise of the downward variables in the lower part of the figure makes the net cash flow lower. Important downward risk variables are the discount rate, interest rate, and fixed O&M cost.

In contrast to the sensitivity analysis results for the tourism area, the fraction of self-use is shown to be a crucial upward risk variable, which indicates that without relying on the subsidy of electricity, the project owners need to compare the difference between the price of electricity sold and the price for their own use and prioritize using the electricity generated by rooftop solar PV systems to meet their own power use needs. Surplus electricity is sold for better overall economic benefit and lower net cash flow sensitivity. According to the analysis results, the power generation should meet the industrial zone's own power demand first, and the higher the proportion of self-use, the more ideal the effects of financial indicators. It is also important to choose when to offset electricity purchases with self-use, as this affects the avoided grid electricity cost of the zones. Therefore, we encourage project owners to increase the fraction of self-use when power consumption peaks.

A slight change in the capacity factor of the Jababeka Industrial Estate will significantly affect the change in net cash flow. If the project site is blocked from sunlight, the project's economic benefits will suffer severely. The net cash flows of the Jababeka Industrial Estate at a discount rate of 5% are shown below.

6 Risk Analysis

There are investment-related challenges and risks that must be properly managed for potential business investment projects, in addition to financial, social and environmental benefits. The proposed projects' possible policy, capital, and operational risks, and the corresponding management measures are described below.

6.1 Policy and Regulatory Risk

Indonesian rooftop solar PV policies are still in a relatively nascent stage. Hence, they are prone to regulatory changes and dynamics, which creates regulatory uncertainty. Since the release of MEMR 49/2018, the regulation has been revised three times. The last version (MEMR 26/2021) is a significant update, which expands its scope to not only PLN's consumers but to other consumers within a private power utility's electricity supply business concession; it also upgrades the export tariff rate to 100% (1:1 net metering, from the previous 1:0.65) (IESR, 2021b). While it is considered a massive advantage for the sector, the implementation of the regulation is hampered by the state-owned utility, PLN. This enterprise not only refuses to update the net metering ratio but has also imposed a unilateral ban on the maximum rooftop solar capacity installation (from 100% to only up to 15%) due to concerns regarding overcapacity (and potential revenue loss) issue. Regulatory risk such as this will create uncertainty on many levels, including business processes and permitting. Although this ban is likely to be temporary, policy and regulatory risk should become the primary consideration when considering a project's development and investment.

6.2 Capital Risk

In the case that a local factory owner/enterprise applies for a loan to implement the proposed project, the lender will be exposed to the risk of default, i.e., the factory owner/enterprise may fail to repay the principal and interest on time, due to a poor financial situation or lagging project implementation. This risk can be controlled through adequate legal guarantees and the increased enthusiasm of project developers. The core earnings (to return the investment) of distributed solar PV generally come from electricity bill savings. If the electricity price drops sharply, the yield rate of distributed solar PV power stations will decline significantly. In addition, the procurement cost of solar PV modules accounts for a large proportion of the power station investment.

6.3 Operational Risk

In addition to the above challenges, other variables will affect the operating cash flow of a proposed solar PV project during the implementation process.

The factory performance factor is a critical variable that affects power generation. Based on the data provided by solar power companies, the performance factor of a proposed project is estimated at 85%. This means that the project is influenced by natural elements (such as temperature, dust, and rainwater), equipment factors (i.e., equipment compatibility, efficiency, failures, and line losses), and human factors (such as design and cleaning). Good design, high-quality equipment, and proper operation and maintenance will improve performance and generate capacity. Therefore, it is recommended to select professional solar power generation companies for implementing and operating solar PV systems. Third-party international audit and certification institutions can also be introduced to ensure project quality and power generation efficiency.

Power load capacity will directly affect whether the power generated by the proposed project can be fully and effectively utilized. Suppose the power load capacity is reduced due to industrial and commercial mismanagement. In that case, the power generated will not be used efficiently, which affects the operation of the system and the return on investment. Therefore, it is necessary to fully understand the initial planning and design of industry and commerce, as well as potential fluctuations in electricity demand, to match users' needs through the better method of solar PV systems.

Electricity price is a critical variable that affects the return on investment of solar power projects. In the previous sensitivity analysis, the proposed project's return on investment is quite sensitive to the changes in electricity price. Therefore, while considering the actual situation of the project location and the development planning of the power grid, it is crucial to set a reasonable electricity price or price range through careful negotiations. In this way, the interests of all stakeholders can be guaranteed, and the possibility of undesirable situations can be minimized.

The unit investment cost of solar power projects is mainly influenced by equipment and material costs, construction cost, and other related expenses. Based on local market prices provided by solar companies, the unit investment cost of the proposed project is estimated at $0.60 per watt. With the rapid development of the global solar industry, the prices of solar PV panels, brackets, inverters, and supporting equipment have been declining. The unit investment cost is expected to continue decreasing as equipment and material prices drop.

The fixed operation and maintenance costs of solar power projects mainly include the routine maintenance, cleaning, monitoring, and testing of solar power systems. Based on the prices of solar power projects in the international market, the operation and maintenance cost of the proposed project is estimated at $19 per kilowatt year. Fixed operation and maintenance costs can be reduced by cooperating with professional solar power companies for operation and maintenance and improving the efficiency of local employees through reasonable incentives. With the maturity and popularity of remote monitoring and cloud platform technologies in the solar energy industry, the need for on-site manpower can be reduced, further lowering the operation and maintenance costs of solar PV power generation projects.

7 Policy Recommendations

7.1. Remove Regulatory Uncertainty

Removing regulatory uncertainty is the first order of business for the Indonesian government to enable and accelerate rooftop solar deployment in the country. Changing policy dynamics and implementation are sending mixed signals to business players, leading to hesitancy. Incoherent policy implementation, such as the current maximum installation capacity limitation ban imposed by PLN, should not be prolonged to avoid regulatory uncertainty in the sector. In this case, the government should quickly find a middle ground for the regulation so as not to hamper rooftop solar development. Without regulatory certainty, it will not be possible to realize rooftop solar development's potential in Indonesia.

7.2. Strengthen Planning and Coordination

Strengthening planning and coordination at all government levels is also paramount in the context of accelerating rooftop solar development to meet the government's target. For a national solar programme, the role of subnational governments is to incorporate the targets in regional development plans or to allocate budgets within specific departments. While national energy policy states the mandatory rooftop solar targets for government buildings, public facilities and luxury houses nationwide, subnational governments could also set other measures, such as utilization ratios for rooftop solar in buildings, integrated with development planning and permits. In addition, by using a less capital-heavy form of business model innovation, such as solar leases, rooftop solar deployment could be accelerated. With proper planning and coordination, project piloting could be implemented and then scaled up to different areas.

7.3. Improve Solar's Quality Infrastructure System

It is essential to improve quality infrastructure systems (i.e., standardization, accreditation, and assessment services, such as technical inspection, testing, product certification, etc.) to meet internationally accepted standards to increase the domestic solar industry's quality and competitiveness. The government could play a role in setting up the regulatory framework and standards by working with the private sector and national laboratories and inspection agencies. In particular, the government could also work on improving the standardization of licensing and permitting, including the price and availability of net electricity meters, to avoid discouraging different sectors indiscriminately.

7.4. Improve the Investment Climate for Solar

In parallel with removing the uncertainties, the government should also focus on improving the investment climate for solar. This might include strengthening support for rooftop solar projects through appropriate policy design and incentives, ensuring good policy planning and implementation governance, facilitating long-term cooperation with international counterparts, and promoting innovation in sustainable business models and local financing.

References

ADB (2016). Indonesia: Energy Sector Assessment, Strategy, and Road Map (Indonesia). Asian Development Bank. https://www.adb.org/documents/indonesia-energy-sector-assessment-strategy-and-road-map

ADB (2020). Renewable Energy Tariffs and Incentives in Indonesia: Review and Recommendations. Asian Development Bank. https://www.adb.org/sites/default/files/publication/635886/renewable-energy-tariffs-incentives-indonesia.pdf

Ashurst (2022). Indonesia Renewables—ICLG Guide on Renewable Energy 2022. https://www.ashurst.com/en/news-and-insights/legal-updates/indonesia-renewable-energy-laws-and-regulations-2022/

Bappenas (2019). Indonesian Vision 2045. https://old.bappenas.go.id/files/Visi%20Indonesia%202045/Ringkasan%20Eksekutif%20Visi%20Indonesia%202045_Final.pdf

BloombergNEF (2020). BNEF Executive Factbook 2020. Bloomberg New Energy Finance. https://data.bloomberglp.com/promo/sites/12/678001-BNEF_2020-04-22-ExecutiveFactbook.pdf

BloombergNEF (2021). BNEF Executive Factbook 2021. Bloomberg New Energy Finance. https://assets.bbhub.io/professional/sites/24/BNEF-2021-Executive-Factbook.pdf

BloombergNEF & IESR (2021). Scaling Up Solar in Indonesia: Reform and opportunity. https://iesr.or.id/en/pustaka/scaling-up-solar-in-indonesia-reform-and-opportunity

CNBC Indonesia (2022). Kejar Target 3,6 GW, Ternyata Baru Segini Kapasitas PLTS Atap. CNBC Indonesia. https://www.cnbcindonesia.com/news/20220210125741-4-314359/kejar-target-36-gw-ternyata-baru-segini-kapasitas-plts-atap

Government of Indonesia (2014). Government Regulation 79 of 2014—National Energy Policy. https://jdih.esdm.go.id/peraturan/PP%20No.%2079%20Thn%202014.pdf

Government of Indonesia (2017). Indonesia's National Energy General Plan (RUEN). https://www.esdm.go.id/assets/media/content/content-rencana-umum-energi-nasional-ruen.pdf

Government of Indonesia (2021a). Indonesia's Long-Term Strategy for Low Carbon and Climate Resilience 2050. https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf

Government of Indonesia (2021b). Indonesia's Updated Nationally Determined Contribution. https://unfccc.int/sites/default/files/NDC/2022-06/Updated%20NDC%20Indonesia%202021%20-%20corrected%20version.pdf

Handayani, N. A., & Ariyanti, D. (2012). Potency of Solar Energy Applications in Indonesia. International Journal of Renewable Energy Development, 1(2), 33–38. https://doi.org/10.14710/ijred.1.2.33-38

Hasan, M. H., Mahlia, T. M. I., & Nur, H. (2012). A review on energy scenario and sustainable energy in Indonesia. Renewable and Sustainable Energy Reviews, 16(4), 2316–2328. https://doi.org/10.1016/j.rser.2011.12.007

ICLEI (2020). Energy Situational and Stakeholder Analysis Indonesia. https://renewablesroadmap.iclei.org/resource/energy-situational-and-stakeholder-analysis-indonesia/

IEA. (n.d., a). Data and statistics. IEA. Retrieved July 15, 2022, from https://www.iea.org/data-and-statistics

IEA (n.d., b). Indonesia—Countries & Regions. IEA. Retrieved July 15, 2022, from https://www.iea.org/countries/indonesia

IEA (2022). Southeast Asia Energy Outlook 2022. https://www.iea.org/reports/southeast-asia-energy-outlook-2022

IESR (2020). National Energy General Plan (RUEN): Existing Plan, Current Policies Implication and Energy Transition Scenario. https://iesr.or.id/en/pustaka/ruen-existing-plan-current-policies-and-energy-transition-scenario

IESR (2021a). Hitting Record-Low Solar Electricity Prices in Indonesia: A study on global solar auctions and Indonesia's existing conditions. https://iesr.or.id/en/pustaka/hitting-record-low-solar-electricity-prices-in-indonesia

IESR (2021b). Indonesia Energy Transition Outlook 2022: Tracking Progress of Energy Transition in Indonesia—Aiming for Net-Zero Emissions by 2050. https://iesr.or.id/en/pustaka/indonesia-energy-transition-outlook-ieto-2022

IESR & GEI (2021). Beyond 207 Gigawatts: Unleashing Indonesia's Solar Potential. https://iesr.or.id/en/pustaka/beyond-207-gigawatts-unleashing-indonesias-solar-potential

IRENA (2021). Renewable Capacity Statistics 2021. https://www.irena.org/publications/2021/March/Renewable-Capacity-Statistics-2021

Marquardt, J. (2014). A Struggle of Multi-level Governance: Promoting Renewable Energy in Indonesia. Energy Procedia, 58, 87–94. https://doi.org/10.1016/j.egypro.2014.10.413

McKinsey & Company (2012). The archipelago economy: Unleashing Indonesia's potential | McKinsey. https://www.mckinsey.com/featured-insights/asia-pacific/the-archipelago-economy

MEMR (n.d.). Indonesia's NRE Development in Energy Transition towards Net Zero Emission. https://britcham.or.id/wp-content/uploads/2021/11/Chrisnawan-Anditya-Director-of-Various-of-New-and-Renewable-Energy-of-Ministry-of-Energy-and-Mineral-Resources.pdf

MEMR (2019). Grid emission factor. Direktorat Jenderal Ketenagalistrikan - Official Website. https://gatrik.esdm.go.id/frontend/download_index/?kode_category=emisi_pl

MEMR (2022). Handbook of Energy and Economics Statistics of Indonesia 2021. https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-and-economic-statistics-of-indonesia-2021.pdf

Norton Rose Fulbright (2019). Renewable energy snapshot: Indonesia | Global law firm | Norton Rose Fulbright. https://www.nortonrosefulbright.com/en/knowledge/publications/0552a1f0/renewable-energy-snapshot-indonesia

Øverland, I., Vakulchuk, R., & Al, E. (2017). Impact of Climate Change on ASEAN International Affairs: Risk and Opportunity Multiplier. 34. https://nupi.brage.unit.no/nupi-xmlui/handle/11250/2465067

PLN (2021). Rencana Usaha Penyediaan Tenaga Listrik PT PLN (Persero) 2021–2030. PT PLN (Persero). https://web.pln.co.id/statics/uploads/2021/10/ruptl-2021-2030.pdf

Provincial Government of Bali (2021). Bali's Clean Energy Policy and Implementation. https://iesr.or.id/wp-content/uploads/2021/06/PAPARAN-KEBIJAKAN-DAN-IMPLEMENTASI-ENERGI-BERSIH-DAN-EBT-DI-PROVINSI-BALI.R2.pdf

PwC (2016). Power in Indonesia: Investment and Taxation Guide, 2016—4th edition.

PwC (2017). The World in 2050. https://www.pwc.com/gx/en/research-insights/economy/the-world-in-2050.html

PwC (2022). Value-added taxes. https://taxsummaries.pwc.com/indonesia/corporate/other-taxes

REN21 (2019). 2019 Asia and the Pacific Renewable Energy Status Report. https://www.ren21.net/asia-report-2019/

Sharvini, S. R., Noor, Z. Z., Chong, C. S., Stringer, L. C., & Yusuf, R. O. (2018). Energy consumption trends and their linkages with renewable energy policies in East and Southeast Asian countries: Challenges and opportunities. Sustainable Environment Research, 28(6), 257–266. https://doi.org/10.1016/j.serj.2018.08.006

Statistics Indonesia (2020). Province of Bali in Numbers, 2020. https://bali.bps.go.id/publication/2020/04/27/c2d74be21e44651b07e2658e/provinsi-bali-dalam-angka-2020.html

Statistics Indonesia (2022). Statistical Yearbook of Indonesia 2022. https://www.bps.go.id/publication/2022/02/25/0a2afea4fab72a5d052cb315/statistik-indonesia-2022.html

Trading Economics (2022). Indonesia GDP Annual Growth Rate & Forecast. https://tradingeconomics.com/indonesia/gdp-growth-annual

World Bank (n.d.). Indonesia's annual GDP growth. Retrieved July 11, 2022, from https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations=ID

World Bank (2022, April). Indonesia Country Overview. https://www.worldbank.org/en/country/indonesia/overview

Worldometer (2022, July). Indonesia's Population (2022). https://www.worldometers.info/world-population/indonesia-population/

Appendix 1 - Key Policies on Rooftop Solar Energy in Indonesia

Table A1. Key policies for solar energy in Indonesia. MEMR and MOI refer to the Ministry of Energy and Mineral Resources, and Ministry of Industry, respectively.

Year	Policies/Law	Issued by	Contents
2007	Law No. 30/2007	President	Law on Energy
2009	Law No. 30/2009	President	Law on Electricity
2014	Regulation No. 79/2014	President	National Energy Policy
2016	Regulation No. 44/2016	President	List of Business Areas Closed to Capital Investment and Areas Open with Conditions
2017	Regulation No. 4/2017	MOI	Provisions and Procedures for Valuing Local Content for Solar Power Plants
2017	Regulation No. 5/2017	MOI	Guide to Using Domestic Products for Electricity Infrastructure Construction
2017	Regulation No. 12/2017	MEMR	Power Purchase Agreement Principles
2017	Regulation No. 22/2017	MEMR	National Energy Plan (RUEN)
2017	Regulation No. 33/2017	MEMR	Procedure for provision of energy saving solar-powered lights for communities that do not have access to electricity yet
2017	Regulation No. 50/2017	MEMR	Utilization of Renewable Energy Sources for Electricity Supply
2019	Decree No. 143K/21 /MEM/2019	MEMR	National Electricity Plan (RUKN) for 2019–2038
2021	Decision No. 188 K/02/MEM/2021	MEMR	National Electricity Supply Business Plan (RUPTL) 2021–2030
2021	Regulation NO. 26/2021	MEMR	Rooftop Solar Power Plant Connected to the Electricity Network of the Holder(s) of Electric Power Supply Business License for Public Interest

Appendix 2 - Input and Output Values of the Sensitivity Analysis

Table A2-1. Input and output values of sensitivity analysis for 625 kWp commercial rooftop solar project at Nusa Dua, Bali

	Spider chart: Discounted net cash flow (NCF)						Tornado chart: Discounted net cash flow (NCF)		
	Input			Output					
Variables	25%	50%	75%	25%	50%	75%	Lower limit	Upper limit	Scope
Plant capacity factor (%)	0.18	0.20	0.21	206,974	262,629	324,600	206,974	324,600	117,626
Subsidy ($/kWh)	0.09	0.13	0.16	256,666	262,144	266,473	256,666	266,473	9,807
Value for self-use ($/kWh)	0.07	0.08	0.09	223,246	262,629	302,012	223,246	302,012	78,766
Electricity price ($/kWh)	0.07	0.08	0.09	245,713	262,629	279,545	245,713	279,545	33,832
Owner's principal (%)	0.40	0.50	0.60	260,118	262,629	265,140	260,118	265,140	5,022
Loan period (years)	9.87	10.82	12.04	262,701	262,629	256,511	262,701	256,511	-6,189
Inflation rate (%)	0.02	0.02	0.03	258,660	261,972	264,202	258,660	264,202	5,542
Interest rate (%)	0.07	0.08	0.09	273,190	262,629	251,793	273,190	251,793	-21,397
Fixed O&M cost ($/kW year)	16.15	19.00	21.85	286,121	262,629	239,136	286,121	239,136	-46,985
Plant capacity factor (%)	0.45	0.59	0.70	225,417	256,688	280,683	225,417	280,683	55,266
Subsidy ($/kWh)	0.05	0.06	0.07	307,794	262,629	213,069	307,794	213,069	-94,726

Table A2-2. Input and Output Values of Sensitivity Analysis for 2.5 MWp industrial rooftop solar project in Jababeka Industrial Estate

	Spider chart: Discounted net cash flow (NCF)						Tornado chart: Discounted net cash flow (NCF)		
	Input			Output					
Variables	25%	50%	75%	25%	50%	75%	Lower limit	Upper limit	Scope
Plant capacity factor (%)	0.15	0.16	0.17	258,137	443,072	628,007	258,137	628,007	369,870
Subsidy ($/kWh)	0.04	0.05	0.06	436,087	443,072	450,057	436,087	450,057	13,970
Value for self-use ($/kWh)	0.07	0.08	0.09	315,421	443,072	570,724	315,421	570,724	255,303
Electricity price ($/kWh)	0.07	0.08	0.09	385,132	443,072	506,075	385,132	506,075	120,943
Owner's principal (%)	0.40	0.50	0.60	436,617	443,072	449,527	436,617	449,527	12,910
Loan period (years)	9.41	10.00	10.59	412,209	443,072	426,847	412,209	426,847	14,638
Inflation rate (%)	0.03	0.03	0.03	439,781	443,072	446,706	439,781	446,706	6,925
Interest rate (%)	0.07	0.08	0.09	481,948	443,072	403,245	481,948	403,245	-78,703
Fixed O&M cost ($/kW year)	16.15	19.00	21.85	536,864	443,072	349,280	536,864	349,280	-187,585
Fraction of self-use (%)	0.45	0.59	0.70	309,663	421,774	507,799	309,663	507,799	198,137
Discount rate (%)	0.05	0.06	0.07	577,270	443,072	296,322	577,270	296,322	-280,948