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UDAYANA INTERNATIONAL RESEARCH COLLABORATION

TECHNICAL ASSESMENTS AND SUSTAINABILITY ANALYSIS OF THREE PILOT PROJECTS OF LARGE-SCALE 1 MW GRID-CONNECTED PHOTOVOLTAIC SYSTEMS IN INDONESIA

Year 1 of 2 Years Research Plan

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SUMMARY

Indonesia has huge potential for utilizing sun's energy for electric power generation using photovoltaic technology, which convert sunlight into electric current with electrical energy potential between 4 to 6 kWh per meter square every day almost all year round and available in most part of the country. Due to its geographical location near the equator, and vast area including land and sea, the country has an enormous potential for generating renewable energy from the sun. In view of diminishing reserves of the country's conventional energy sources such coal, oil, and gas and the fact that the country has huge potential of renewable energy resource, the central government has released National Energy Policy (NEP) which serves as the reference for national energy development. With respect to PV implementation, the government has set to achieve 5,000 MW PV capacity by 2019 and further increasing to become 6,400 MW by 2025. Despite, the huge potential and also the government plan, however, the progress to date is unclear. Stakeholders have quoted different figures for the current PV achievement of the country as there is no single and reliable figure to indicate the current progress.

Application of PV in Indonesia started in the late 70s but government supported projects started in the 80s, so the country has accumulated nearly 50 years of PV experience. PV implementation includes solar home system, off-grid system, and the most recent is grid-connected power plant. The government built three 1 MW grid-connected PV plant in 2013. Two plants were built in Bali and the third was built in District of Labangka, island of Sumbawa. The large-scale grid-connected PV will be a large component of the PV project portfolio together with SHS and off-grid community-based PV. Therefore, there is the need to learn lesson from the first large-scale PV project of the country. The lesson covers technical aspect as well as sustainability of such projects.

ASEAN countries pose similar characteristics both natural resources as well as demographic features and the region also pursue the implementation of as renewable power generation. Each country has set goal and progresses to achieve its national target. In this context, Indonesian progress will be compared with other ASEAN members and qualitative analysis will be carried out to understand factors that affect PV development in ASEAN members which could be learned by Indonesia as the largest ASEAN member.

Three key questions proposed in this research proposal are: 1) What is the current national capacity of PV in Indonesia and what factors that affect its development both which hinders and enables the progress, 2) What is the performance index of the first large-scale 1 MW grid-connected PV plants of Indonesia and what lessons can be learned as this type of PV will form a significant component of the PV portfolios, 3) How is the PV development of Indonesia as the largest member of ASEAN in term of natural resources and demographic features compared to other ASEAN members and what lesson can be learned from the neighboring countries.

Based on the current findings, the following conclusions are drawn: Solar PV Indonesia has started from 1977 and continue to 2017 and will continue to reach target as set by National Energy Policy. The current solar PV capacity is 155 MW installed throughout the country. Simulation of performance index of PLTS Kayubihi is 70% while its actual performance is changing from 72.5% to 48.4% which suggest problems occurred. Simulation of performance index of PLTS Karangasem is 85% while its actual performance is changing from 69% to 87% to 43% and finally to 29% which suggest problems occurred. Simulation of performance index of PLTS Labangka is around 70% while its actual performance is 0% as the power plant never connected to the PLN's grid. Among ASEAN member Indonesia is in the fourth place in the total installed solar PV capacity. Solar PV ASEAN is led by Thailand with around 2.7 GW solar capacity by the end of 2017. The implementation of adder and feed-in-tariff is two major policy/regulation that bring Thailand as the leader of solar PV in ASEAN.

PREFACE

We thank God the Almighty for His direction and blessing that the Final Report of the Joint Research between Udayana University and Murdoch University Australia can be completed. The research is a joint research of TECHNICAL ASSESMENTS AND SUSTAINABILITY ANALYSIS OF THREE PILOT PROJECTS OF LARGE-SCALE 1 MW GRID-CONNECTED PHOTOVOLTAIC SYSTEMS IN INDONESIA.

The objective of the research is to obtain technical information regarding power plant's specification, potential of energy production, and its actual energy production of the 1 MW PV plant known as PLTS Bangli, PLTS Karangasem, and PLTS Sumbawa. The research also analyzes the sustainability of the project and emphasize is given to PLTS Sumbawa. The project also reviews the latest status of PV development of Indonesia and in ASEAN countries.

We thank many people and agencies who have supported this research. We thank LPPM Universitas Udayana for financing this research project. We thank PT PLN (Persero) Distribusi Bali for providing data of actual energy production of PLTS Bangli and PLTS Karangasem. We also thank PT PLN (Persero) Distribusi Sumbawa for providing data on PLTS Sumbawa. We thank District Government of Bangli, District Government of Karangasem, District Government of Sumbawa for providing data regarding project development and status of the project.

We hope that the results presented in this Final Report will allow us and energy stakeholder in particular to get better understanding on the development of solar PV in Indonesia and with references to the three-pilot project of large-scale grid-connected solar PV.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ATTACHMENTS

CHAPTER 1 INTRODUCTION

1.1 Background

Indonesia has huge potential for utilizing sun energy for electric power generation using photovoltaic technology which convert sunlight into electric current. Based on the sun energy map produced by Ministry of Energy and Mineral Resources (MEMR) of Indonesia, the potential is between 4 to 6 kWh per meter square per day (ESDM, 2015). And as the country lies near the equator means the sun is available most of the time during day time and all year round. And the fact that total area of the country both land and waters at nearly xxx square kilometers (ref2) mean it really has an enormous potential for generating renewable energy from the sun.

the target set by the government (Kumara, et al., 2014).After nearly 50 years of solar electricity experience and the fact that sun energy potential is abundant, however, the pace of solar energy development is rather slow. The first solar power introduction to Indonesia was dated back in the late 70s in which solar power was used for train signaling. However, the first Indonesian government official solar electricity project was launched in the village Sukatani, West Java, in the early 80s in which solar lighting used by villagers in remote areas. According to ADB, Indonesia is one among a few developing countries who received projects assistance or has developed own projects related to solar photovoltaic development especially solar home system as solution for providing lighting for people beyond utility networks.

Application of photovoltaics has now reached parts of society both urban and remote areas. This is due to the fact that industry and trades that support PV development has been operating in the country. This can be seen with the availability of PV systems and components as reported by Kumara (Kumara, 2010). The use of 50 to 150-Watt solar home systems to provide lighting for million of people has been done and would continue to reach for people who live in many remote islands and villages of Indonesia. Street lighting using solar system has been used both in the city and also villages. A larger PV system typically 10 to 30 kW systems forming off-grid plants for community has also been implemented around the country (Nugraha, et al., 2013) (Arimbawa, et al., 2016) (Andita Putra, et al., 2015) (Anggara, et al., 2014). Hybrid PV-wind-and diesel systems have also implemented as pilot projects in different part of the country mainly in the eastern part of Indonesia. Rooftop PV with capacity from 10 kW to 200 kW both for residential and urban buildings pilot projects have been started. And the most recent was the operation of large scale grid-connected megawatt-capacity PV systems (Kumara, et al., 2013), (Nathawibawa, et al., 2017) and with the largest is the 5 MW grid-connected plant in the city of Kupang (Kumara, et al., 2017).

Government of Indonesia has released National Energy Policy (NEP) as the country's reference for energy development both using conventional and renewable sources. Following the release of NEP, many other ministerial regulations have been produced. The government planned to develop 5,000 MW PV by 2019. And the final target is to have 6,400 MW PV plants by 2025 part of 23% EBT energy mix. To meet this target means more PV plants projectimplemented throughout the country.

As part of the plan to achieve NEP, the government of Indonesia has developed three large-scale grid connected PV plant each with 1 MW capacity. These three PV plants were the first pilot projects of grid-connected PV distributed generation. Two of the plant is installed in Bali in which the two locations have extreme weather or climate. One plant is installed in District of Bangli with wet type weather and one in District Karangasem with dry climate type. Another plant is installed in Sumbawa island. The three-power plant has similar technical specification but very different environments. The plants have been in operation for more than four years. The large-scale PV plant will be a significant component of total Indonesian PV systems by 2025. There have been no reports available concerning the performance evaluation of the three pilot projects either in its technical aspects nor its sustainability. What currently available are our initial reports regarding technical specification and environmental characteristics of the plant as described by the authors (Kumara, et al., 2013). We also have studied through simplified approach to see how the power plant performs in term of energy production. However, factor such as shading of the site is assumed non-existence although its effect is quite substantial (Setiawan, et al., 2014). Another study to see the cost of energy and the investment analysis has also conducted by the Authors but the analysis and discussion are related to the cost of energy generation and the current feed-in-tariffs (Sugirianta, et al., 16).

Although PV development has been promising in the last decade and ambitious plan to develop more power plant to reach for the 23% RE by 2025, but there have been little reports regarding how past projects have been developed, what are the status of the current PV plants, and what would be the future of these power plant or indeed the future of the new projects. Little is known regarding the actual national capacity of PV in Indonesia. Information such as the current accumulated installed PV capacity is non-existence as stakeholders use different figures. It is important to know the current capacity in order to set up base line, measure achievement, conducting review, and making better plan to achieve the ultimate PV target of 2025 and beyond.

The research questions formulated in this proposal are: 1) What is the current national installed capacity of PV systems in Indonesia after nearly 50 years development and factors which affect its progress? 2) What is the performance index of the three large-scale grid-connected 1 MW PV plant which will form significant part of the future national PV capacity and what lessons can be learned from this project implementation. 3) How is Indonesia among other neighboring countries such as ASEAN or Australia with respect to PV development.

Also, there is little technical information regarding existing plant's performance both in term of prediction nor their actual performance. The technical information will provide insight into technology deployment and its performance, economic aspect of such investment, as well as understanding the effects of plant's location.

This research project will review PV development of Indonesia from its early application up to the current time and also its future direction. In this context, current capacity of PV application will be obtained including its milestone and also what are the enabling conditions necessary to further develop PV application in Indonesia.

The project will also conduct technical assessment of the three large-scale 1 MW grid-connected PV pilot projects to understand how these plants have performed and conducts comparison among the three-power plants as they are installed in very differentbest environment.

The project will also look at sustainability of the three projects andBrief analysis and comparison between Indonesia and South East Asian countries will be made to see how Indonesia in par with the neighboring countries in developing or utilizing sun power for renewable generation.

1.2 Research Problem Formulation

The research carried out here is formulated as three questions as follows:

1. What is the current national installed capacity of PV systems in Indonesia after nearly 50 years development and factors which affect its progress?
2. What is the performance index of the three large-scale grid-connected 1 MW PV plant which will form significant part of the future national PV capacity and what lessons can be learned from this project implementation?
3. How is Indonesia among other neighboring countries such as ASEAN with respect to PV development?

1.3 Objective of Research

The objective of the research is to obtain data of PV project in Indonesia and its current national capacity as baseline to plan future development.

Also, the research is aimed to obtain information regarding the performance of the first grid-connected large-scale PV project of Indonesia. The three power plants are PLTS Bangli, PLTS Karangasem, and PLTS Sumbawa.

The third objective is to obtain some insights on the status of PV development of Indonesia among ASEAN members. ASEAN is a region which share similar characteristics with respect to potential of solar energy. Therefore, it would be useful for country members to learn from o ne another on how other country have achieved good results while some other need to catching up.

CHAPTER 2 LITERATURE REVIEW

2.1 Profile of Country - Indonesia

Indonesia is the largest archipelagic country with 17, 000 more islands although only around 6,000 islands are inhabited. One of the largest island, Kalimantan cross the equator. The land around 1,922,570 square kilometers (Ikawati & Setiawati, 2009) makes around 33% and waters is 67% of the total area.

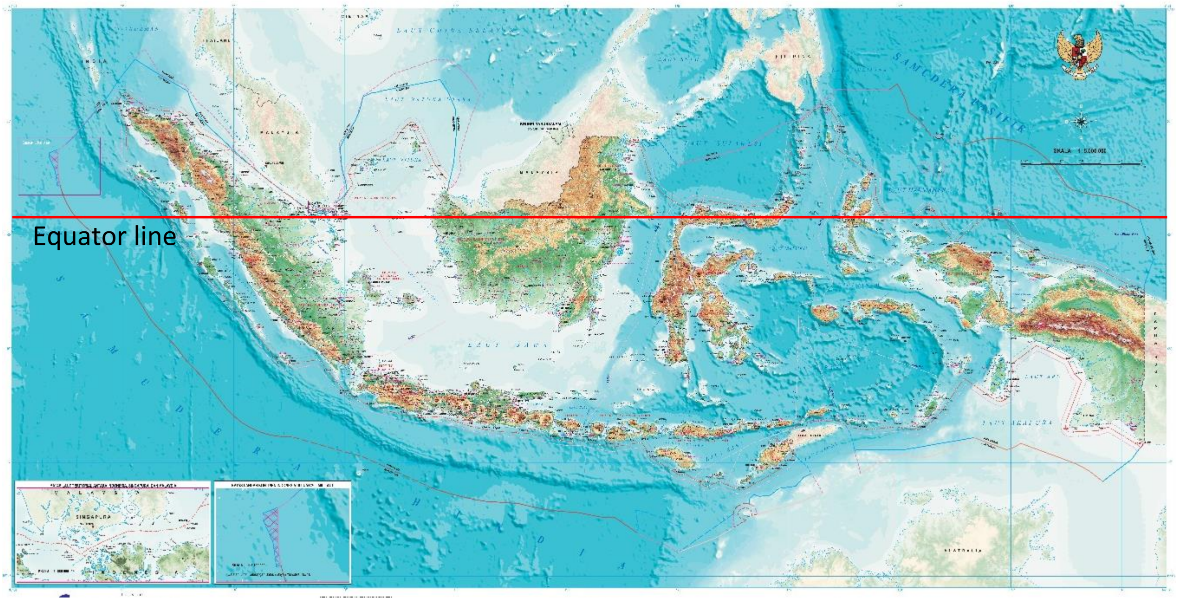

Figure 1 Map of Indonesia (Badan Informasi Geospasial, 2017)

Indonesia is the fourth most populous country after China, India, and USA. The population is estimated around 260 million people. The GDP of Indonesia is at USD 932 billion in 2016. Indonesia is also member of G20. G20 is countries. Despite, these achievements, energy access in term of electricity is far from complete. The state electricity company PLN reported that in 2017, the electrification ratio was 87% (ESDM, 2017) meaning 13% or nearly 20 million people still have no access to electricity. A basic need in the modern society. In the SDG particularly the seventh goal is dedicated to ensuring access to affordable, reliable, sustainable and modern energy for all by 2030. SDG also emphasize the direct linkage between household energy access and consumption and poverty and development (Goozee, 2017). Most of these people live in remote areas or in the small islands spread across the archipelago. The huge task of the government is to develop electricity that meets existing demand and also to provide new power for the unelectrified areas of the country.

Figure 2 Map of Indonesian electrification ratio (ESDM, 2017)

2.2 Renewable Energy in Indonesia

As the largest archipelagic country of the world, Indonesia is rich with natural resources. The resources include sun energy both photovoltaic and thermal, hydropower, wind energy, biomass, and ocean. Table 1 shows estimated potential of energy that can be generated from the country's renewable energy sources.

Table 1 Potential of renewable energy of Indonesia (ESDM, 2015)

	No	Jenis Energi	Sumber Daya	Kapasitas Terpasang	Pemanfaatan (%)
Energi Baru, Terbarukan	1	Hidro	75.000 MW	8.111 MW	10,81 %
	2	Panas Bumi	28.910 MW	1.403,5 MW	4,9 %
	3	Biomassa	32.000 MW	1.740,4 MW	5,4 %
	4	Surya	4,80 kWh/m²/day	71,02 MW	-
	5	Angin dan Hybrid	3 – 6 m/s	3,07 MW	-
	6	Samudera	49 GW[3]	0,01 MW[4]	-
	7	Uranium	3.000 MW[1]	30 MW[2]	-

#esdm

[1] di Kalan-Kalimantan Barat
[2] Sebagai pusat penelitian, non-energi
[3] Sumber Dewan Energi Nasional
[4] Prototype BPPT

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Dewan Energi Nasional (DEN) or equivalent to national energy council has released document that serve as the reference for energy development of Indonesia.

The Ministry of Energy and Mineral Source estimated that 441 GW power can be generated from all of the country's renewable energy source. The actual utilization of the renewable resource is only 8.86 GW.

The potential of photovoltaic energy based on Table 1 is 4.8 kWh/m2/day. BPPT has done observation on the potential of sun energy in some locations around the country as shown in Table 2 which shows that the potential varies from location to location but within the range of 4 kWh/m^2 to 5.1 kWh/m^2. Another map that shows potential of sun energy around the country is shown in Figure 3. It can be seen that general potential of sun energy in term of GHI varies between 1.6 to 2.2 kWh/m^2. These figures show that indeed Indonesia has huge potential for generating power from the sun.

Table 2 Sun intensity at various location of Indonesia

Propinsi	Lokasi	Tahun Pengukuran	Posisi Geografis	Intensitas Radiasi (Wh/m^2)
NAD	Pidie	1980	4°15' LS; 96°52' BT	4.097
SumSel	Ogan Komering Ulu	1979-1981	3°10' LS; 104°42' BT	4.951
Lampung	Kab. Lampung Selatan	1972-1979	4°28' LS; 105°48' BT	5.234
DKI Jakarta	Jakarta Utara	1965- 1981	6°11' LS; 106°05' BT	4.187
Banten	Tangerang	1980	6°07' LS; 106°30' BT	4.324
	Lebak	1991 - 1995	6°11' LS; 106°30' BT	4.446
Jawa Barat	Bogor	1980	6°11' LS; 106°39' BT	2.558
	Bandung	1980	6°56' LS; 107°38' BT	4.149
Jawa Tengah	Semarang	1979-1981	6°59' LS; 110°23' BT	5.488
DI Yogyakarta	Yogyakarta	1980	7°37' LS; 110°01' BT	4.500
Jawa Timur	Pacitan	1980	7°18' LS; 112°42' BT	4.300
KalBar	Pontianak	1991-1993	4°36' LS; 9°11' BT	4.552
KalTim	Kabupaten Berau	1991-1995	0°32' LU; 117°52' BT	4.172
KalSel	Kota Baru	1979 - 1981	3°27' LS; 114°50' BT	4.796
		1991 - 1995	3°25' LS; 114°41' BT	4.573
Gorontalo	Gorontalo	1991-1995	1°32' LU; 124°55' BT	4.911
SulTeng	Donggala	1991-1994	0°57' LS; 120°0' BT	5.512
Papua	Jayapura	1992-1994	8°37' LS; 122°12' BT	5.720
Bali	Denpasar	1977- 1979	8°40' LS ; 115°13' BT	5.263
NTB	Kabupaten Sumbawa	1991-1995	9°37' LS; 120°16' BT	5.747
NTT	Ngada	1975-1978	10°9' LS; 123°36' BT	5.117

2.3 PV Application in Indonesia

Indonesia is one among of a few countries in the world that experience early introduction of photovoltaic as reported by ADB. The first application of PV was in the late 70s when PV system was installed for train signaling. Since then, the implementation of PV has fluctuated following policy and regulation set by the government. Application of PV includes solar home systems which has power capacity between 10 W to 100 W, street lighting from 50 to 200 W, water pumping system, lighting for fisherman, traffic lights, power supply for community waste treatment plant, power supply for base transmission station (BTS), 5 KW to 30 KW PV system for off-grid community power supply, 10 KW to 200 KW rooftop PV in urban areas as pilot project, as well as large-scale grid-connected systems with capacity of 1 MW, 2 MW, 3 MW, 5 MW and including the plan to build 10 MW PV systems.

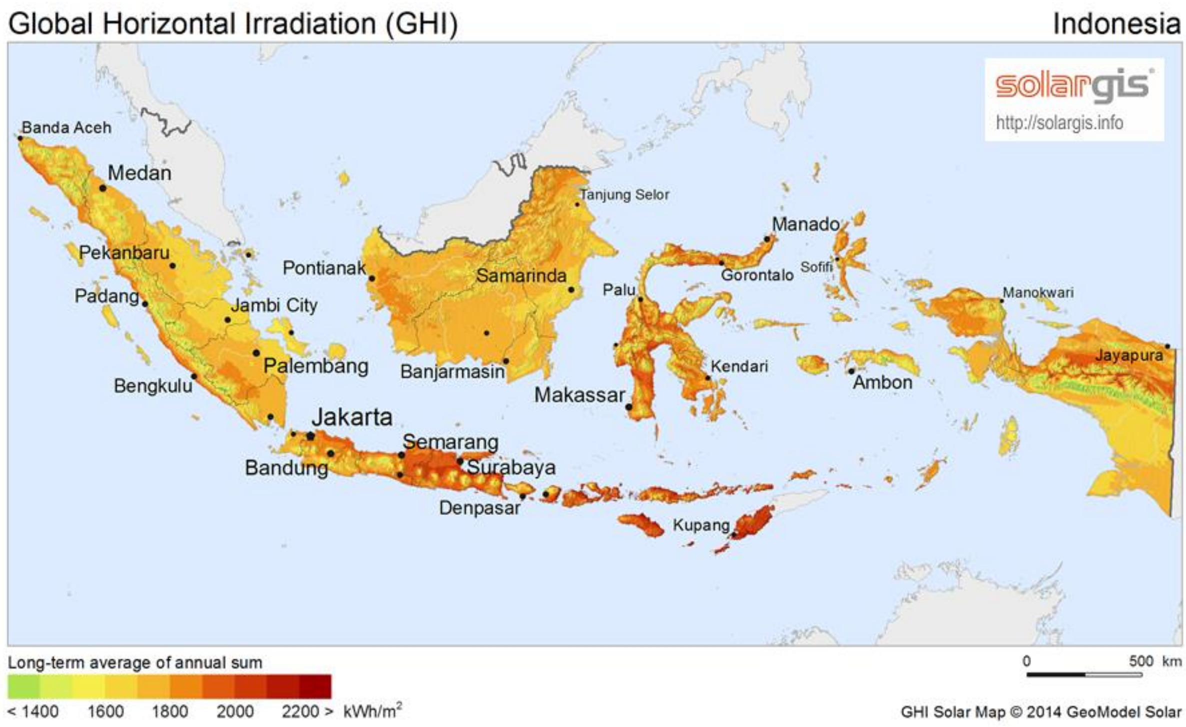


Figure 3 Map of Indonesia's sun energy potential

2.4 PV Assessments and Evaluation

Performance of grid-connected PV system is normally assessed using guidelines presented in Standard IEC 61724 (BS 61724, 1999). The standard was issued in Europe but many countries in the world have adopted this standard for PV assessment. System parameters include array yield, final system yield (Yf), reference yield (Yr), array capture losses (Lc), Balance of System (BOS) losses (LBOS), performance ratio (PR), mean array efficiency, and overall plant efficiency. These parameters provide information in terms of energy production, solar resource, system losses, and use of capacity factor of the PV plant. Among these parameters, three parameters are considered most important; they are final yield, reference yield, and performance ratio (PR) (Jahn & Nasse, 2004) (Marion, et al., 2005). The final yield is ratio of net AC energy output of the system and nameplate power of total installed PV array at STC. The reference yield is total in-plane solar insolation (kWh/m^2) divided by array reference irradiance. The performance ratio is the final yield divided by the reference yield. It represents total losses in the system when converting from nameplate DC rating to AC output. Another parameter used to indicate performance of PV plant is capacity factor (CF). Capacity factor is defined as ratio between energy output and maximum power capacity for certain period of time and denoted in percentage (Madaeni, et al., 2012).

Many PV plant performance around the world have been reported in the literature. IEA PVPS reported that low yield of PV plant was mainly caused by inverter failure although over time the failure rate of inverter decreases. The study also found that over rated module capacity, partial array shading and soiling had contributed to low energy performance of the plant . Jahn and Nasse reported that PV plants installed in Germany over two different periods, 1992-1995 and 1996-2002, showed significant increase in their performance ratio. The first group showed an average performance ratio of 65% and the second group of 74% (Jahn & Nasse, 2004). In Greece, performance ratio of 171.23 kW grid-connected system was reported at 67% with average capacity factor of 15% (Kyamakis, et al., 2008). Study on 1 kW plant in Poland found that the performance ratio of the plant varied from 50% to 80% (Pietruszko & Gradzki, 2005). Moore et al reported performance ratio of 4.6 MW system installed in Springfield Colorado produced average performance ratio of 79% (Moore, et al., 2005). In South Korea, Soa et al reported performance ratio of grid-connected 3 kW system varies from 63% to 75% (Soa, et al., 2007). In, Cairo a study on 3.3 kW plant was reported by Elhodeibly et all to have an average daily final yield of 4.35 kWh/kW (Elhodeibly, et al., 2011). Analysis of grid-connected plant operated on varying climatic conditions in Europe and Japan for 7 up 21 years was reported by Mau and Jahn. It was found that PV plant can maintain stable performance over relatively long time, and most of performance degradation was associated with soiling of module and decreasing components efficiency (Mau & Jahn, 2006). Woyte et al reported PV plant performance analysis over the last 20 years and concluded that performance ratio had increased from 65% to 85% (Woyte, et al., 2013) and similar report on performance ratio and their improvement was also discussed in the report published by IEA-PVPS. A recent publication by Hamzeh et al reported performance ratio of 87.5% from PV plant installed in Jordan and Syria (Hamzeh, et al., 2015).

Various tools have been developed to simulate energy production of PV system to provide information regarding plant's performance. IEA PVPS published report on worldwide available tools for estimating energy production and performance of PV system. This report discuses tools for assessing performance of PV system in different configurations such as grid-connected, hybrid system, and system with battery storage (IEA-PVPS, 2011).

2.5 Renewable Energy Project and Sustainability

As reviewed by Dhital *et. al.* that there have been a number of attempts to define criteria for the assessment of the sustainability of the market products. In this respect, the Working Group of United Nations Environment Program (UNEP) on Sustainable Development has come out with qualitative criteria for the assessment of the product design (Afgan, 2008). In the context of rural and renewable energy, sustainability indicators have been suggested for the qualitative and quantitative assessments of the sustainability. Efforts have been made by (Hak, et al., 2012) to critically review the state-of-the-art in assessing the quality of sustainability indicators and contribute to the development of a suitable methodology. They (Hak, et al., 2012) started with a broad review of the vast body of work in this field – in both practice and academic research. After that, they showed that both scientists and practitioners have sought developing and using methods for assessing quality of the indicators. According to Hak et. al., both scientists and practitioners have usually defined some criteria for that; however, neither science nor practitioners have provided major support by developing reliable as well as practical and operative methods for indicator assessment. Therefore, it can be said that there is no general consensus among scientists and practitioners on the exact sustainability indicators and the methods of assessments of the indicators (Dhital, et al., 2014).

The term, sustainable development, was popularized in Our Common Future, a report published by the World Commission on Environment and Development (WCED) in 1987. Also known as the Brundtland report, Our Common Future included the "classic" definition of sustainable development: "development which meets the needs of the present without compromising the ability of future generations to meet their own needs". Acceptance of the report by the United Nations (UN) General Assembly gave the term political salience; and in 1992 leaders set out the principles of sustainable development at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil, also referred to as the Rio Summit and the Earth Summit (Drexhage, 2010). Sustainability is a major concern for the design of rural electrification projects because without such consideration projects can fail leading to waste of resources. Securing a sustainable energy provision is one of the central political challenges of the present. Ever since the United Nation conferences on climate change held in Rio de Janeiro (1992), Kyoto (1997) and Bali (2007) and reports published by the intergovernmental panel on climate change;

sustainable energy provision has become an important topic for political decision makers throughout the world (Carrera, 2010).

In Indonesia, rural and renewable energy projects are built with a full funding from government and only limited projects are built by non-governmental agencies such as international air projects, NGO's and local or community program. After installation of the energy system, it is the responsibility of the participating community or the users to operate, maintain and manage the system. The sustainability of renewable energy projects considered largely depends on how much revenue it can generate from its users for operation, maintenance and management. Revenue from users depends upon multiple factors categorized as technical, financial / economic, social, institutional and environmental. As such, sustainability of the projects needs to be evaluated based on the multiple criteria in a holistic manner. The sustainability evaluation of rural and renewable energy projects is of great importance because large some of investment has been put by the government and this will continue so to achieve the renewable energy target by 2025. Therefore, it is a great concern of everybody to understand whether such a huge investment has impacted on sustainability of the energy systems installed.

The triangular approach, which takes into account the three dimensions of Sustainable Development- economic, social and environmental- continues to be highly influential. This approach forms the basis of the structure of the indicators of Sustainable Development collected by key organizations all over the world, including the UN, the OECD and the European Commission (Nieves et al., 2010). The figure below shows dimension of sustainability and their interrelationships based on triangular approach:

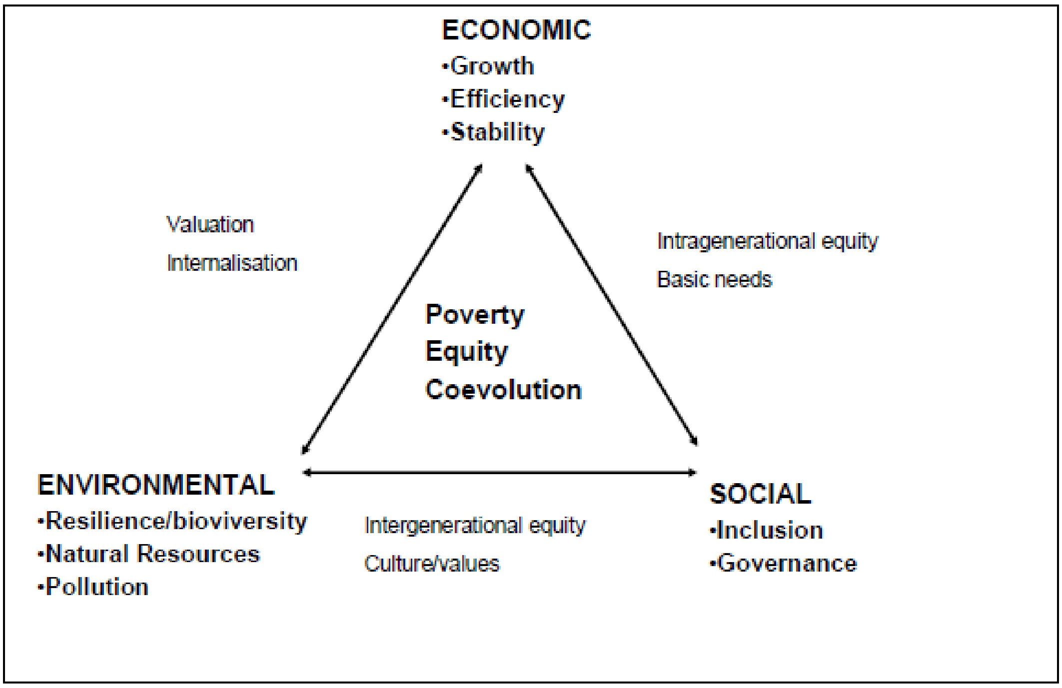


Figure 4 Dimensions of sustainability and their interrelationships (Nieves et al., 2010)

Other dimensions have also been suggested in different studies. The United Nations Commission on Sustainable Development (CSD) devised a framework of monitoring the various sustainability indicators for assessing the performance of government towards sustainable development goals. The structure of framework comprises four dimensions viz. social, environment, economic and institutional and it is broken down into 38 sub-indicators and 15 main indicators. Another set of indicators formulated by The Institution of Chemical Engineers (IChemE) has also formulated sustainability metrics covering three dimensions environment, economic and social which are further sub-divided into set of indicators. This metrics was initiated to assess the sustainability performance of process industry (Singh et al., 2012). The Wuppertal Institute also developed framework of sustainability by addressing the four dimensions of sustainable development, as defined by the United Nations CSD. These four aspects are linked through set of various indicators (Singh et al., 2012). Overall, based on literature reviews presented above, it can be said that various research organizations have developed different sets of indicators to assess sustainability. There is no rigid set of dimensions and indicators universally adopted and the indicators can change on case by case basis.

For rural and renewable energy projects, efforts have been made by various researchers to identify the dimensions of sustainability. A total of five dimensions/indicators suggested for rural electrification (Ilskog et. al., 2008) are as below:

- Technical sustainability focused on maintaining the energy services during the economic lifetime of the initial investment;
- Economic sustainability focused on survival of the service beyond the economic lifetime of the initial investment;
- Social sustainability focused on equitable distribution of the benefits offered by electrification;
- Environmental sustainability focused on the conservation of natural resources, avoiding degradation of the environment and preventing in- door air pollution;
- Institutional sustainability focused on survival of the organization and its ability to maintain adequate performance with respect to the other dimensions of sustainability.

According to Sovacool, qualitative factors that contribute to sustainability of rural and renewable energy projects suggests that the following features are important for successful and sustainable renewable energy projects (Sovacool, 2013):

- Selecting appropriate technology through feasibility studies and surveys that, by asking local users what they want, are able to identify community needs and desirable energy services;
- Coupling renewable energy with income generating activities and partnering with livelihood groups such as farmers and crop processors, small businesses, restaurants, and community cooperatives;
- Providing access to financing and micro credit to overcome the first cost hurdle with purchasing systems; Having political leadership and a requisite alignment of national and local policies;
- Building capacity and investing in local institutions rather than merely providing technology; Being flexible in terms of deadlines and changing circumstances, including the avoidance of promoting technology selected only by donors;
- Conducting outreach and marketing campaigns and research to ensure that economic, social, and policy issues are addressed alongside traditional engineering and environmental aspects;
- Encouraging active participation (and feedback) from communities, essentially creating as much interaction among designers, producers, and users as possible;
- Avoiding giving away systems for free and instead requiring community contributions and cost-sharing;
- Enforcing technical standards and certifications so units, components, installation practices, and maintenance procedures are all sufficient to ensure reliable system operation.

CHAPTER 3 RESEARCH METHOD

The objectives proposed in this research proposal is divided into three main parts: 1) conducting state of the art review of PV development in Indonesia from its early period until today and also the future plan, 2) conducting technical assessments of the first large-scale grid connected PV plants after operating for nearly five years, 3) conducting sustainability assessment on the three grid-connected PV pilot projects, 4) review of PV development in ASEAN countries and compare how Indonesia among the members.

Review of the PV development in Indonesia will be carried out by literature review, examining unpublished reports, discussion with relevant stakeholders, field observation, industry publication, examining project procurements publication, scanning social media, and other source of information including personal communication with people from private sector. The objective of this stage is to obtain state of the art information on PV development in Indonesia based on reliable data/ source. The work stage is shown in the flowchart below.

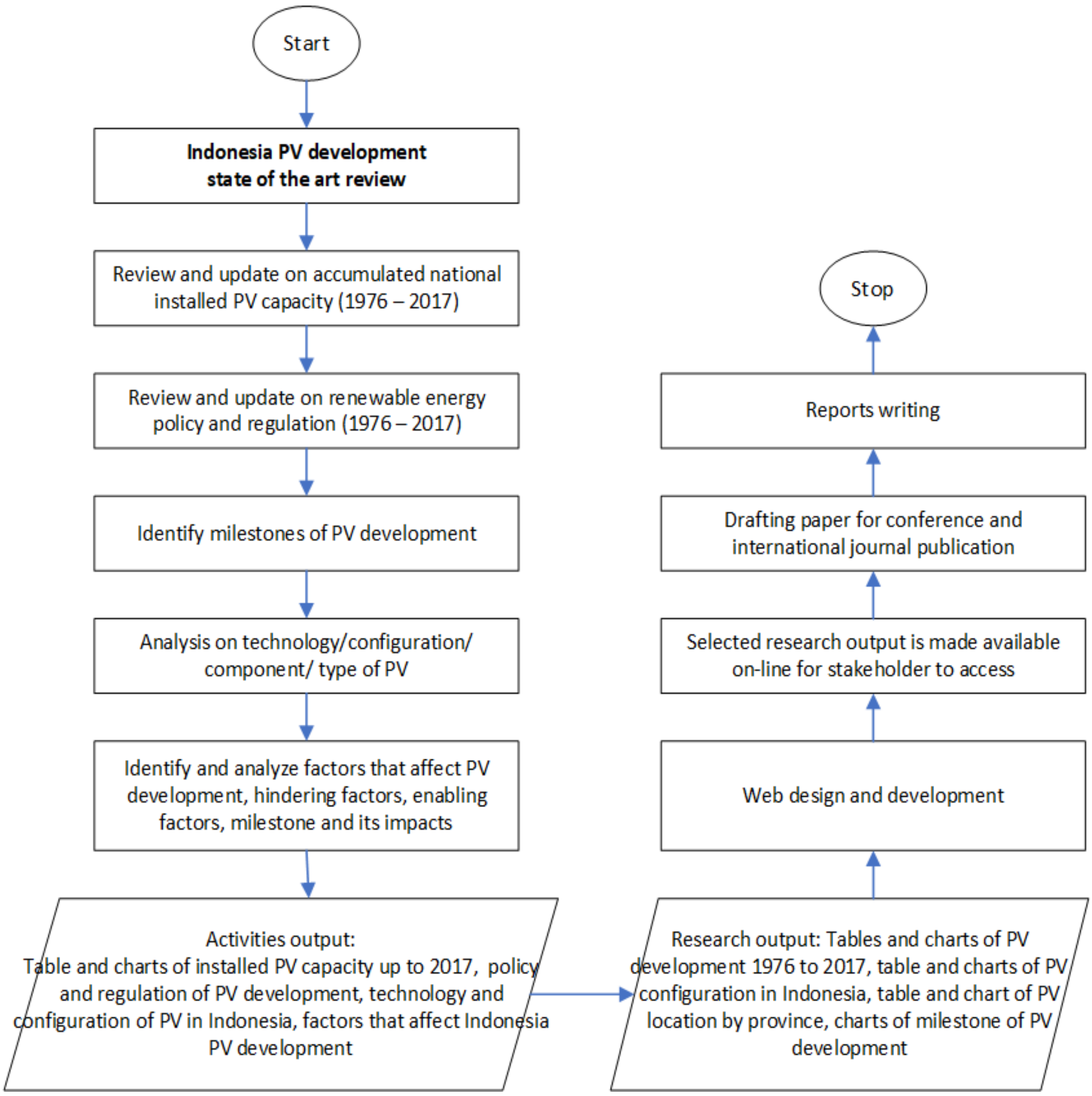


Figure 5 Flowchart for Indonesian PV development review

Technical assessment will enable energy stakeholder to understand how PV plant has performed in converting sun energy into electrical power. The assessment will be done using international standard as described in IEC 61724 standard. The results will provide insight into how the existing PV plant has performed and then to analysis what factors that affect their operation and performance. The work stage is shown in the flowchart below.

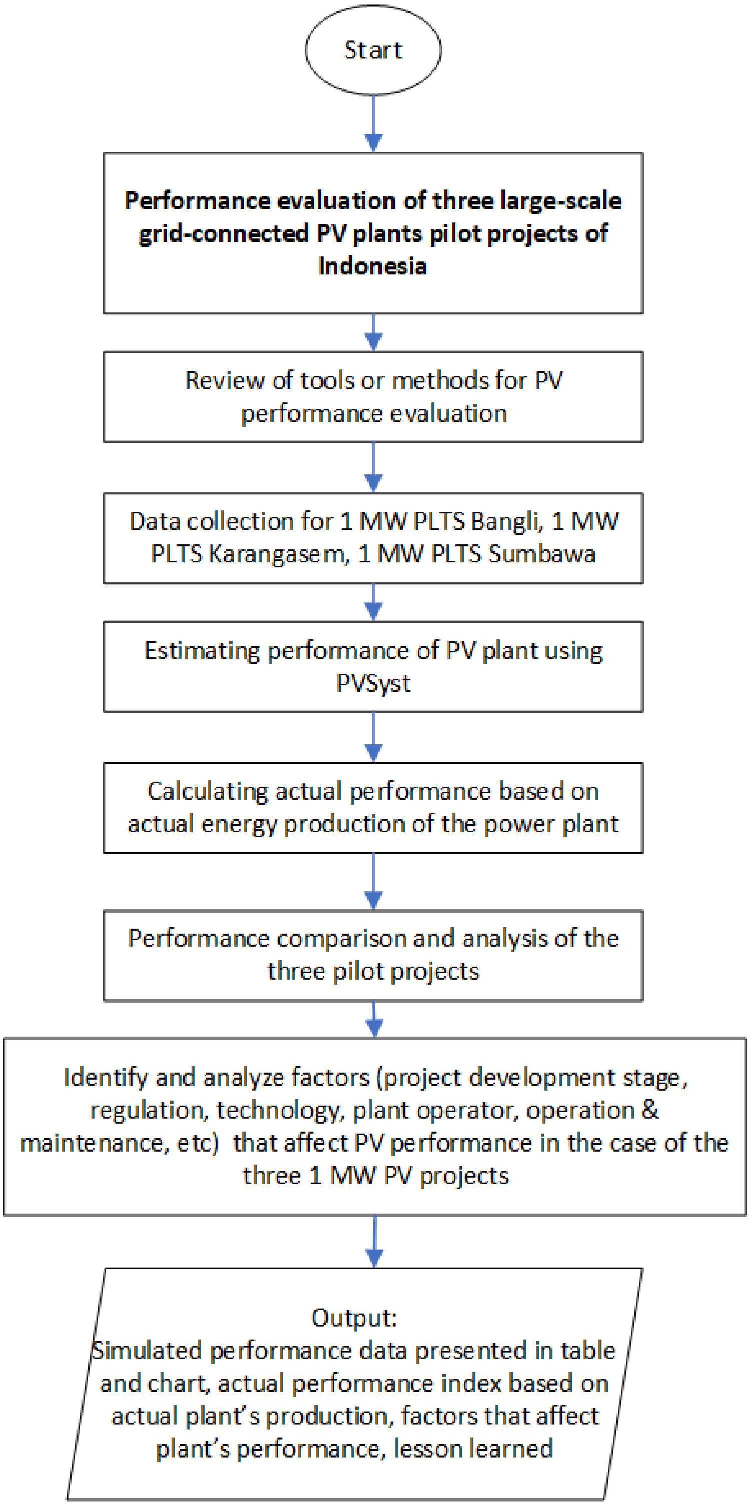


Figure 6 Flowchart for technical assessments of large-scale grid-connected PV Indonesia

Sustainability assessment will be carried out to see how the pilot projects have been developed and how likely is the project to achieve its project objectives. The research will look at various documents produced by government (law, regulation, guideline, etc.) related to PV developments and how these regulations or guidelines are implemented and have affected the PV development of the country. Also, the research will look at PLN plan regarding renewable energy development and specific standards used/ released by PLN to accommodate distributed generation (DG) penetration.

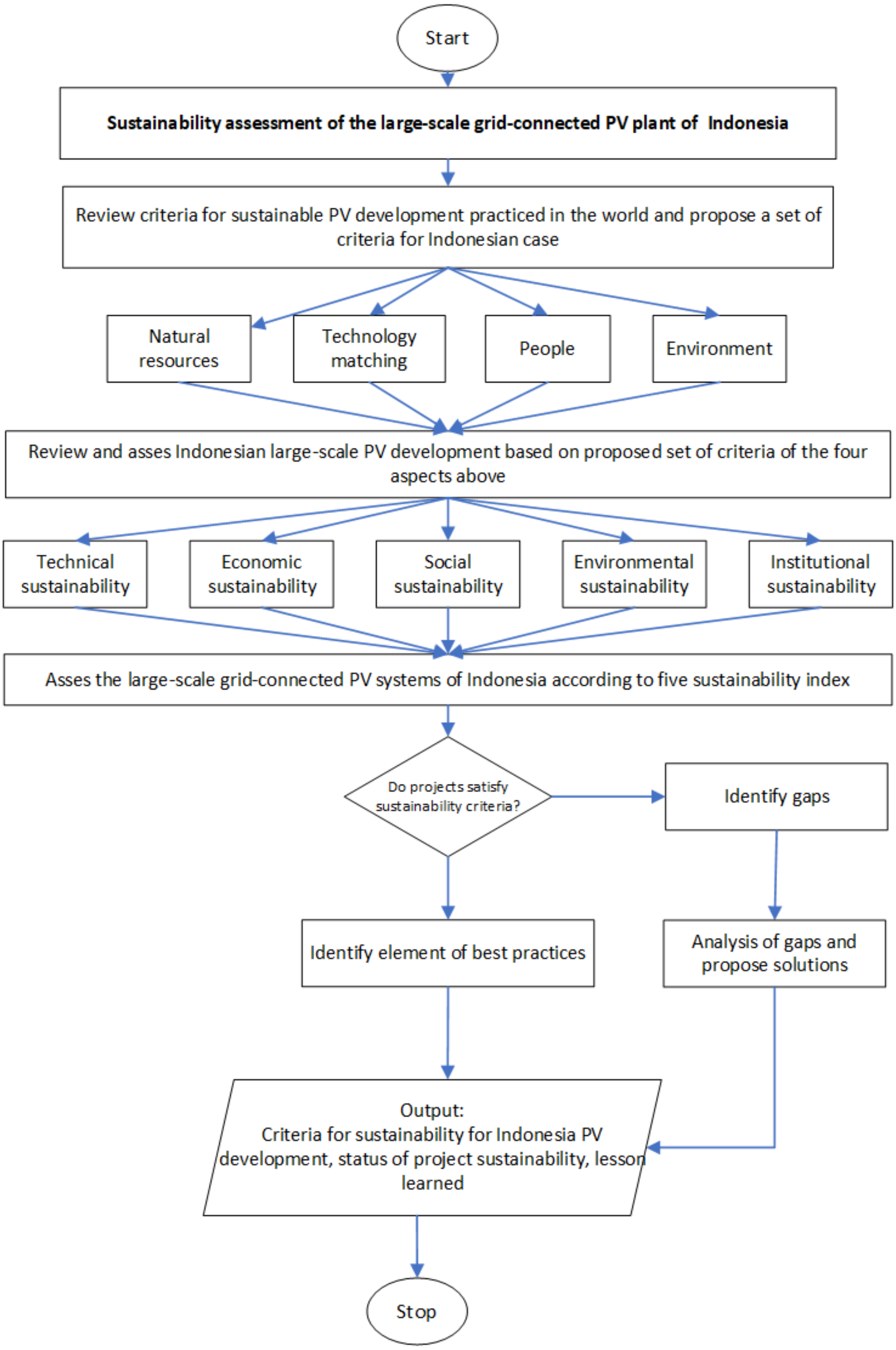


Figure 7 Flowchart for sustainability assesments

ASEAN is one of the region that has similar history among its members. Due to geographical position, most the country members have similar characteristics in terms of climate, weather, and to an extend the natural resources including demographic features. Renewable generation is an area which has become topic of discussion in all members. Each country has set target and progressing to achieve its targets. Part of this proposal is to compare plan and achievement of each ASEAN members in term of PV development and including analysis how Indonesia is among the neighboring countries as the largest ASEAN member. Flowchart of activities is shown below.

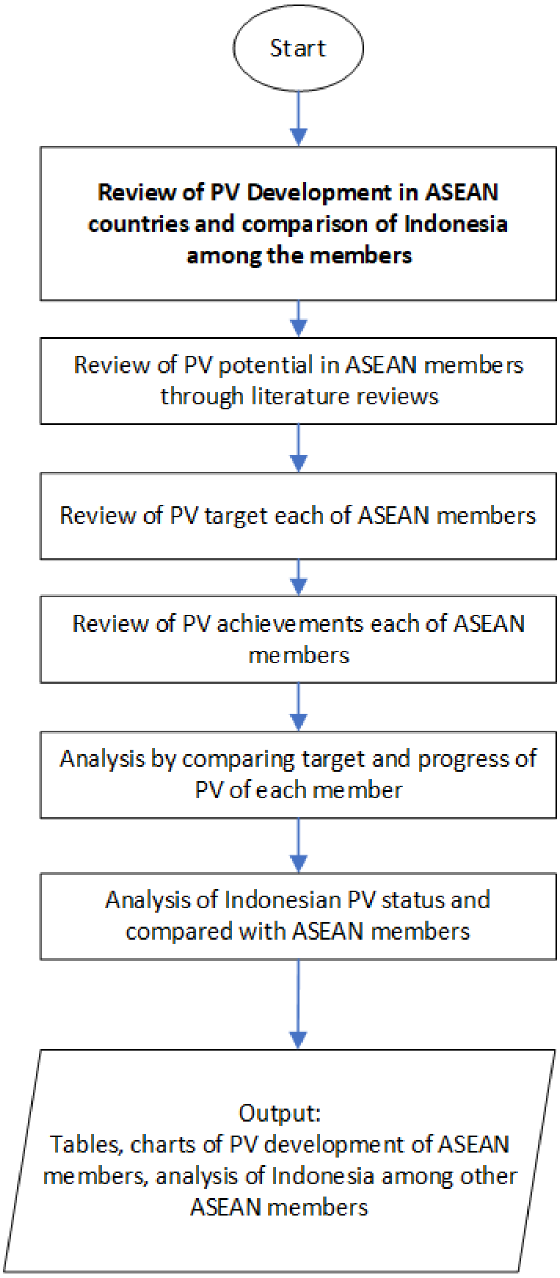


Figure 8 Review of ASEAN PV development

CHAPTER 4 RESULTS AND OUTPUT OF RESEARCH

4.1 Indonesia PV Development

Indonesia is located near the equator hence the sun energy is abundant and available almost twelve hours every day all year round. In terms of sun energy potential, a number of publications released by the authorities such as LAPAN, BPPT, and project such as USAID, etc.

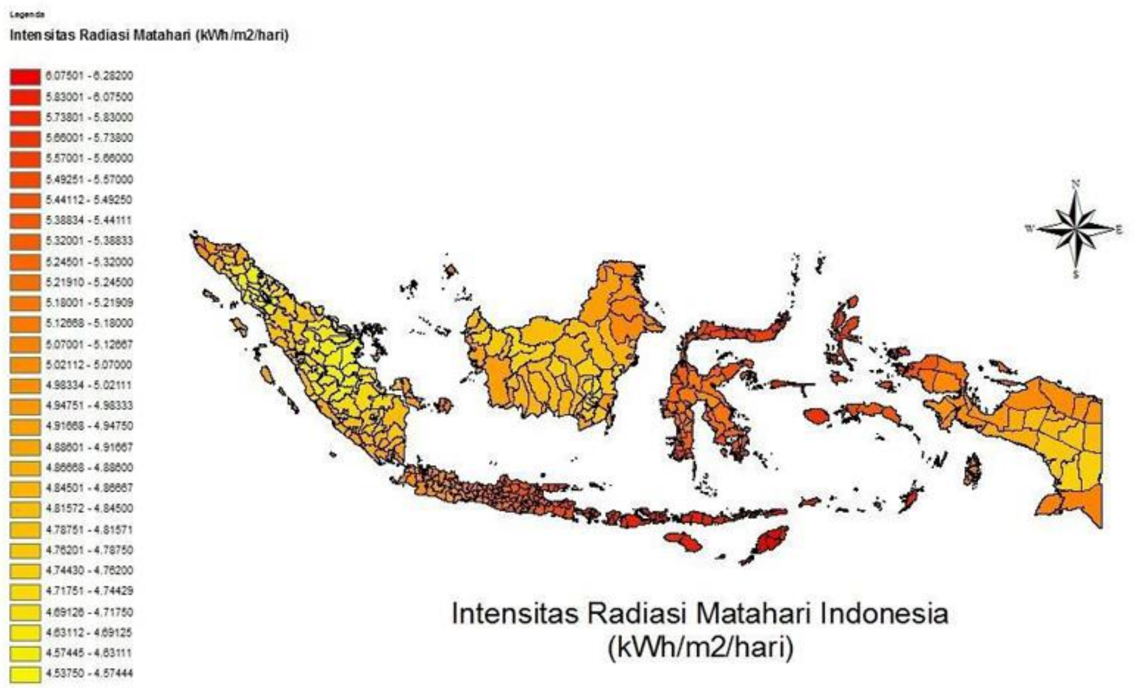


Figure 9 Indonesia solar energy potential

Indonesia is the 4th largest country in the world. The total land area is xxx. The sea is yyy. Therefore, in terms of area or space for PV development is also promising.

Development of PV in Indonesia has been long as it spans for 40 years. The first PV application of the country was dated back in 1977 when the railway company installed solar systems for radio signaling. And today after 40 years of experience, the progress of PV development is still rather slow seen by the accumulative installed PV capacity. This subsection discusses progress of PV development from its early time until 2017.

One of the background for reviewing PV development is the unavailability of reliable figure regarding the total capacity of PV in the country. Getting data of PV installed capacity in Indonesia is rather challenging due to the fact such data is not available. Many agencies that work in the field of RE produce data which are different from one another. For example, ESDM reported total capacity by 2016 was xx MW (ref). BPPT reported the total capacity was xx MW (ref).

Motivated by the unavailability of reliable data regarding accumulated capacity therefore a comprehensive review and including site surveys and discussion with EBT stakeholder were carried out. The objective is to have a reliable information on the accumulated PV capacity from the first known project up to the current progress at 2017. Through this review and mapping, the following information will be presented: (1) annual PV progress from 1977 – 2017, (2) accumulated PV capacity for forty years of project development, (3) PV capacity by province, (4) electrification ratio by province, (5) PV capacity by PV type which will grouped into grid or off-grid and other classes, (6) PV capacity by number of unit installed, (7) PV capacity grouped into type and its capacity, (8) PV capacity by developer.

Reviews on publications released by government agencies such as Balitbang EBTKE ESDM, Puslit EBTKE, BPPT or research institution such as LIPI, and universities were conducted.

The number of data/ document/ source of data examined. This review has examined thousands of documents sourced from stakeholder of EBT in Indonesia, article from international publication, conference proceedings, company's presentation/ publication, government agencies, local governments, NGOs, international project donor/ developer.

Site visits and observation to PLTS Bangli, PLTS Karangasem, PLTS Sumbawa, and PV projects around Bali such as 15 KW off-grid PV at six different locations in Bali and including the Nusa Penida island that was selected as national renewable energy pilot project. was carried out observe the power plant and to meet with the local stakeholder.

After reviewing documents and combing data/ information gathered during site visit/ observation a table which consist of PV plant built in Indonesia from 1977 up to 2017 is compiled. The column of the table is shown below. The columns are number, name of PV plant, the year the plant was built, power capacity in kilowatt, number of units, total power capacity, grid or off-grid configuration, location of the plant such as province, district, sub-district, village and sub-village, current status of the plant, source of data, source of funding, total investment, and other notes.

Document review combined with site visit and observations produce data of 2,264 PV projects located across the country which was built between 1977 until 2017.

Table 3 PV development of Indonesia 1977 to 2017

No	PV Plant	Year Was Built	Power Capacity (KW)	Unit Number	Capacity (Wp)	Grid/Off Grid	No of User/ Customer	PV Location					Current Status	Source of Data	Source of Funding	Total Investment	Remark
								Province	District	Sub-district	Village	Sub-village					
1269	SHS Radio Kereta Api	1977	0.25	250		Off grid		Jawa						https://ac.els-cdn.com/S1876610215000454/1-s2.0-S1876610			Pemasanga
1434	PLTS Picon	1979	5.5			Off grid 5.5 kw	350 orang	Jawa Barat						https://ac.els-cdn.com/S1876610215000454/1-s2.0-S1876610			Plts ini di g
30	SHS-PLTS	1982	0.42	10	42	SHS 42 Kw		Papua	Perbatasan PNG					http://www.casindo.info/fileadmin/casindo/TWGII/TWG			
10	SHS-PLTS	1985	1.5	70	20	SHS 20 Wp		Papua	Merauke	Murau				http://www.casindo.info/fileadmin/casindo/TWGII/TWG_II-_UNCEN.pdf			
714	SHS-PLTS	1986	1.5	37	50	SHS 50 Wp		Papua	Merauke	Jagobah				http://www.casindo.info/fileadmin/casindo/TWGII/TWG_II-_UNCEN.pdf			
1190	SHS Sukatani	1987	6.4	80	80	SHS 80 Wp		Jawa Barat	Depok	Tapos	Sukatani			http://majalahpeluang.com/kalkulasi-kelaikan-tenaga-surya/ , https://ideas.r			

The chart below shows progression of installed PV capacity from 1977 to 2017.

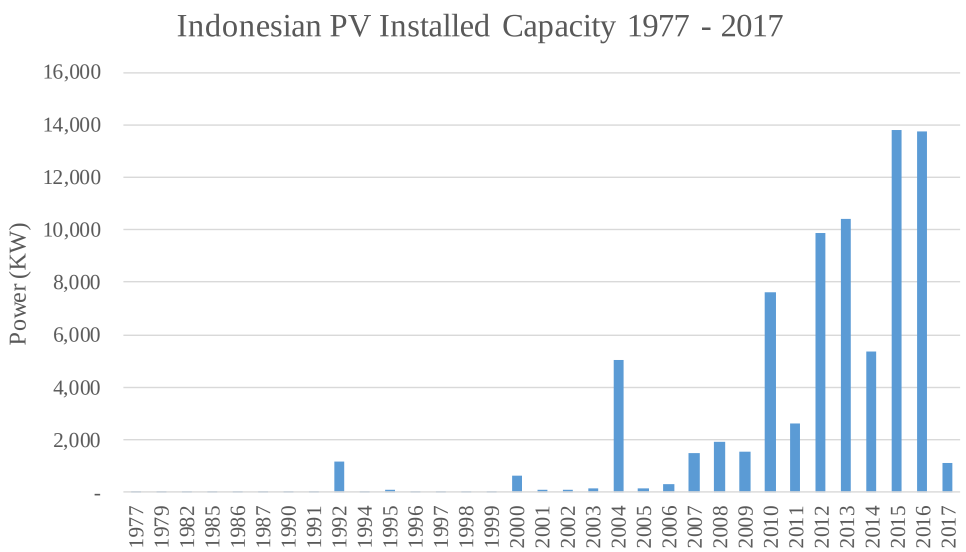


Figure 10 PV development of Indonesia 1977 to 2017

Milestone of PV development in Indonesia.

1977 is the year when Indonesian oil production reached its peak at 1,685 thousand barrel/day [Helmy, 2008]. This decade was marked by energy crisis around the world [Ref]. Total installed PV capacity in many developed countries at the time was still very low [Ref]. For example, Germany as currently, the top country for PV capacity at the time was only xx MW. While in the USA, by 1977 the total manufacturing capacity reported just exceed 500 KW [DoE, History of Solar]. For Indonesia, to experience the early application of PV was beneficial as around the time PV or solar energy R&D was not yet started before 1979 [Adjat Sudrajat B2TE BPPT, 2011]. The train company of Java A German company installed 250 unit of solar powered radio station for train signaling over an 800 km distance in Java island [Schott Solar, 2011].

1978

1979 R&D of solar energy/ PV of Indonesia mostly under the coordination of State Minister of Research and Technology [Adjat Sudrajat B2TE BPPT, 2011] and the support from the German Federal Ministry for Education, Science, Research and Technologies (BMFT). The collaboration worked on the first solar project known as Solar Village Indonesia (SVI). The project run until 1984.

1979 5.5 KW Picon village solar pumping systems, 5.5 KW, 220 V, 50 Hz output Ref: H. Driesen, S. Vojdani, Design, Installation and First Evaluation of a Photovoltaic Power Plant System for The Indonesian Village of Picon in West Java, Third E.C. Photovoltaic Solar Energy Conference, Proceedings of the International Conference, Cannes, France, 27-31 October 1980

- 1980 Badan Koordinasi Energi Nasional (BAKOREN) or the National Energy Coordination Agency was established to coordinate the country energy affairs [Keppres 46/80].
- PLTS di Sumba, Sipirok di Sumatera Utara, Pelaw di Maluku, Kepulauan Seribu, dan Nusa Penida

1981 Solar Village Indonesia
1982 Solar Village Indonesia
1983 Solar Village Indonesia
1984 Solar Village Indonesia

1985 – 1996 Renewable Energy Indonesia (REI) Project as the continuation of the Solar Village Indonesia.

1986 Renewable Energy Indonesia

1987 Renewable Energy Indonesia

1988 Sukatani photovoltaic project; 88 SHS (2 x 34Wp module and 100 AH battery) and 15 street lighting. Inaugurated by BJ Habibie, Minister of Ristek.

1989 Renewable Energy Indonesia

1990 Renewable Energy Indonesia

1991 Renewable Energy Indonesia

1992 Renewable Energy Indonesia

1992 Many PLTS project in Papua mainly by Depkes, also some by USAID

1993 Renewable Energy Indonesia

1994 Renewable Energy Indonesia

1995 Renewable Energy Indonesia

1995 B2TE BPPT SNI 04-3850.2-1995 module certification

1996 Renewable Energy Indonesia

1997 AUSAID 36,400 unit of 50 Wp SHS for Indonesia and 14 PV Hybrids in Sulawesi

1998 economic crisis hit Indonesia

1999

- economic and political crisis continued

Table 4 IEA PVPS report of Indonesian PV

Country	**PV Power installed at the end of 1996 (kW_p)**	**Country**	**PV Power installed at the end of 1996 (kW_p)**
Brazil	2 000	Morocco	1 000
Cook Islands	NA	Namibia	800
Dominican Republic	225	Philippines	133
Ethiopia	NA	Senegal	800
French Polynesia	NA	South Africa	5 500
Ghana	350	Tanzania	NA
India	35 000	Thailand	2 500
Indonesia	1 800	Tuvalu	50
Kenya	2 000	Uganda	150
Malaysia	640	Vietnam	100
[illegible]	[illegible]	[illegible]	[illegible]

- IEA PVPS reported in 1999 that by 1996 the total PV capacity was 1.8 MW

2000

- SNI:04-6298-2000 corrosion test report
- The available test laboratory for the Solar Home System and component is provided in the Energy Technology Centre (B2TE) BPPT. This laboratory is accredited by the ISO17025. The B2TE test laboratory was developed in cooperation with TUEV Rhineland and Fraunhofer ISE Germany. This laboratory was certified by the National Certification body of Indonesia (BSN) in the year of 2000.
- Paper PLTS pd arsitektur bangunan
-

2001

2002

2003

- BPPT announced to build 1 million PV

2004

2005

- PLN established Nusa Penida Renewable Energy Park

2006

- Perpres No 5/2006 Kebijakan Energi Nasional

2007

- Undang-undang Nomor 30 Tahun 2007 tentang Energi
- RENDEV Project by EU
- Indonesia hosted UNFCC 2007
- Desa Wisata Energi Nusa Penida (PLTS, PLTB dan PLTD)
- Paper ENERGI TERBARUKAN DALAM PEMBANGUNAN BERKELANJUTAN Abubakar Lubis - BPPT

2008

- Peraturan Presiden Nomor 26 Tahun 2008 tentang DEN dan paradigma baru pengelolaan energi nasional
- Networking ESDM Deplu Asian countries dalam Renewable Energy Workshop
- Malimping Jadi Desa Pencontohan Energi Terbarukan

2009

- UU 30/2009 Ketenagalistrikan
- PT Len rencana membuat pabrik modul surya yang beroperasi th 2011
- ITB registered Solare (PLTS + LED)
- International Conference On Sustainable Energy 2009 by ITB
- Peraturan Menteri Energi dan Sumber daya Mineral No. 31 Tahun 2009 tentang harga pembelian tenaga listrik oleh PT.PLN (Persero) dari Pembangkit Tenaga Listrik yang menggunakan Energi Terbarukan skala kecil dan Menengah atau kelebihan listrik, menyebutkan bahwa segala bentuk pembelian listrik dari pembangkit Energi Terbarukan dilakukan oleh PT.PLN (Persero). PT PLN (Persero) wajib membeli tenaga listrik dari

pembangkit tenaga listrik yang rnenggunakan energi terbarukan skala kecil dan menengah dengan kapasitas sampai dengan 10 MW atau kelebihan tenaga listrik (excess power) dari badan usaha rnilik negara, badan usaha milik daerah, badan usaha swasta, koperasi, dan swadaya masyarakat guna memperkuat sistem penyediaan tenaga listrik setempat.

2010

- APAMSI
- EBTKE was set up

2011

- EBTKE Connex,
- PLN established RE Division
- PLN plan of 100% Solar Energy for 100 Islands using Lampu Super Extra Hemat Energi (SEHEN)

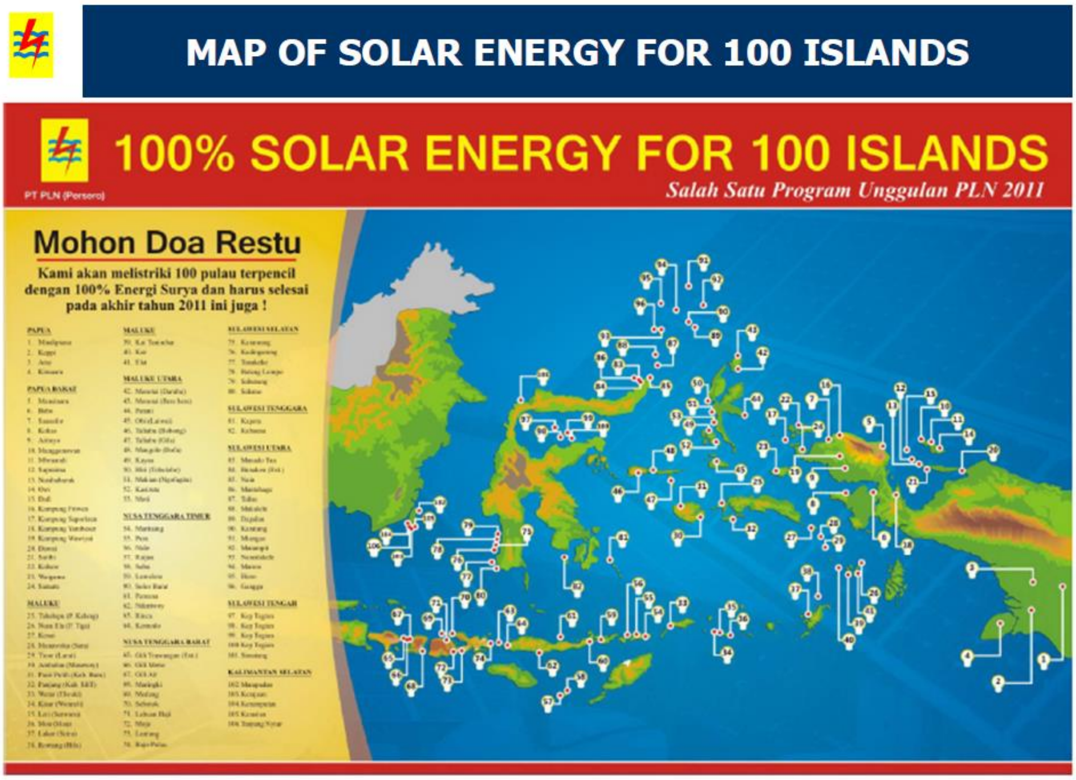


Figure 11 Map of Solar energy for 100 islands

2012

- EBTKE Connex

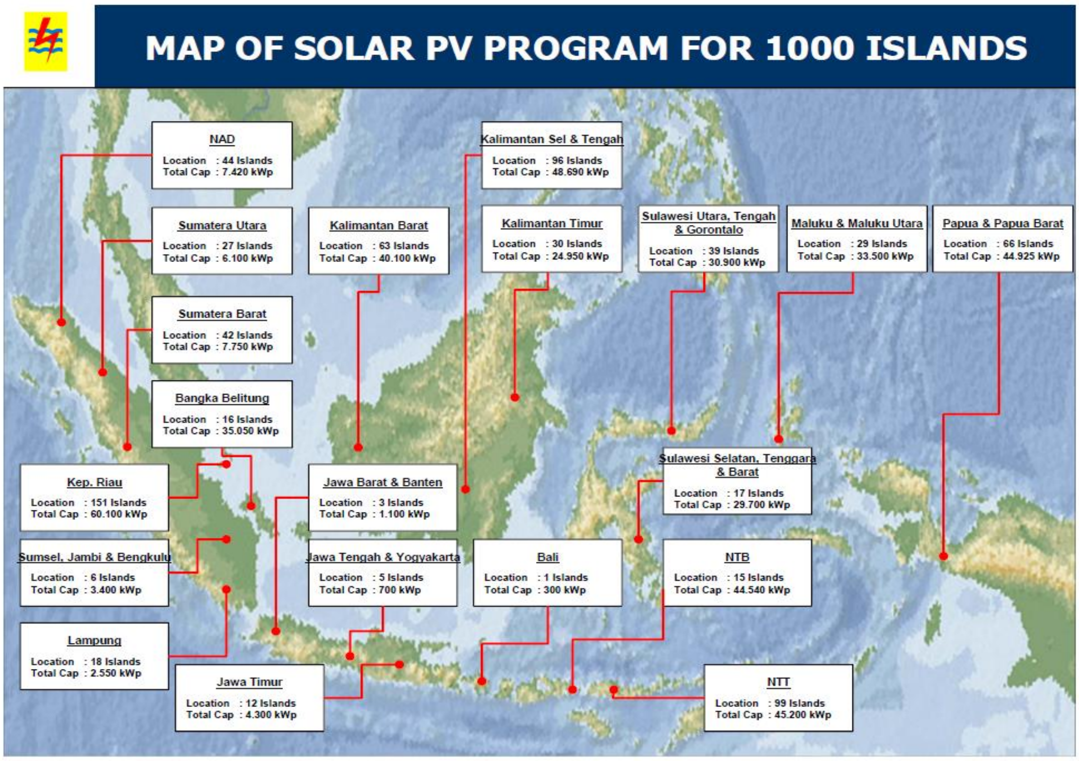


Figure 12 Solar map for 1000 islands

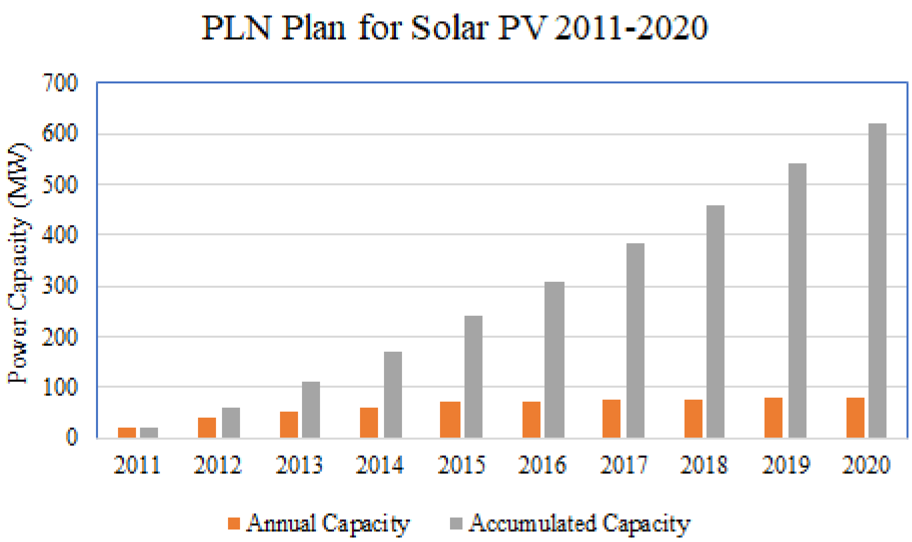


Figure 13 PLN plan for solar PV 2011 to 2020

2013

- EBTKE Connex
- PT Energizer Indonesia donated 1,200 solar LED lights to 6 villages in West Java to help areas that are still experiencing power limitations.
- Pilot project of large-scale grid-connected PV (PLTS Bangli, PLTS Karangasem, PLTS Sumbawa)

- Permen ESDM No.30 Tahun 2009 tersebut pada tahun tahun 2013 dirubah menjadi Permen ESDM No. 17 Tahun 2013 tentang Pembelian Tenaga Listrik Oleh PT Perusahaan Listrik Negara (Persero) Dari Pembangkit Listrik Tenaga Surya Fotovoltaik. Hal yang membedakan dari Permen sebelumnya adalah harga tarif listriknya. Dimana, pada Permen ini tarif EBT kusunya Photovoltaic (Mulai Terbentuknya Feed in tariff) untuk semua kapasitas terpasang dengan harga patokan tertinggi sebesar US$ 25 sen / kWh. Sedangkan bagi pengembang yang mempunyai TKDN sekurang-kurangnya 40% pada instalasi PV solarnya maka akan diberi insentive dan ditetapkan dengan harga patokan tertinggi sebesar US$ 30 sen /kWh.

2014

- Peraturan Pemerintah Nomor 79 Tahun 2014 tentang Kebijakan EnergiNasional
- EBTKE Connex

2015

- 1 Juta Rumah Jokowi Dilengkapi Solar Cell, Penghuni Bisa Jual Listrik ke PLN
- EBTKE Connex
- Sumba Iconic Island: 100 Renewable Energy Island

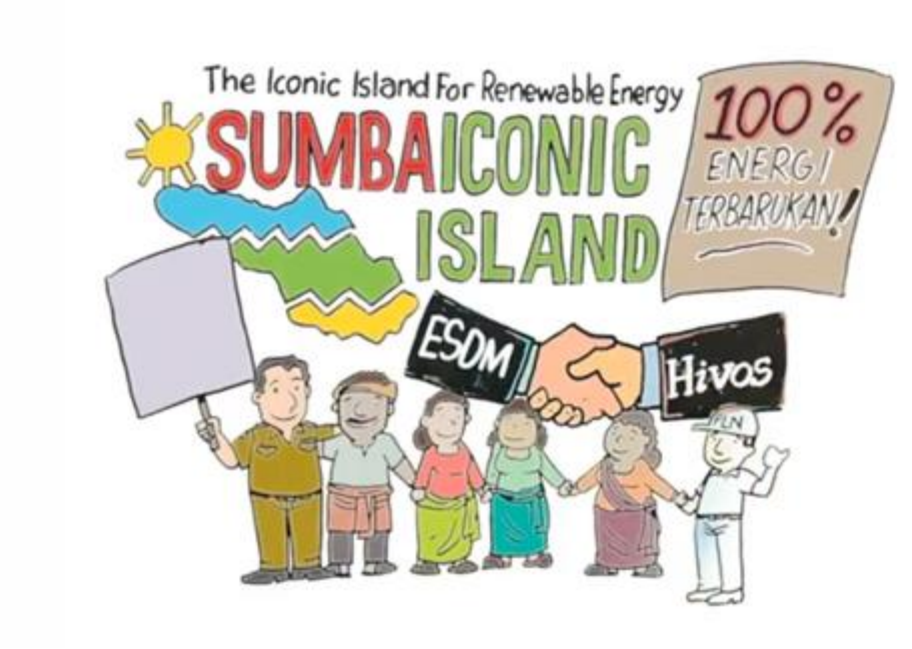


Figure 14 Iconic island of Sumba - 100% renewable energy

- Panasonic solar lantern (2000 unit) for people in NTT

2016

- EBTKE Connex
- Bali Clean Energy Forum 2016
- ISPVRP – Indonesian Solar PV Rooftop
- ESDM planned to set up PLN special for EBT
- Pemerintah melalui Kementerian Energi dan Sumber Daya Mineral mengeluarkan Peraturan baru yakni Permen ESDM no.19 Tahun 2016 tentang Pembelian Tenaga Listrik dari PLTS FOtovoltaik oleh PT.PLN Persero. Pada peraturan baru ini telah ditetapkan Feed in Tariff untuk PLTS di masing-masing wilayah.

Table 5 Feed in Tariff for provinces of Indonesia

No.	Wilayah	Kuota Kapasitas (MWp)	Harga Pembelian (sen USD/kWh)
1.	DKI Jakarta	150,0	14,5
2.	Jawa Barat		
3.	Banten		
4.	Jawa Tengah dan DIY		
5.	Jawa Timur		
6.	Bali	5,0	16,0
7.	Lampung	5,0	15,0
8.	Sumatera Selatan, Jambi, dan Bengkulu	10,0	15,0
9.	Aceh	5,0	17,0
10.	Sumatera Utara	25,0	16,0
11.	Sumatera Barat	5,0	15,5
12.	Riau dan Kep. Riau	4,0	17,0
13.	Bangka-Belitung	5,0	17,0
14.	Kalimantan Barat	5,0	17,0
15.	Kalimantan Selatan dan Kalimantan Tengah	4,0	16,0
16.	Kalimantan Timur dan Kalimantan Utara	3,0	16,5
17.	Sulawesi Utara, Sulawesi Tengah, dan Gorontalo	5,0	17,0
18.	Sulawesi Selatan, Sulawesi Tenggara, dan Sulawesi Barat	5,0	16,0
19.	NTB	5,0	18,0
20.	NTT	3,5	23,0
21.	Maluku dan Maluku Utara	3,0	23,0
22.	Papua dan Papua Barat	2,5	25,0

2017

- EBTKE Connex 2017
- Bali Clean Energy Forum 2017
- **Gerakan Nasional Sejuta Atap Menuju Gigawat Fotovoltaik di Indonesia**
- **Government has included power generation related industry as one of industry priority and has been described in the Rencana Induk Pembangunan Industri Naisoonal (RIPIN) 2016-2035 which serve as the penjabaran of UU No 3/2014 regarding Industrialization of Indonesia. The photovoltaik industry has become focs of the Ministry of Industrialization.**
- Perpres 47/2017 Lampu Tenaga Surya Hemat Energi bagi masyarakat tanpa akses listrik secara gratis
- Perpress 22/2017 tentang RUEN
- Permen ESDM 12/2017 PLN wajib membeli listrik dari pembangkit EBT, maksium df kapasitas 10 MW secara terus menerus (must run)
- Permen ESDM 12/2017 Baru-baru ini Menteri Energi dan Sumber Daya Mineral (ESDM) Ignasius Jonan mengeluarkan Peraturan Menteri ESDM (Permen ESDM) Nomor 12 Tahun 2017 Tentang Pemanfaatan Sumber Energi Terbarukan untuk Penyediaan Tenaga Listrik. Peraturan ini dinilai terlalu menekan para investor yang ingin mengembangkan energi baru terbarukan (EBT). Pasalnya, dalam permen 12 tersebut ditetapkan, harga listrik dari EBT seperti pembangkit listrik tenaga angin, air, matahari, biomassa, dan biogas, dipatok sebesar 85% di bawah harga biaya pokok produksi (BPP). Namun, untuk jenis pembangkit listrik dari tenaga panas bumi dan sampah, harga listriknya berbeda.
- Penetapan tariff untuk PLTS tidak hanya berhenti pada Permen ESDM no 19 Tahun 2016. Dikarenakan tingginya harga listrik yang harus dibeli oleh PLN dan diatas BPP PLN, maka pemerintah mengeluarkan Keputusan Menteri ESDM no. 1404 k/20/MEM/2017 tentang Besaran Biaya Pokok Penyediaan Pembangkitan PT.PLN Persero. Dalam surat keputusan ini, mengatur BPP/kWh pada wilayah/distribusi/sistem/subsistem yang dikelola oleh PT.PLN.

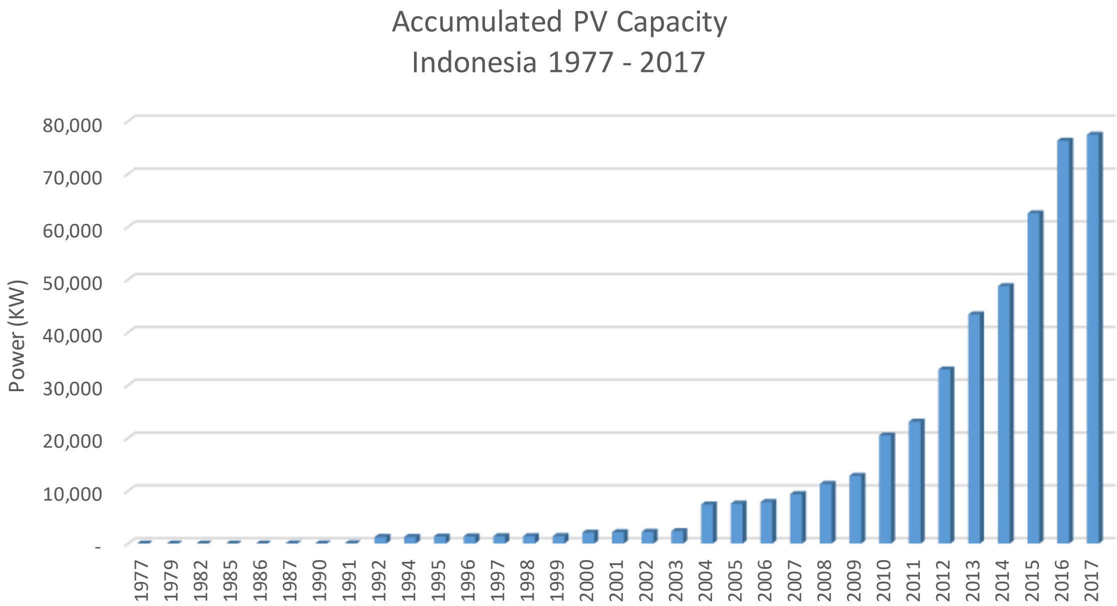


Figure 15 Accummulated PV capacity Indonesia 1977 - 2017

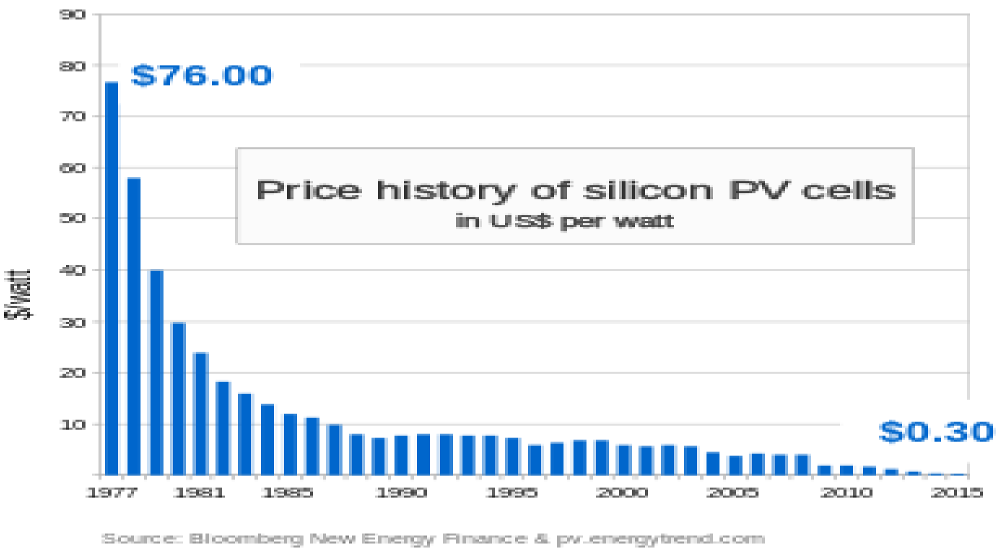


Figure 16 Price of PV energy from 1977 to 2015

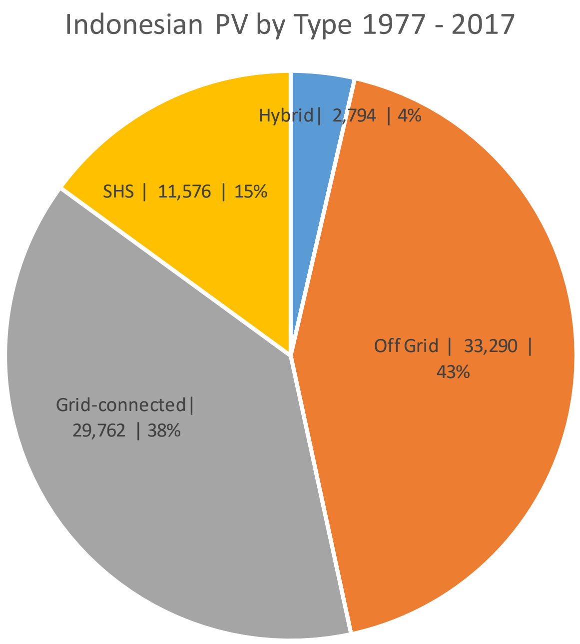


Figure 17 PV Indonesia by type 1977 - 2017

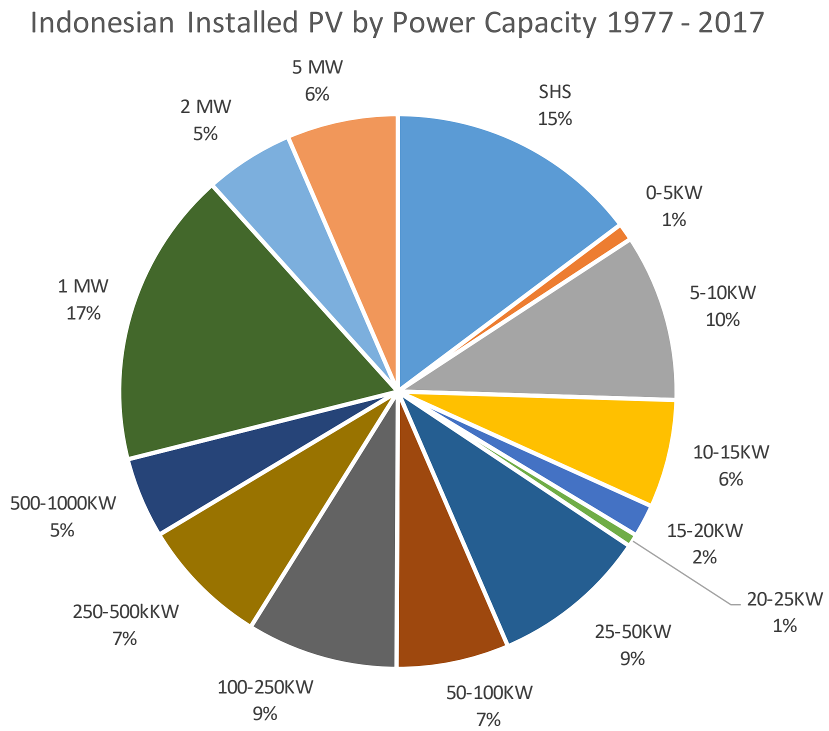


Figure 18 PV Indonesia by plant's size

Table 6 PV unit installed in Indonesia

Unit Size/ Capacity	Number of Installed Unit
SHS (25 - 250 Wp)	223,537
0-5 KW	3,819
5-10 KW	501
10-15 KW	329
15-20 KW	74
20-25 KW	23
25-50 KW	176
50-100 KW	59
100-250 KW	43
250-500 KW	17
500-1000 KW	5
1 MW	12
2 MW	2
5 MW	1

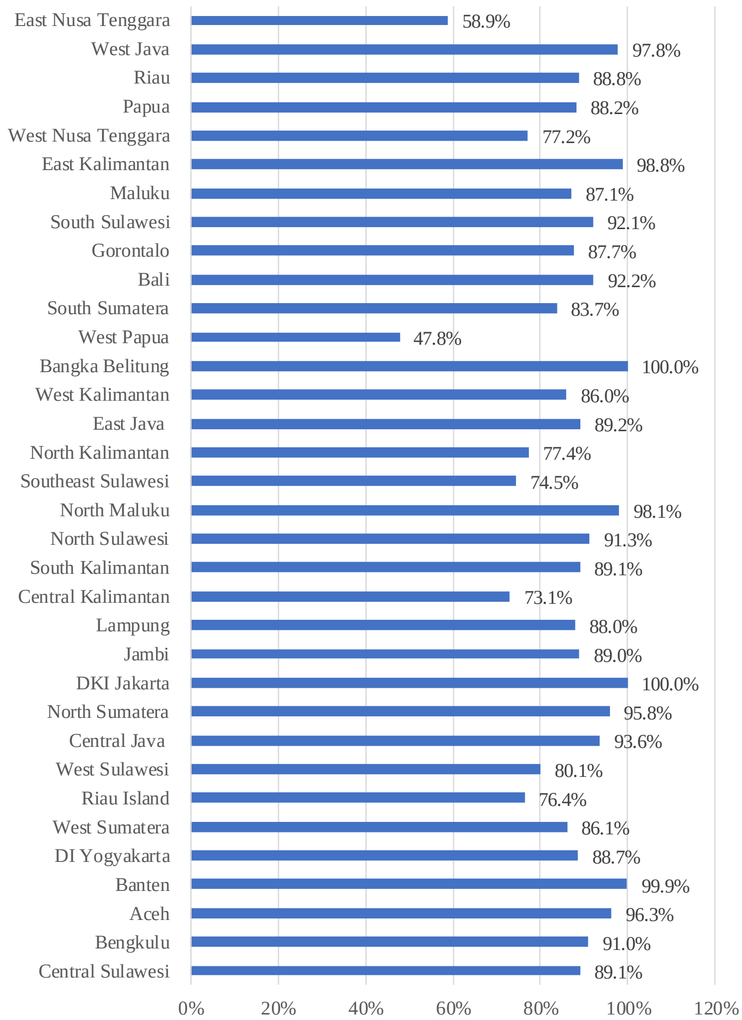


Figure 19 Electrification ratio by Province of Indonesia 2017

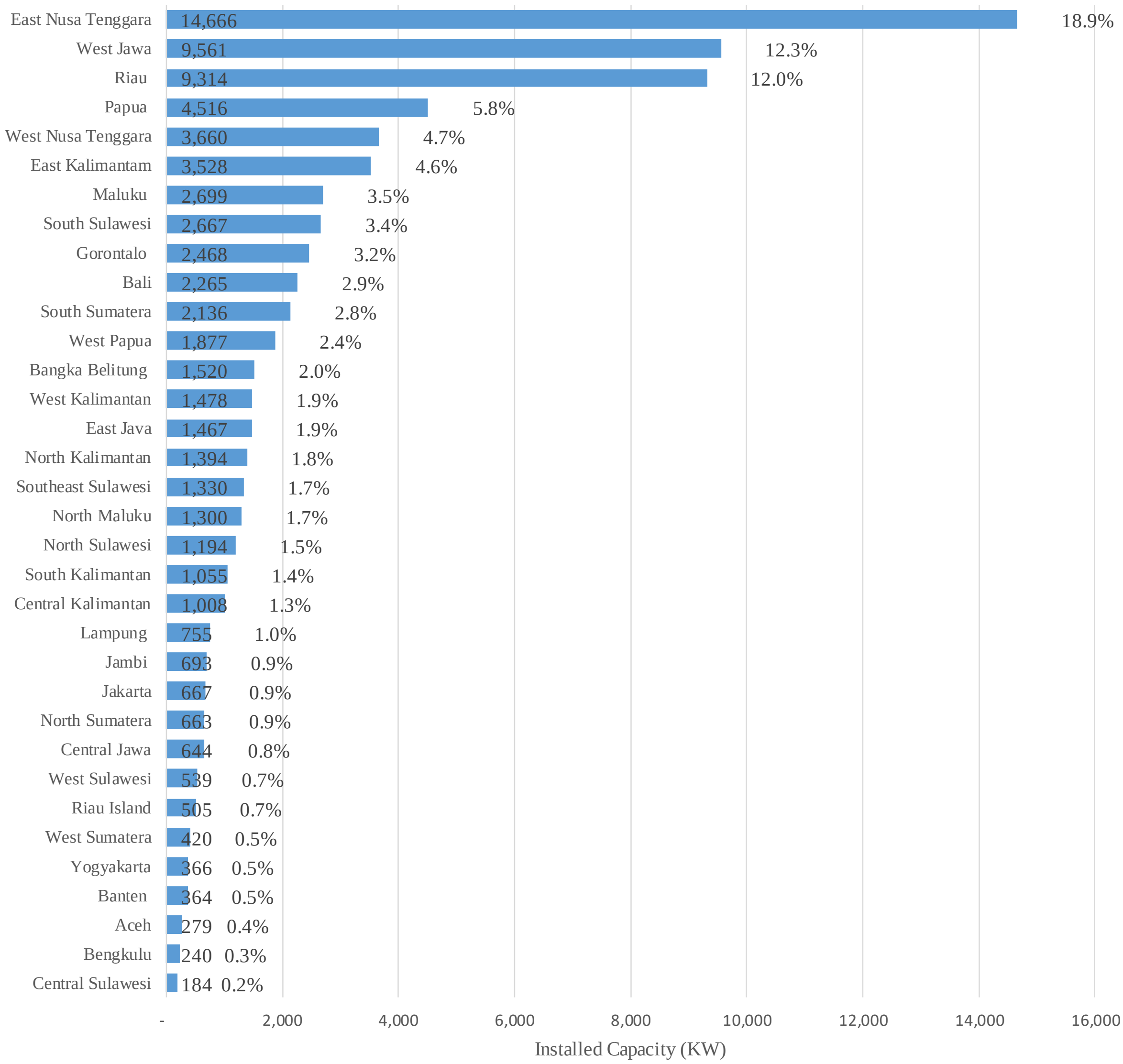


Figure 20 Installed PV by Province of Indonesia 1977 - 2017

PLTS progressing in 2018

Jan

- 46 KW rooftop PV at Tol Bakahuni for gate power supply
- Politeknik Elektronika Negeri Surabaya (PENS) hibahkan PLTS untuk Warga desa Bringsang, Kecamatan Gili Genting, Pulau Gili Genting, Sumenep Madura, demi hemat biaya untuk penerangan dan pompa air.
- PLTS tersebut merupakan hasil kerja sama SMAN 8 dengan PT Paiton Energy dan Institut Ekonomi Bisnis dan Ekonomi Kerakyatan (IBEKA). Pembangunan fasilitas PLTS tersebut dilakukan mulai 2017 dan mendapat bantuan juga dari alumni SMAN 8. PLTS ini berkapasitas 15,36 on-grid dengan 50 panel dan menghabiskan dana Rp1,5 miliar.
- PLTS Terangi Lung Barang dan Metut
- Bupati Manggarai Barat (Mabar), Drs. Agustinus Ch. Dula menyampaikan ucapan terima kasih kepada Kementerian Energi dan Sumber Daya Mineral (ESDM) RI yang telah membangun Pembangkit Listrik Tenaga Surya (PLTS) di pulau Longos Desa Pontianak

Kecamatan Boleng. Pembangunan PLTS di Pulau Longos tersebut, menunjukan perhatian yang tinggi dari Pemerintah Pusat terhadap kebutuhan masyarakat di Manggarai Barat.

Feb

- 100 KW off gird PLTS Desa Balang Datu, Mappakasunggu, Kabupaten Takalar. Kementerian Energi dan Sumber Daya Mineral (ESDM) pada Jumat (9/2) ini meresmikan Pembangkit Listrik Tenaga Surya (PLTS) Terpusat dengan kapasitas 100 kilo watt peak (kWp), di desa terpencil, yakni Desa Balang Datu, Kecamatan Mappakasunggu, Kabupaten Takalar, Provinsi Sulawesi Selatan.
- Indonesia yang diwakili oleh PT. Pembangkit Jawa Bali (PJB) telah menandatangani kontrak kerjasama dengan Masdar (perusahaan EBT asal UEA) untuk membangun pembangkit listrik tenaga surya (PLTS) terapung di waduk Cirata, Purwakarta. Kapasitas PLTS terapung Cirata adalah 200 MW yang akan menghabiskan lahan waduk seluas 225 hektar[2].
- PLTS Bangli. Manager Perencanaan PLN Distribusi Bali Putu Putrawan mengatakan, dengan dilakukannya penandatanganan perjanjian, maka proses jual beli listrik sudah mulai bisa dilakukan antara Perusda dan PLN. Dia menyebutkan, besaran tarif listrik yang harus dibayarnya nanti ke perusda BMB sesuai dengan Permen ESDM 39 tahun 2017 yakni Rp 750 per Kwh.

- Sebanyak 316 rumah warga di Desa Pontianak, Kecamatan Boleng, Kabupaten Manggarai Barat (Mabar) sejak akhir tahun 2017 lalu telah diterangi listrik dari Perusahaan Listrik Tenaga Surya (PLTS). PLTS tersebut merupakan bantuan gratis dari Pemerintah Pusat (Pempus) dalam hal ini Kementerian Energi dan Sumber Daya (ESDM) Republik Indonesia (RI) tahun 2017 lalu.
- Pemerintah Kabupaten Luwu Timur merealisasikan program penerangan rumah tangga menggunakan tenaga surya sebanyak 236 unit di 5 desa dengan nilai anggaran sebesar Rp2,5 miliar.
- Kabupaten Lanny Jaya mendapatkan 29.155 unit LTSHE yang tersebar di 21 Distrik, dengan jumlah terpasang sebanyak 20.851 tersebar di 15 Distrik, sedangkan di 6 distrik lainnya yaitu Distrik Balingga, baru terpasang sebagian, Distrik Ayumnati dan Distrik Melagi sedang dalam proses pemasangan, sementara Distrik Goa Balim, Distrik Guna dan Distrik Dimba masih belum terpasang, berjumlah 8.304 unit LTSHE.
- Pihak Direktorat Jenderal EBTKE membagikan sebanyak 380 unit LTSHE untuk Kabupaten Meranti pada tahun anggaran 2017. Setiap unit yang terdiri dari 1 modul sel surya, 4 lampu, 1 kabel charger, remote kontrol dibagikan kepada setiap KK. Sejak bulan November 2017, warga sudah bisa menikmati listrik sel surya program LTSHE itu untuk keperluan sehari-hari.
- Penyusunan Rencana Usaha Penyediaan Tenaga Listrik/RUPTL periode 2018 hingga 2027 telah selesai. Salah satu isi RUPTL itu adalah memangkas porsi pembangkit listrik dari sumber Energi Baru Terbarukan/EBT.

Mar

- PLTS Nunukan 75 KW Dana pembangunan PLTS ini sebesar Rp 5,9 miliar, dan telah beroperasi sejak Desember 2017. Adalah PLTS Desa Tepian yang membuat lebih hidup desa tersebut. Dibangun dengan dana sebesar Rp 5,9 miliar, pembangkit itu sebenarnya telah beroperasi sejak Desember 2017 lalu. Namun baru diresmikan oleh Direktur Jenderal Energi Baru Terbarukan dan Konservasi Energi (EBTKE), Kementerian Energi dan Sumber Daya Mineral (ESDM), Rida Mulyana, Sabtu (10/3). PLTS 75 KW.

- Direktur Inisiatif Bisnis Ekonomi Kerakyatan (IBEKA) Tri Mumpuni mengatakan PLTS di Pondok Pesantren Annuqayah berkekuatan 30,72 KWP. Sebagai penyuplai listrik di seputar

Annuqayah, juga dijadikan tempat pembelajaran oleh peserta didik dan santri di pondok pesantren terbesar di Madura ini.

- “Sistem dari PLTS ini on-grid. Jadi, langsung terhubung dengan PLN. Ada kalanya juga kita beramal ke PLN karena PLTS ini juga bisa dipakai,” katanya.
- Pemerintah Provinsi (Pemprov) Sulawesi Tenggara (Sultra) menganggarkan Rp46,7 miliar untuk pembangunan pembangkit listrik tenaga surya (PLTS) terpusat di 6 kabupaten di Sultra yang terdiri dari 8 desa. Anggaran tersebut bersumber dari dana alokasi khusus (DAK) Sultra 2018. Delapan desa dari 6 kabupaten itu adalah, Desa Runduma, Kecamatan Tomia, Kabupaten Wakatobi dengan anggaran Rp7.105.751.060, Desa Lentea, Kecamatan Kaledupa Selatan, Kabupaten Wakatobi dengan anggaran Rp7.742.687.500. Kemudian Desa Taduasa, Kecamatan Batu Atas, Kabupaten Buton Selatan dengan anggaran Rp8.283.062.500. Selanjutnya Desa Namu, Kecamatan Laonti, Kabupaten Konawe Selatan, Rp4.288.374.710, Desa Saponda Darat Kecamatan Soropia, Kabupaten Konawe, Rp4.395.404.913, Desa Kogholifano, Kecamatan Pasir Putih, Kabupaten Muna, dengan anggaran Rp4.330.562.500, dan Desa Bhontu-Bhontu Barat, Kecamatan Towea, Kabupaten Muna, Rp2.792.556.299, serta Desa Watumendonga, Kecamatan Mowewe, Kabupaten Koltim, dengan anggaran Rp7.775.758.006.
- Pada tanggal 15 Maret 2018, Badan Perencanaan Pembangunan Daerah (BAPPEDA) Provinsi Nusa Tenggara Barat bekerja sama dengan GIZ-ENDEV dan Dinas Energi dan Sumber Daya Mineral Provinsi Nusa Tenggara Barat menyelenggarakan Lokakarya dengan tema Strategi Pembangunan Desa Penerima Bantuan Pembangkit Listrik Tenaga Surya (PLTS) Terpusat di Provinsi Nusa Tenggara Barat. Lokakarya ini adalah bagian dari *exit strategy* pasca Proyek RUMI yang digagas oleh GIZ-ENDEV dan Dinas Energi dan Sumber Daya Mineral Provinsi Nusa Tenggara Barat. Ide besarnya adalah menjamin keberlanjutan kegiatan-kegiatan yang telah dirintis melalui integrasi dengan program-program dari sektor lain di 4 (empat) dusun lokasi proyek RUMI.
-

Apr

- Pembangkit Listrik Tenaga Surya (PLTS) 50kWp Terpusat Bencah Umbai, Kabupaten Siak, Riau, Kamis (5/4/2018). PLTS yang dibangun sejak September 2017 oleh PT. Wijaya Karya Industri Energi itu memiliki nilai aset mencapai Rp 14 miliar yang dianggarkan melalui dana APBN 2017
- Politeknik Elektronika Negeri Surabaya (PENS) hibahkan PLTS untuk Warga desa Bringsang, Kecamatan Gili Genting, Pulau Gili Genting, Sumenep Madura, demi hemat biaya untuk penerangan dan pompa air.
- 26 April 2018 – Masyarakat di tiga desa di Berau, Kalimantan Timur, yakni desa Long Beliu, Merabu, dan Teluk Sumbang kini dapat menikmati listrik 24 jam dari Pembangkit Listrik Tenaga Surya (PLTS) dan Pembangkit Listrik Tenaga Mikro Hidro (PLTMH). Hari ini, Wakil Bupati Berau Agus Tantomo dan Kepala Biro Administrasi Pembangunan Provinsi Kalimantan Timur Muhammad Ramadhan meresmikan pembangkit listrik energi bersih tersebut bersama perwakilan dari Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional (PPN/BAPPENAS), Kementerian Energi dan Sumber Daya Mineral, serta Kementerian Desa, Pembangunan Daerah Tertinggal, dan Transmigrasi. Ketiga PLTS berkapasitas total 1,2 MWp dan satu PLTMH berkapasitas 30 kW ini akan mengalirkan listrik untuk 400 rumah dan 41 fasilitas umum.

- PT Len Industri melalui anak usahanya yakni PT Surya Energi Indotama (SEI) telah mengerjakan proyek pengembangan Pembangkit Listrik Tenaga Surya (PLTS) dengan total 492 kWp di Sumba Timur. PLTS ini nantinya akan melistriki 909 rumah di area-area terpencil di lintasan sepanjang 48 km menggunakan tiang-tiang yang dapat membangkitkan listrik menggunakan panel surya yang dipasang di atasnya. Dengan desain ini, tidak lagi diperlukan lahan yang luas seperti halnya pada PLTS konvensional. Terdapat 11 sistem yang dibangun di lima desa, yaitu Tawui, Lailunggi, Praimadita, Tandula Jangga, dan Praiwitu. Program bantuan ini menjadi penting karena di daerah-daerah terpencil yang belum terjangkau perusahaan penyedia listrik, penggunaan PLTS akan mengatasi masalah ketersediaan listrik dengan biaya yang relatif terjangkau bagi masyarakat pedalaman. Pembangunan sistem oleh PT Surya Energi Indotama dilakukan pada September 2017 sampai dengan Maret 2018.

- Gubernur Kalimantan Utara (Kaltara) Dr H Irianto Lambrie mengungkapkan, pembangunan Pembangkit Listrik Tenaga Surya (PLTS) terpusat di Desa Tepian, Kecamatan Sembakung, Kabupaten Nunukan telah rampung. Rencananya, PLTS yang dibangun oleh Kementerian Energi dan Sumberdaya Mineral (ESDM) itu akan diresmikan oleh Direktur Jenderal (Dirjen) Energi Baru Terbarukan dan Konservasi Energi (EBTKE), Rida Mulyana, hari ini (9/3). PLTS ini, pada 2015 atau sejak dialihkannya kewenangan penyelenggaraan urusan pemerintahan (pilihan) bidang energi yang dibagi antara pemerintah pusat dan daerah provinsi sesuai Undang-Undang (UU) Nomor 23 Tahun 2014 tentang Pemerintahan Daerah maka usulannya disampaikan Pemerintah Provinsi (Pemprov) Kaltara melalui Gubernur Kaltara. Gubernur menyebutkan, kapasitas PLTS di kawasan tersebut sebesar 75 kilo watt peak (kWp). Untuk melayani 159 rumah di desa setempat serta fasilitas umum. “Dengan asumsi tiap rumah mendapatkan jatah 600-watt hour (Wh),” sebut Irianto, kemarin (8/3).
- Kementerian PUPR telah melakukan pemasangan sebanyak 936 panel surya berukuran 1,6 meter x 1 meter pada lereng utara Bendungan Jatibarang, Kota Semarang, Jawa Tengah pada tahun 2017. Kapasitas listrik terpasang yang dihasilkan sebesar 304,2 kilowatt-peak (kWp) atau setara 291.000 kilowatt-jam (kWh) per tahun.

Future Plan of Indonesian PV

23% RE by 2025 and 50% RE by 2050?

In term of PV:

KEN

ESDM

BPPT

860 MW by 2025?

5000 MW by 2019

6400 MW by 2025

4.2 Performance Evaluation of the First Grid-connected 1 MW PV Plants

4.2.1 PLTS Kayubihi

Indonesia is the world largest archipelago that consists more than 17,300 islands which are spread around the equator and home to 250 million people. In 2014, national grid capacity was 52 GW with energy consumption at 229 TWh [1]. Majority of power was generated from fossil-based fuels such as coal, oil, and gas with some contribution from hydropower, geothermal, and photovoltaic plants. As of 2014, national electrification ratio was 84.3% with plan to complete electrification by 2025 in which grid capacity would be around 115 GW [2].

In 2006, Government of Indonesia released National Energy Policy (NEP) 2005-2025 in view of the country’s natural resource, energy demand and access, renewable energy potential, as well as environmental protection. On this initial NEP, contribution of renewable energy for 2025 was set to 17%. According to NEP, renewable energy source consists of geothermal, hydropower, biomass, solar, wind, liquefied coal, and nuclear [3]. In 2014, NEP was revised to increase contribution of renewable energy to 23% [2].

Indonesia's potential of solar electricity is abundant with daily insolation value from 4.5 to 6 kWh/m^2. Estimated potential of solar power generation was 50,000 MW while total installed capacity to date was around 132 MW [4]. Therefore, to achieve 2025 solar generation target of somewhere in the range of 1,000 MW, Indonesia needs to develop around 800 MW PV-based power plants for the next nine years and thus an average of 70 to 80 MW additional capacity every year.

Since late 80s, photovoltaic have been used in rural areas of Indonesia where typical 50 W or 80 W solar home system (SHS) was installed by central government for lighting to replace kerosene lamps. To date, PV system are used for various application both off-grid and grid-connected systems. Off-grid application includes rural community power supply, street and billboards lighting, and remote telecommunication equipment power supply [5]. In 2013, the central government developed three pilot projects on large scale 1 MW grid-connected PV systems. One plant was installed in Kayubihi village in Bali. The pilot project was followed by the release of feed in tariff (FIT) for PV generation to attract more developer. These two programs were strategic milestone for solar electricity development in Indonesia.

Performance of grid-connected PV system is normally assessed using guidelines presented in Standard IEC 61724 [6]. The standard was issued in Europe but many countries in the world have adopted this standard for PV assessment [7]. System parameters include array yield, final system yield (Y_f), reference yield (Y_r), array capture losses (L_c), Balance of System (BOS) losses (L_{BOS}), performance ratio (PR), mean array efficiency, and overall plant efficiency. These parameters provide information in terms of energy production, solar resource, system losses, and use of capacity factor of the PV plant. Among these parameters, three parameters are considered most important; they are final yield, reference yield, and performance ratio (PR) [8], [9]. The final yield is ratio of net AC energy output of the system and nameplate power of total installed PV array at STC. The reference yield is total in-plane solar insolation (kWh/m^2) divided by array reference irradiance. The performance ratio is the final yield divided by the reference yield. It represents total losses in the system when converting from nameplate DC rating to AC output. Another parameter used to indicate performance of PV plant is capacity factor (CF). Capacity factor is defined as ratio between energy output and maximum power capacity for certain period of time and denoted in percentage [10].

Many PV plant performance around the world have been reported in the literature. IEA PVPS reported that low yield of PV plant was mainly caused by inverter failure although over time the failure rate of inverter decreases. The study also found that over rated module capacity, partial array shading and soiling had contributed to low energy performance of the plant [11]. Jahn and Nasse reported that PV plants installed in Germany over two different periods, 1992-1995 and 1996-2002, showed significant increase in their performance ratio. The first group showed an average performance ratio of 65% and the second group of 74% [12]. In Greece, performance ratio of 171.23 kW grid-connected system was reported at 67% with average capacity factor of 15% [13]. Study on 1 kW plant in Poland found that the performance ratio of the plant varied from 50% to 80% [14]. Moore *et al* reported performance ratio of 4.6 MW system installed in Springfield Colorado produced average performance ratio of 79% [15]. In South Korea, So *et al* reported performance ratio of grid-connected 3 kW system varies from

63% to 75% [16]. In, Cairo a study on 3.3 kW plant was reported by Elhodeibly *et al* to have an average daily final yield of 4.35 kWh/kW [17]. Analysis of grid-connected plant operated on varying climatic conditions in Europe and Japan for 7 up 21 years was reported by Mau and Jahn. It was found that PV plant can maintain stable performance over relatively long time, and most of performance degradation was associated with soiling of module and decreasing components efficiency [18]. Woyte *et al* reported PV plant performance analysis over the last 20 years and concluded that performance ratio had increased from 65% to 85% [19] and similar report on performance ratio and their improvement was also discussed in [20]. A recent publication by Hamzeh *et al* reported performance ratio of 87.5% from PV plant installed in Jordan and Syria [21].

Various tools have been developed to simulate energy production of PV system to provide information regarding plant's performance. IEA PVPS published report on worldwide available tools for estimating energy production and performance of PV system. This report discuses tools for assessing performance of PV system in different configurations such as grid-connected, hybrid system, and system with battery storage [22].

The work reported on this paper was the result of study through simulation, monitoring, and observation on the operation of 1 MW grid-connected PV system in Kayubihi village in Bali. Simulation using PVSyst was conducted to estimate annual energy production and performance indicators. To reflect the effect of on-site shading, this factor was measured using Suneye Solmetric tool. The actual energy production was recorded by on-site computer-based data monitoring system.

The 1 MW grid-connected photovoltaic system in Kayubihi village begun to operate on February 2013 and since then data such as voltage, current both AC and DC, energy and other variables used for analyzing the performance of the system have been recorded using computer-based monitoring system. Site observation and measurement were carried out to obtain actual systems installation and configuration, location condition, and other factors that affect operation hence performance of the plant. One factor that affect performance of PV plant is the existence of shading from neighboring structure or objects. For this purpose, shading index of the location was measured using Suneye Solmetric tool which provide information on solar access of the site.

Annual energy production together with other performance indicators were estimated using PVSyst. This simulation tools uses historical meteorological condition to calculate output of the PV systems. Input meteorological data for Kayubihi village, was taken from NASA-SSE available from the PVSyst. The performance of the plant was then assessed using guidelines presented on the IEC 61724.

The 1 MW Kayubihi PV plant is a grid-connected plant with no power storage facility hence its output is directly injected to 20 kV utility grid. The system is controlled using voltage reference derived from the utility hence it only works if the utility grid is on. The PV array is fixed and tilted at 15^o which is an optimum tilt angle for the location. Schematic of the plant is shown in Figure 1. The total number of modules is 5,004 units of 200 W mono crystalline module developed by Indonesian semiconductor company. Dimension of the PV module is 806 mm x 1567mm. 18 numbers of modules are connected in series to form string arrays to match voltage input of inverter. 50 units of 20 kW inverter is used to convert arrays' DC output into 230/400 V AC, 50 Hz. Five units of 250 kVA step up transformers are used to connect inverters' output to 20 kV utility distribution network. Further technical specification of Kayubihi PV plant can be found here [23].

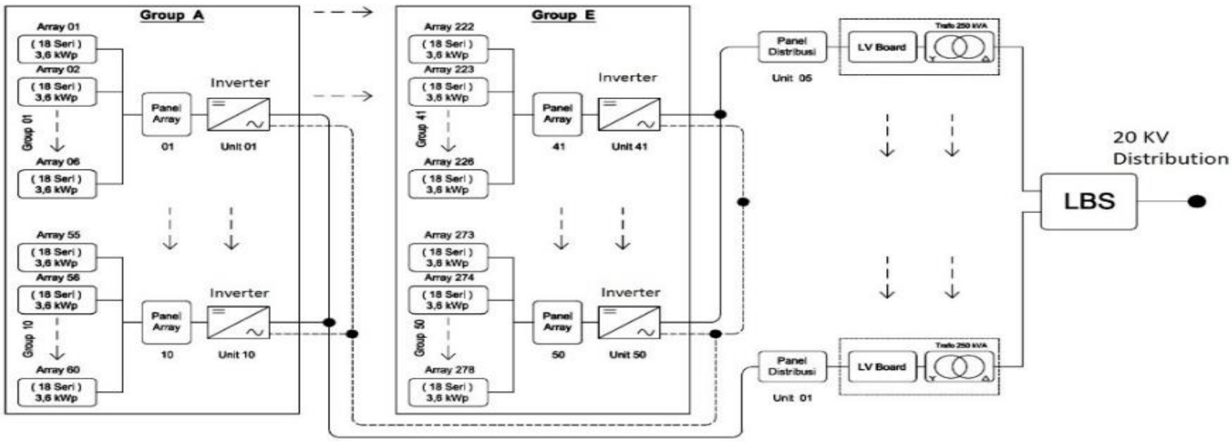


Figure 21 Schematic of 1 MW Kayubihi PV plant

The village of Kayubihi is located in the southern hemisphere with GMT +8 time zone and 870 meter above sea level. Climate of the area is classified as medium wet type with annual rainfall from 900 to 3,500 mm. The site is part of waste disposal area of the district with total area of 18,450 square meter. Around 8,700 square meter is used for installing PV arrays. The site is surrounded by green vegetation. There are also buildings on site that already exist prior installation of the plant as it was previously used for district dumping site. Satellite snapshot of the site taken from Google earth is shown in Figure 2.

Figure 22 Satellite image of 1 MW Kayubihi PV plant site

The shading of Kayubihi PV plant comes from vegetation such as tree, bushes and also on-site buildings. Figure 3 shows result of shading measurement using Suneye tools. The measurements were conducted at three different points. The location of the measurement was the triangle points of PV arrays' layout as shown in Figure 2. This shading measurement generate solar access information. An all year round fully-shaded module will have 0% solar access but a clear no-obstruction site will result in 100% solar access. The average solar access varied from 80% to 93% and with average of 88%.

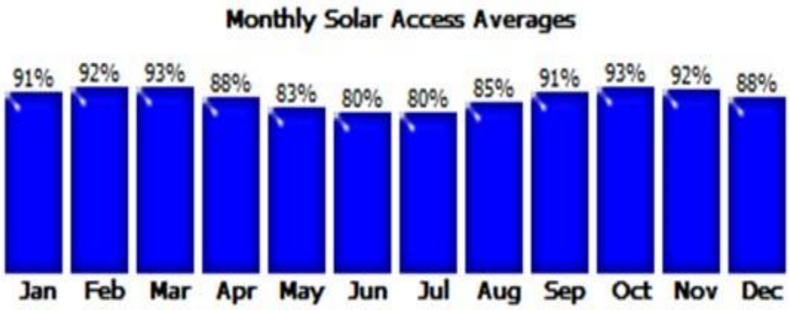


Figure 23 Average monthly solar access of Kayubihi PV plant

The PV arrays is mounted on the ground using fix-tilted galvanized metal structure with around 70 cm ground clearance at the lower end and around 200 cm at the upper end. Figure 4 shows picture of the plant taken facing the upper end.

Figure 24 Array installation of 1 MW Kayubihi PV plant

Input variables for PVSyst is geographical profile of PV location, technical specification of the plant, optional shading measurement, and meteorological data. The meteorological data was using NASA-SSE satellite data which hold historical data for many parts of the world since 1995 – 2005. Simulation results is shown in Table 1.

Table 7 Simulation of 1 MW Kayubihi PV plant

Period	GlobHorz kWh/m^2	T amb ^{o}C	GlobInc kWh/m^2	GlobEff kWh/m^2	E-Array MWh	E-Grid MWh	Eff Arr R %	Eff Sys R %
Jan	152.70	26.70	140.00	114.00	100.60	98.00	11.31	11.01
Feb	141.00	26.70	134.50	109.30	96.70	94.30	11.31	11.03
Mar	168.30	26.60	168.60	138.60	122.40	119.50	11.42	11.15
Apr	161.60	26.90	171.40	138.60	121.80	118.90	11.19	10.91
May	160.80	26.80	178.60	143.30	126.00	123.00	11.10	10.84
Jun	145.20	26.40	166.30	132.00	116.30	113.50	11.00	10.74
Jul	148.40	25.80	166.90	131.90	116.80	114.10	11.01	10.75
Aug	165.20	25.40	178.40	143.70	127.30	124.30	11.22	10.96
Sep	178.50	25.50	182.80	154.50	136.70	133.50	11.77	11.49
Oct	191.90	26.00	185.70	158.80	140.20	137.00	11.88	11.60
Nov	170.00	26.40	156.90	129.40	114.80	112.10	11.52	11.24
Dec	163.60	26.60	148.60	121.70	108.20	105.60	11.46	11.18
	1,947.20	26.32	1,978.70	1,615.80	1,427.80	1,393.80	11.35	11.08

Global horizontal irradiance or GlobHorz is the total irradiance received by a horizontal surface on earth. For Kayubihi PV plant, GlobHorz varied with minimum and maximum values of 141.0 and 191.9 kWh/m^2 respectively. The global incident is the irradiance received by a tilted surface on earth and its value is affected by direct beam, diffused, and ground reflected irradiance as well as the configuration of array whether it is fix-tilted angle or using sun tracking mechanism. The GlobInc on Table 1 shows the irradiance received by the array varied from minimum value of 134.5 kWh/m^2 during February to maximum value of 185.7 kWh/m^2 during November. The irradiation that effectively reaches PV arrays and corrected for shadings and the incidence effect (IAM) is denoted as GlobEff. The global effective irradiance varied from 109.3 kWh/m^2 to 158.8 kWh/m^2. Electrical energy at the array's output is denoted as EArray which varied from minimum value of 96.7 MWh during February and maximum value of 140.2 MWh during October. Annual array's energy output is 1,428 MWh. And finally, the monthly electrical energy injected into the grid, considering losses, varied from 94.3 MWh to 137 MWh, which produce annual grid-injected energy to 1,394 MWh.

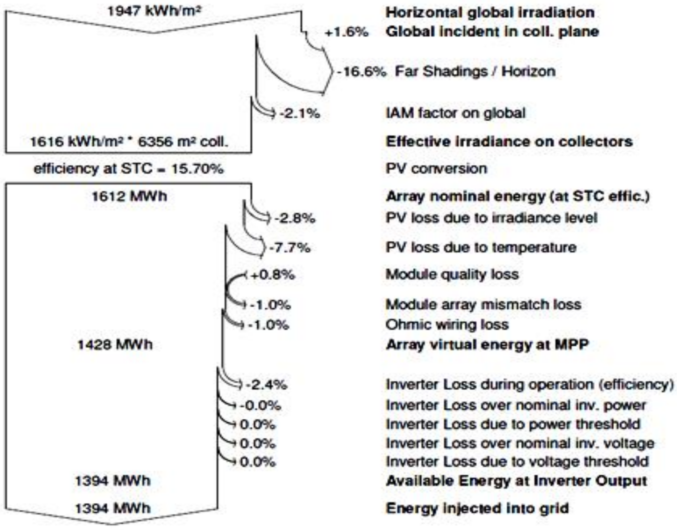


Figure 25 Simulated flow of energy and losses of Kayubihi PV plant

Figure 5 shows the flow of energy and losses of Kayubihi PV plant, from 1,947 kWh/m^2 horizontal global irradiation and after corrections for shadings, incidence effect, losses due to irradiance level, module temperature, module array mismatch, ohmic resistance, and inverter loss, the plant inject energy of 1,394 MWh into the grid.

The actual energy production of Kayubihi PV plant is shown in the Table 3. The plant begun to operate on February 2013 and it continued to operate until December 2013 with no major problems. But during 2014, it experienced various set back due to inverter's problem, lightning strikes, soiling, increasing shading from surrounding vegetation, and non-technical problems which led to lower energy production than the previous year. Actual energy production recorded from February to December 2013 is shown in column #2. To get idea of a full 12 months operation then the production of January 2014 is added to 2013 and is shown in column #3. Energy production throughout 2014 is shown in column #4. There is no data for 2015 operation due to failure on the data monitoring system hence column #5 has no values. Another scenario is to use the best month production out of 23 months data available to construct maximum annual energy output of the plant and this is shown in column #6.

Table 8 Actual energy production of Kayubihi PV plant

Month	2013 (11m: Feb to Dec) (MWh)	2013 (12m: Jan to Dec) (MWh)	2014 (MWh)	2015 (MWh)	Best Month (MWh)
Jan	-	87.97	87.97	NA	87.97
Feb	49.70	49.70	56.68	NA	56.68
Mar	146.20	146.20	79.34	NA	146.20
Apr	182.10	182.10	45.99	NA	182.10
May	150.10	150.10	85.25	NA	150.10
Jun	45.60	45.60	83.60	NA	83.60
Jul	40.90	40.90	72.58	NA	72.58
Aug	78.80	78.80	47.09	NA	78.80
Sep	111.60	111.60	65.66	NA	111.60
Oct	135.60	135.60	60.52	NA	135.60
Nov	80.20	80.20	5.79	NA	80.20
Dec	69.90	69.90	36.38	NA	69.90
Total	**1,091**	**1,179**	**727**	**NA**	**1,255**

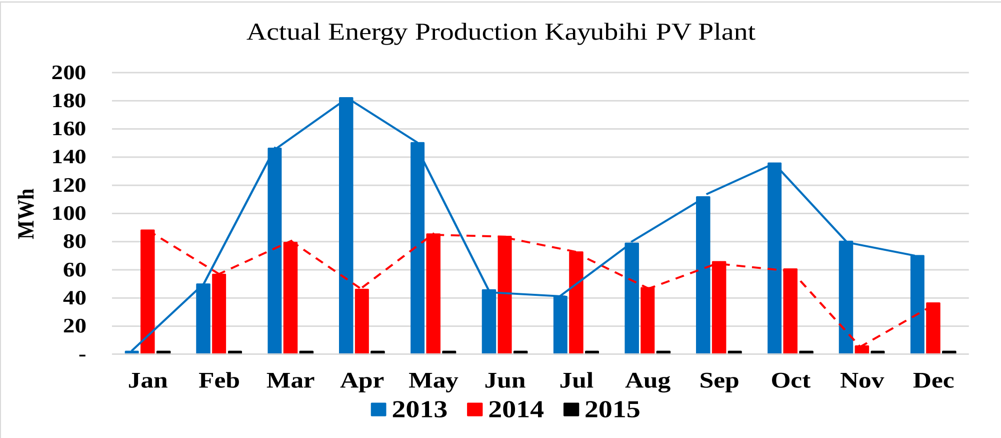


Figure 26 Actual energy production of Kayubihi PV plant

Table 3 shows that monthly energy production of the plant varied considerably and from the two years data, monthly minimum and maximum energy production is 45.6 MWh and 182.1 MWh respectively.

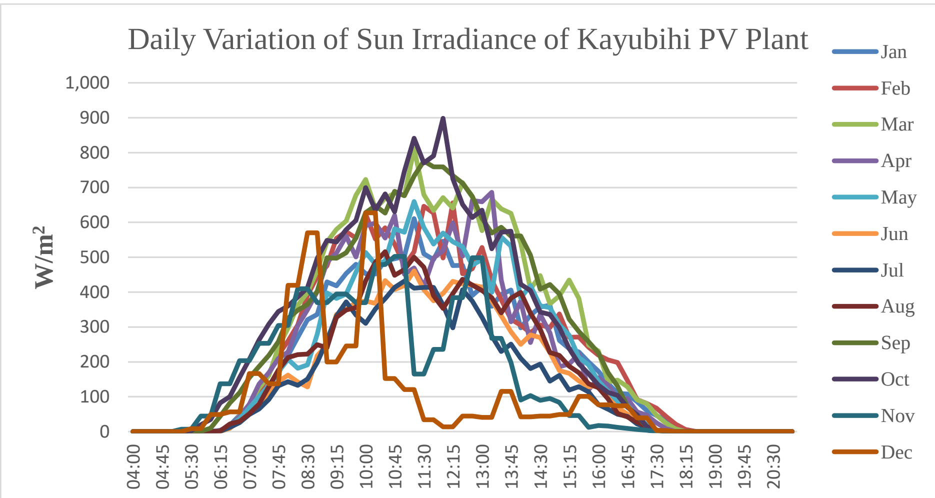


Figure 27 Measured 24 hour sun irradiance of Kayubihi PV plant

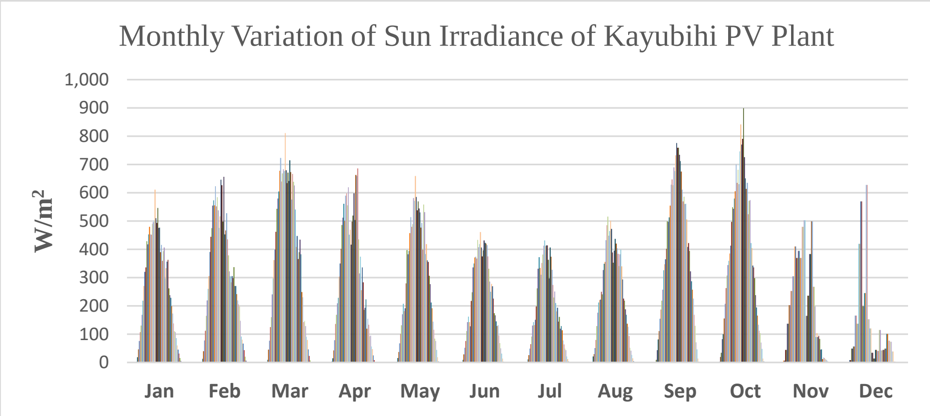


Figure 28 Measured sun irradiance of Kayubihi PV plant

Figure 7 shows average of sun irradiance or sun power measured at the plant's location with annual average of 284.3 W/m^2. The sun irradiance was measured using pyranometer positioned at horizontal with respect to ground surface therefore measuring Global Horizontal Irradiant (GlobHorz). According to IEC 61724, it is necessary to measure irradiance on the array plane to asses performance of the plant. This measured GlobHorz however still provides indicator on how the sun power was received at the plant's site. Figure 8 shows GlobHorz at the plant and energy output in 2013 both measured and simulated values.

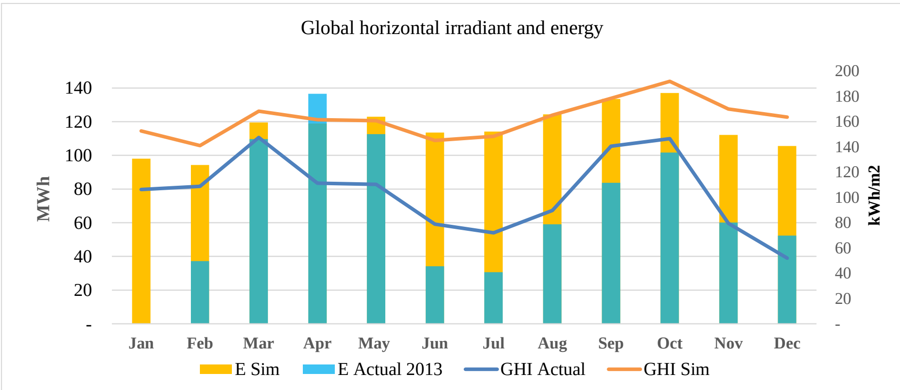


Figure 29 Global horizontal irradiance and energy production 2013

The simulated GlobHorz is much higher than actual value received on site and consequently energy production also follows similar pattern, where the simulated energy is greater than actual output of the plant. However, the two variables are relatively in agreement in which they follow similar trends.

Performance ratio of PV plant as described in IEC 61724, provide information on how PV plant produce actual energy from theoretically available energy. It is nearly independent on the location and system size and indicates the overall effect of losses due to module temperature, incomplete utilization of irradiance, and systems' component efficiencies or failures. The monthly performance ratio based on the simulation is presented in Table 2. The value varies from 0.682 to 0.737 giving average performance ratio of 70.5%.

Table 2. Simulated performance indicators of Kayubihi PV plant

Table 9 Simulated performance of Kayubihi PV plant

Period	Yr kWh/m^2·day	Lc	Ya kWh/kWp/day	Ls	Yf kWh/kWp/day	Lcr	Lsr	PR
Jan	4.51	1,272.00	3.24	0.085	3.16	0.282	0.019	0.699
Feb	4.80	1,353.00	3.45	0.085	3.37	0.282	0.018	0.701
Mar	5.44	1,494.00	3.94	0.093	3.85	0.275	0.017	0.708
Apr	5.71	1,654.00	4.06	0.098	3.96	0.290	0.017	0.693
May	5.76	1,699.00	4.06	0.097	3.97	0.295	0.017	0.688
Jun	5.54	1,670.00	3.87	0.091	3.78	0.301	0.016	0.682
Jul	5.39	1,621.00	3.76	0.088	3.68	0.301	0.016	0.683
Aug	5.76	1,654.00	4.10	0.095	4.01	0.287	0.017	0.696
Sep	6.09	1,537.00	4.55	0.107	4.45	0.252	0.018	0.730
Oct	5.99	1,470.00	4.52	0.106	4.41	0.245	0.018	0.737
Nov	5.23	1,404.00	3.82	0.092	3.73	0.269	0.018	0.714
Dec	4.79	1,303.00	3.49	0.085	3.40	0.272	0.018	0.710
	5.42	**1,510.92**	**3.91**	**0.094**	**3.81**	**0.279**	**0.017**	**0.703**

With the absent of global irradiance incident measurement, actual performance ratio of the plant is then obtained using simulated effective global sun irradiant or GlobEff. The performance ratio is calculated based on total energy injected to the grid and anticipated energy production for one year. The anticipated energy is calculated using sun irradiant of 4.34 kWh/m^2 for the entire generator area and with the PV module conversion efficiency [6], [24].

$$PR = \frac{Energy\ injected\ to\ the\ grid\ (MWh)}{Anticipated\ energy\ production\ (MWh)} x\ 100\% \ldots\ldots\ldots\ldots\ (1)$$

$$Anticipated\ energy\ = sun\ irradiant\ x\ PV\ area\ x\ module\ efficiency \ldots\ldots\ (2)$$

Generator area of the plant is obtained by multiplying the total number of PV module with individual area of the module and found at 6,320.06 m^2. Using equation (1) and (2), and actual energy output, the performance ratios are presented on Table 3.

TABLE 10 Actual performance ratio of Kayubihi PV plant

<table>
<tr><th>Case #</th><th>Injected Energy (MWh)</th><th>Sun irradiant (kWh/m^2/day)</th><th>Generator Area (M^2)</th><th>Module Efficiency (%)</th><th>Anticipated Energy (MWh)</th><th>Performance Ratio (%)</th></tr>
<tr><td>2013 - 11 months (actual)</td><td>1,090.70</td><td rowspan="4">4.34</td><td rowspan="4">6,320.06</td><td rowspan="4">15.00%</td><td rowspan="4">1,501.74</td><td>72.6%</td></tr>
<tr><td>2013 - 12 months (uses Jan 2014)</td><td>1,178.67</td><td>78.5%</td></tr>
<tr><td>2014 (actual)</td><td>726.85</td><td>48.4%</td></tr>
<tr><td>Best 12 months from 2013 and 2014</td><td>1,255.33</td><td>83.6%</td></tr>
</table>

It is shown on Table 4, actual performance ratio of the plant varied from 72.6% in 2013 to 48.4% in 2014. The PR value for 2013 is quite close with the performance ratio obtained using PVSyst. However, PR value for 2014 is very low which indicates problem occurred. Through site observation and interview with the operator, it was noted that in 2014 the site received lightning strike which affected the plant although lightning protection is on site. It was also found that some inverters did not work properly due to quality of installations or substandard components. It is also observed that soiling and shading from the growing vegetation have contributed to the lower energy production.

To have indication on how the plant might have been performed for one full year, the 2013 output is added with plant's output of January 2014. With this, the plant has better performance ratio of 78.5%. This PR figure is perhaps more representative of the plant's performance as it reflects current PV technology status in which higher performance ratio is expected due to generally better components hence higher efficiency. And to get insight over maximum potential performance ratio of the plant, the best 12-month actual energy output were selected which give performance ratio of 83.6%. This figure suggests that if Kayubihi PV plant is well maintained so it works properly then higher energy output is certainly possible.

On this paper, simulation to estimate performance of 1 MWp Kayubihi PV plant has been presented and found the annual energy output is 1,394 MWh. Correspondingly, the system's yield is 3.82 kWh/kWp/day and reference yield of 5.42 kWh/m^2/day which result in performance ratio of 70.4%.

The highest actual energy output of Kayubihi PV plant was in 2013 in which the plant produced total energy of 1,091 MWh for 11 months and so resulting in performance ratio of 72.6%. A full 12-month scenario of 2103 gave energy production of 1,178 MWh and resulting in performance ratio of 78.5%. Further, if the best monthly energy production were to use to make up the annual energy output, then the plant could have produced annual energy of 1,255 MWh resulting in potential performance ratio of 83.6%.

The 1 MW Kayubihi PV plant has been in operation since January 2013 and worked relatively well until December 2013. During, 2014 operation, the plant experienced various setbacks due problems associated with reliability of inverters, soiling, shading and other non-technical problems which led low energy production. The 2015 operation was no different than the previous year and added with failure of the data monitoring system to record data. The plan to rectify the problem was scheduled for 2016. Nevertheless, the 1 MW Kayubihi PV plant has provided experiences both on technical, non-technical aspects of PV development and including management of large scale grid-connected PV plant in Indonesia.

4.2.2 PLTS Karangasem

Being in tropical belt presented Indonesia with huge potential of solar electricity generation. Average daily sun irradiant is estimated around 4.8 kWh/m^2 (Hermawan & Hadi, 2006). This index solar radiation combined with a large land area of around 1,922,570 square kilometers that make up one-third of Indonesia total area (Ikawati & Setiawati, 2009), offers a huge potential for renewable solar electricity generation. Off-shore photovoltaics has also been developed elsewhere in the world (Kyocera, 2013) and in this context, Indonesia has large inland water, a great length of coastline, and sea surface area which are potential for photovoltaics sittings. Around 112 GW electric power could be generated through photovoltaic conversion in Indonesia (Hutapea, 2015).

According to National Energy Policy, Indonesia has planned to achieve photovoltaic generation capacity between 800 to 1,000 MW by 2025 (Priyanto, 2013). Meanwhile, the current total photovoltaic capacity is 77 MW (Rosyid, 2015). Comparing these two figures implies a huge task to develop around 800 MW photovoltaic plant within the next nine years; around 80 MW new plants every year until 2025. Currently, most of the existing photovoltaic plants were developed by governments in the form of small solar home system (SHS), and microgrid or off-grid rural electricity supply. The more recent development is the installation of grid-connected plant as pilot projects for large-scale photovoltaic integration. On February 27th, 2013, Ministry of Energy and Mineral Resources officially turned on the first 1 MW grid-connected photovoltaic plant in Indonesia. The power plant is located in Kubu village, District of Karangasem in the eastern of Bali around 80 kilometer east of Denpasar city, the capital of

Bali. It is predicted the plant could generate around 5.15 MWh energy every day (DIRJEN EBTKE, 2013). After testing and commissioning, the plant is granted to local government (Kumara , et al., 2013).

Over more than three decades of photovoltaic application in the country, there has been little information regarding how each of the plant performed in terms of energy production and performance ratio. The role of data monitoring and performance assessment on photovoltaic plant are very important. To assess the performance of a plant, a dedicated computer-based monitoring system is required to monitor and record various electrical parameters of the power plant. The type of data, hardware specification, including performance indexes associated with photovoltaic plant is governed in IEC XXXX.

Photovoltaics plant's output is greatly affected by local environmental factors such as sun irradiant, and to some degree by ambient temperature, module temperature, and wind speed. Indonesian climate according to Koppen-Geiger is mostly classified as tropical Af but the south-eastern area is classified as Aw (Kottek, et al., 2006). Most part of the country has average annual rainfall between 1,500 to 4,500 mm (BMKG, 2012). Only small areas receive rainfall of less or in excess of those ranges. The average temperature varies from 14.4^{o} to 39.9^{o}C (BMKG, 2015). Indonesian National Institute of Aeronautics and Space reported that wind speed is very low to moderate except the eastern part which has wind speed from 3.2 up to 6.5 m/s.

This paper presents energy production of 1 MW grid-connected photovoltaic plant located in Karangasem District of Bali. The energy output is obtained from simulation and actual energy output taken from plant's data monitoring system. Also, measured injected energy to the grid is presented. The paper also reviews technical aspects of the plant and environmental profile of location. A qualitative discussion is presented on how environmental factors might have affected plant's actual energy production.

This subsection reviews the 1 MW Karangasem photovoltaic plant to get insight into technology, components, and other technical data of the power plant. The motivation of the review is also to provide quick reference and document archive of plant's technical information.

Schematic of 1 MW Karangasem photovoltaics plant is shown in Fig. 1. Its main components are photovoltaic array, inverter, and step up transformer. The plant uses 5004 modules which are grouped into 278 arrays. The string array is formed by combining 5 or 6 arrays. For conversion from DC power to AC system, the plant uses 50 inverters off which 22-unit is fed by 5 arrays string and 28-unit is fed by 6 arrays string. The output of inverter is fed to 5 units of step up transformers to increase plant's voltage to match utility's 20 kV voltage system. At the end of the connection, a motorized load-break-switch (LBS) is installed to connect the plant to the utility network. Summary of technical specifications of the plant's components is shown in Table 11 (PT LEN, 2010), (Sungrow, 2014), and (PT Schneider, 2015). The photovoltaic module is of the monocrystalline type with 200 W maximum output. 18-modules are series-connected to form single array to match inverter's input voltage range. Further, either 5 or 6 arrays is parallel-connected to match input power of the inverter. Each module is equipped with Schotky bypass diode to minimize the effect of partial shading.

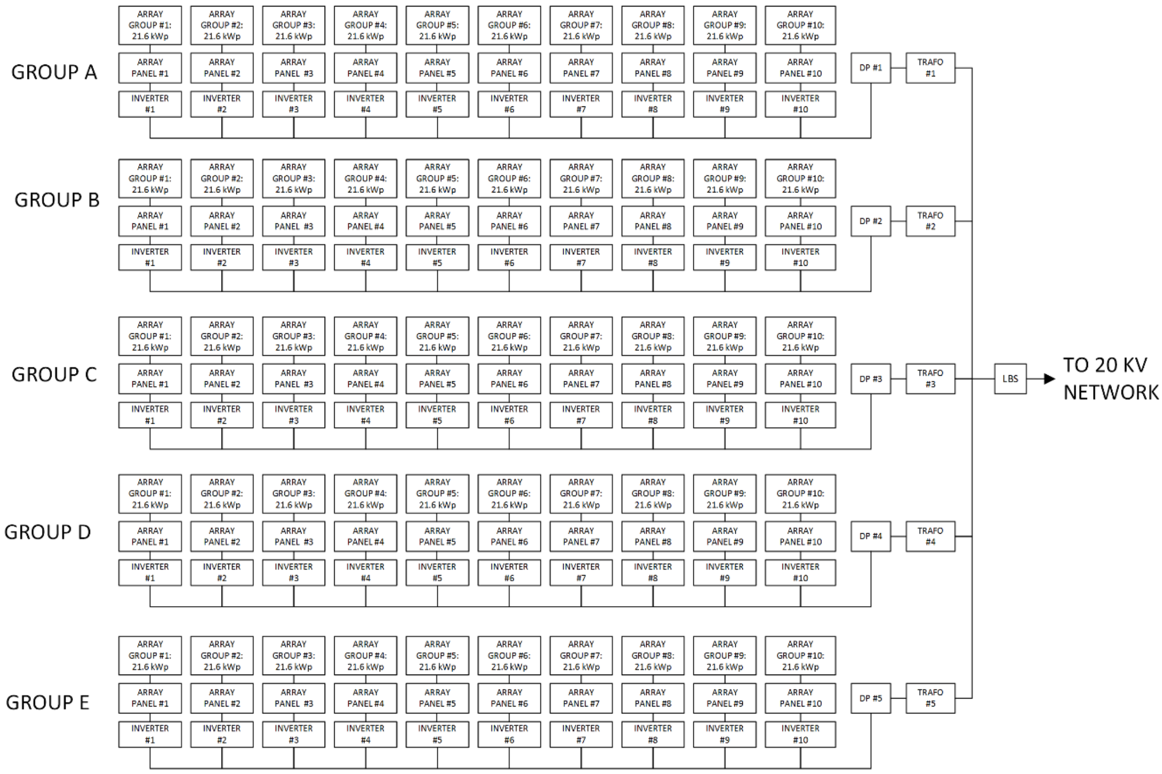


Figure 30 Schematic of 1 MW Karangasem photovoltaics plant

Fig. 1

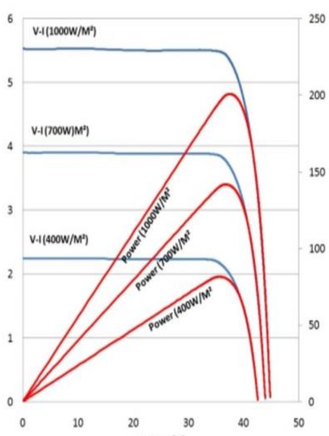
The inverter uses the phase-locked-loop technique to synchronize its output with grid's voltage which also works as a voltage reference. If the grid is off either due to faults or scheduled maintenance then inverter will be off too, hence no power is injected into the grid.

Table 11 Summary of technical information 1 MW Karangasem photovoltaics plant

PV Module Electrical Characteristics	
Optimum Operat. Voltage (Vmp)	37.4 V
Optimum Operat. Current (Imp)	5.3 A
Open Circuit Voltage (Voc)	44.2 V
Short Circuit Current (Isc)	5.5 A
Maximum Power at STC (Pmax)	200 W
Operating Module Temperature	-40ºC to +85ºC
Maximum System Voltage	1000 V DC
Power Tolerance	< 3%

PV Module Mechanical Characteristics	
Solar Cell	Mono-crystalline
No of Cells	72 (6 x 12)
Dimensions	1576 x 806 x 50 mm
Weight	16.5 Kg
Junction Box	IP65
Constructions: Front: high transmission low-iron 3.2 mm tempered glass; back: Tedlra/ TPE/ TPT encapsulated; Frame: anodized aluminium alloy	

PV Module I-V and P-V Curve at 25ºC



TRANSFORMER DC Side: Electrical Characteristics	
Max DC Voltage	1,000 V
Min DC Voltage	280 V
MPP Voltage Range	480 to 800 V
Max Input Power (per MPPT)	21 kW (10.5 kW)
Rated DC Power	20.4 kW
Rated DC Voltage	650 V
Max Input Current	42 A (21 A*2)
Max Input Current per string	10 A

TRANSFORMER AC Side: Electrical Characteristics	
Rated Output Active Power (Pnom)	20 kW
Max Output Reactive Power (Qmax)	10 kVAR
Max Output Apparent (Smax)	22.2 kVAR
Rated Output Phase Current	28.87 A
Rated Output Voltage	3/N/PE, 230V/400V
Rated Output Frequency	50 Hz
Output Current THD	<3% at nom. power
Max Efficiency	98.0 %

TRANSFORMER Mechanical Characteristic	
Enclosure	IP54 (fans), IP65 (others)
Safety Class	I
Wet Location	Yes
Ambient Temp.	-25ºC to 60ºC (>45ºC derat.)
Relative Humid.	0 to 90%, non-condensing
Cooling	Controlled force air cool.
Max Altitude	4000m derat. >2000m
Weight	55 kg

Step Up Transformer	
Rated Power	250 kVA
Rated Frequency	50 Hz
Input Voltage	380 V
Output Voltage	20 kV
Type of Cooling	ONAN
Installation	Indoor/Outdoor

Load Break Switch	
Model	RL 27
Rated Continuous Current	630 A
Rated Full Load Operation	600 A
Mechanical Operations	3,000
Ambient Temperature	-10ºC to +50ºC
Radiation max	1.1 kW/m^2

Environmental Monitoring	
Wind Speed/ direction	0 to 96 m/s/ 0 to 360
Speed Tolerance	+/- 0.1 m/s
Radiation Spectral	300 to 3000 nm
Sensitivity Solar Sensor	7 to 14uV/Wm^2
Temperature Sensor Range	-55ºC to +125ºC
Sensitivity of Temp. Sensor	+/- 0.1ºC

Karangasem photovoltaics plant is located at -8.25 south latitude and 115.56 east longitudes. The array is ground-mounted supported by galvanized steel support structure. The low side of the array is around 70 cm from the ground surface and the high level is around 200 cm from the ground. As it is located in southern hemisphere then array should be oriented north. Also, photovoltaics array should be tilted from the ground surface to allow for optimum capture of sun power. Calculation of array tilt angle is described by Masters and using this formula the angle is found at 15^{o} (Masters, 2013). On-site measurement confirmed the actual tilt angle of the array. Also, the actual array is north oriented, so from these two basic conditions, the plant is in its optimum configuration. **Error! Reference source not found.** shows photo of the Karangasem PV arrays. **Error! Reference source not found.** shows the plan layout of Karangasem PV plant (PT SEI, 2013).

Figure 31 Array of Karangasem PV plant

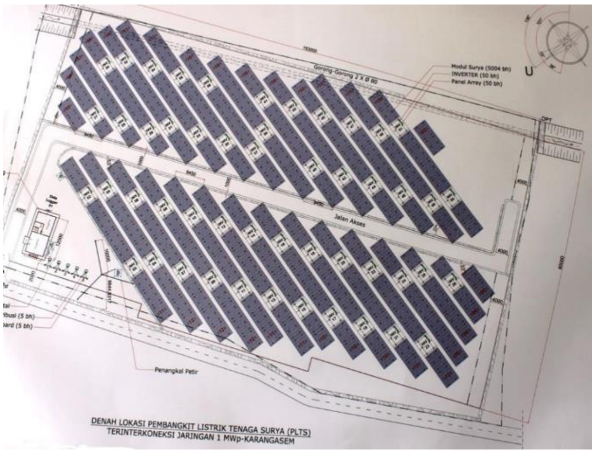


Figure 32 Plan layout of Karangasem PV arrays

The site of Karangasem photovoltaics plant is located 76 meters above sea level. Based on Koppen-Geiger classification, the climate of the area is classified as tropical. Weather parameters such as annual rainfall, the number of rain days, ambient temperature, humidity, and wind speed of the district are presented in Table 12. These secondary data are obtained from local meteorological office and the office of bureau statistics.

Table 12 Weather record compiled from BMKG publication

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	440	353	142	156	14	5	227	8	1	0	51	401
Number of rain days (day)	22	24	8	10	5	3	11	8	1	0	6	16
Min. Temperature (oC)	23	23	23	24	24	24	23	23	23	24	25	24
Max. Temperature (oC)	30	29	31	31	31	30	29	29	30	32	32	30
Average	26	25	26	27	27	26	26	26	26	28	29	27
Humidity (%)	86	87	81	85	86	84	75	73	68	66	71	83
Sun duration (%)	36	36	66	63	61	54	68	88	95	95	85	36
Wind speed (Knot)	6	5	7	7	7	7	7	8	10	9	7	7
Air pressure (mbar)	1010	1010	1011	1011	1012	1012	1014	1014	1014	1014	1012	1010

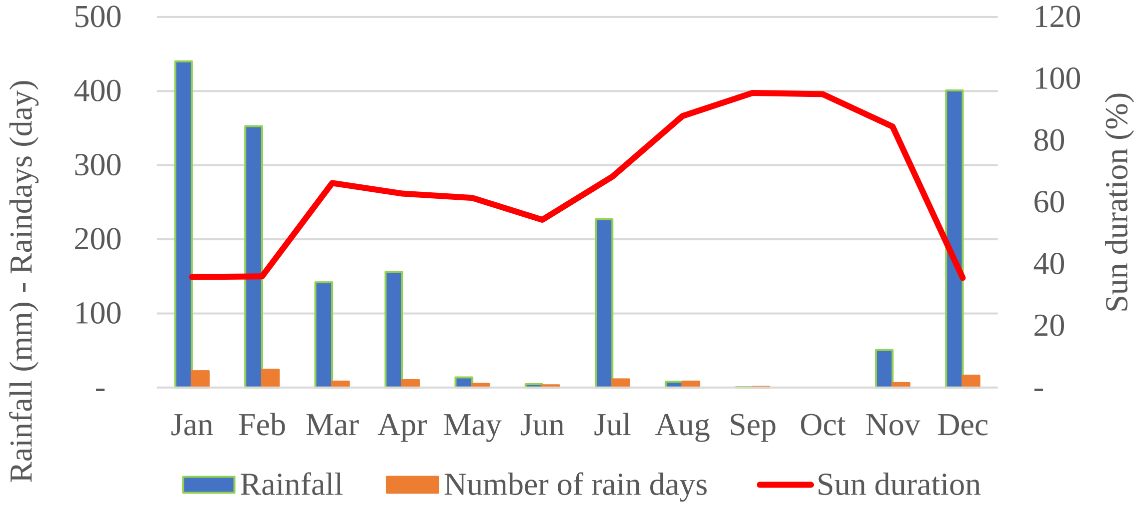
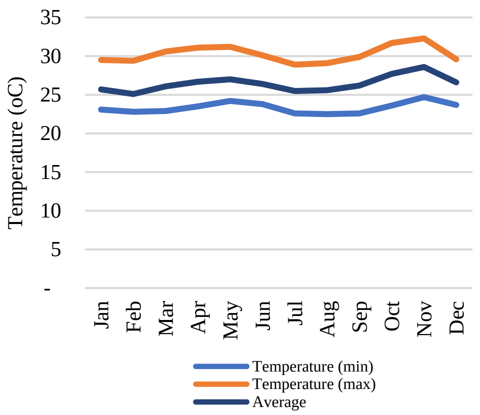
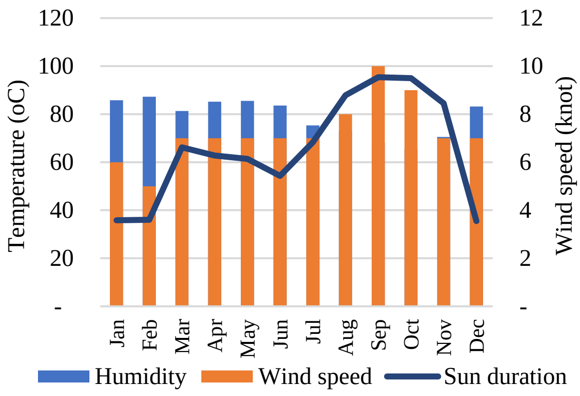
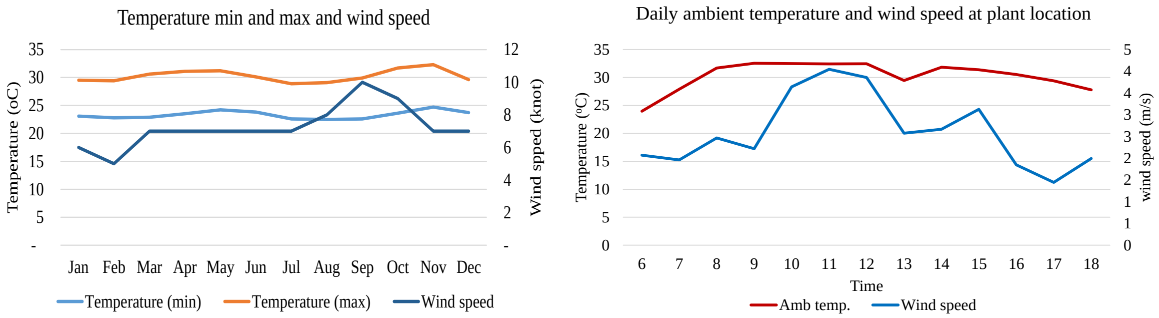


Figure 33 Rainfall, rain days and sunshine index near Karangasem

From **Error! Reference source not found.**, it can be seen that rainfall in the area varies considerably from 0 mm to 440 mm. The peak of rain occurs in January and peak of dry occurs in October. Rain is associated with clouds and hence its present is not conducive for photovoltaics production. With relatively small amount of rainfall suggests that energy production is likely high during low rainfall periods and low during high rainfall periods. Tropical climate also brings about the good environment for vegetation as well as birds or other animals to inhabit the area surrounding the power plant. Consequently, shading from nearby trees or bushes, fallen branches, birds' droppings, and animal could also roam the area to create deposits on arrays or partial shading which in turn affect plant's production.







(a) (b)

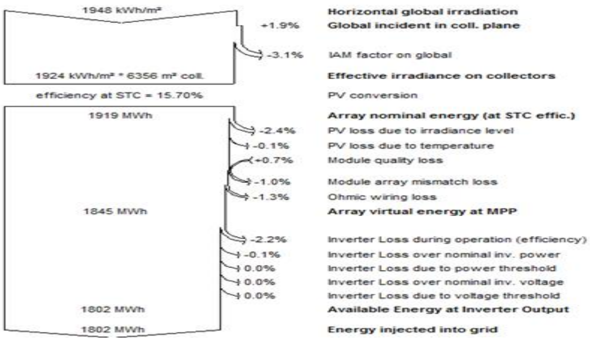
Figure 34 Weather parameters at power plant

Based on Fig. 3, one could expect that energy production would be high during May, June, July, August, September, and October. In contrast, low energy production is expected to occur during December, January, February, or March. In Fig. 4 (a), it is shown that temperature is relatively stable all year round. Wind speed also shows a similar trend with slight higher wind speed during August, September, and October. Based on the two graphs, Fig. 3 (b) and Fig. 4 (a), high sun duration means greater sun power and higher wind speed which means better cooling effect, and if these factors work together then it would lead to peak energy output which could occur in September or October. Fig. 4 (b) confirms the agreement between data taken from the meteorological station and actual on-site measurements. The weather station is located away from plant's location but the two data shows a close agreement. Weather data which is easily available from meteorological office throughout Indonesia could be used to get insight over energy production of photovoltaics plant.

PVSyst is used to simulate energy output of the power plant. Detail of this tool and other platforms available for predicting energy production and performance of photovoltaic plant is discussed in a report published by IEA-PVPS, (IEA-PVPS, 2011). The simulator uses historical meteorological data designated as NASA SSE. Other data inputs are the technical specification and geographical position of the plant. Results of the simulation are presented in Fig. 5. Simulation yielded plant's annual output 1802 MWh with monthly production varies from minimum 121 MWh to maximum 169 MWh, hence the monthly average of 150 MWh or 4.94 MWh daily. Month to month energy production varies moderately and with peak production occurred during October. The period of low energy production occurred during November, December, January, and February which is within the rainy season of the country.

Month	Sim - Energy (MWh)	Sim - GlobHorz (kWh/m^2)	Sim - T ambient (^oC)	Act - Energy (MWh)	Act - T ambient (^oC)
Jan	125	153	27	49	29
Feb	121	141	27	48	29
Mar	153	168	27	53	31
Apr	156	162	27	123	31
May	166	161	27	132	31
Jun	153	145	26	125	30
Jul	153	149	26	104	29
Aug	165	165	25	147	30
Sep	167	179	26	135	31
Oct	169	192	26	138	32
Nov	141	170	26	99	33
Dec	133	164	27	42	28

(a)



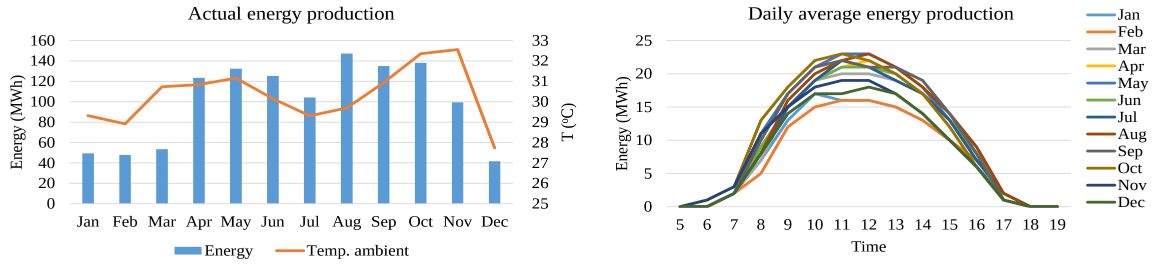
(b)

Figure 35 Simulated and actual output of 1 MW Karangasem photovoltaics plant

The simulated figure of the global horizontal index of sun irradiant varied from minimum 141 to 191 kWh/m^2 with monthly average 162 kWh/m^2 or daily average 5.34 kWh/m^2. Based on this data, month of December, January, and February has lower energy output among other months and a similar situation for June and July. Energy production moderately varies from month to month with 8.9% variation from the average of 150 MWh. A relatively stable energy production is due to the absent of site conditions and environmental parameters on the simulation. Variation of local weather, site conditions, and plant's reliability are not accounted on the simulation, while many have studied the effect of these factors over plant's energy production. Factors that affect energy production include local temperature (Rahman, et al., 2014), shading (Sharma, et al., 1991), arrays condition (Mani & Pillai, 2010), and non-technical factors (Zahedi & Hallenstain, 2007).

Fig. 5 (b) shows losses schematic of the plant simulated performance, from horizontal global irradiance of 1984 kWh/m^2 to become effective irradiance on the collector of 1924 kWh/m^2. Photovoltaic conversion at STC with 15.7% module efficiency and a collector area of 6,356 square meters is 1919 MWh. And after considering photovoltaic losses due to irradiance level, photovoltaic loss due to temperature, module quality loss, module array mismatch loss, and ohmic wiring losses, it produces array virtual energy at maximum power point (MPP) of 1845 MWh. Finally, after taking into account inverter's losses, the available energy at inverter output is 1802 MWh. If then further assumed that the step up transformer carries 98% efficiency then the annual energy injected into the grid is 1766 MWh.

The actual energy output of the plant is recorded using computer-based monitoring system which measured electrical parameters of the power plant. Guidelines for photovoltaics plant monitoring which covers the type of data and hardware requirements are specified in BS EN 61724 (1995). Results of energy monitoring for 2014 is shown in Table 3. Annual energy production of the plant is 1180 MWh. Energy output varies from minimum 42 MWh to maximum 147 MWh with a monthly average of 98 MWh. Graph of energy production is shown in Fig. 6. It is clearly shown that energy production varies considerably from month to month according to the level of sun power received on-site. One measure of sun power level received on-site is ambient temperature; the more sun power hence the higher the temperature. Plotted with ambient temperature, Fig.6 (a) shows the fluctuation of plant's energy output.



(a) (b)

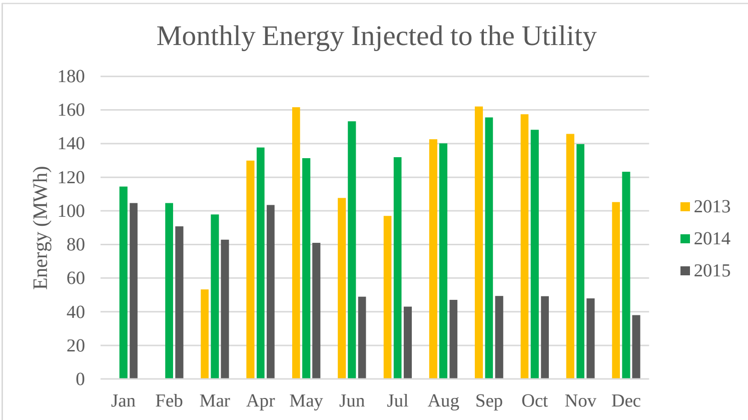
Figure 36 Actual energy production of Karangasem photovoltaics plant

Fig. 6 (b) shows how the daily average of sun power received on-site which is reflected on the energy generated by the plant, varies moderately from month to month. The most productive month is August and the least productive is December.

In Bali, electricity distribution to consumers is carried out by *PT. PLN Distribusi* Bali. By law, the company has to buy energy generated by Karangasem photovoltaics plant. For this reason, they have installed energy meter at the connection point of photovoltaics plant and 20 kV network. Energy injected into the medium voltage network for three consecutive years is shown in Fig. 7. The plant was turned on for the first time at the end of February 2013 hence data records begun from March 2013. In 2014, the plant run fairly smoothly with relatively stable outputs. Total injected energy into the grid seen by the utility meter in 2013, 2014, and 2015 are 1263, 1578, and 784 MWh respectively. The monthly average for 2013 is 126 MWh. For 2014, monthly average is 131 MWh. In 2015, monthly average is 70 MWh and fluctuates from 43 to 105 MWh.

Month	ENERGY (MWH)		
	2013	2014	2015
Jan	0	115	105
Feb	0	105	91
Mar	53	98	83
Apr	130	138	104
May	162	131	81
Jun	108	153	49
Jul	97	132	43
Aug	143	140	47
Sep	162	156	49
Oct	157	148	49
Nov	146	140	48
Dec	105	123	38

(a)



(b)

Figure 37 Actual energy metered by utility

To compare simulation result and actual energy output, the two quantities are plotted together as shown in Fig. 8 (a). Sunshine index is also plotted in the graph to show how this factor varies and to see if it relates to output of the plant. Fig. 8 (b) shows trends of simulated and actual energy output and ambient temperature. Each quantity is divided by its average value. It is shown that simulation and actual output generally exhibit similar trends from month to month. The three quantities rise and fall at the same time hence in close agreements except during the period of the rainy season. The difference among themselves is larger than 50% particularly during the rainy season where large offsets are shown for December, January, February, and March. The large different is largely due to local environmental factors and reliability of equipment. On the simulation, the plant is assumed to work perfectly within their technical specification and operating condition. However, in reality, plant's outage due to partial faults or maintenance occur. The number of rain days and volume of rainfall greatly vary which further affect accumulated energy output of the power plant.

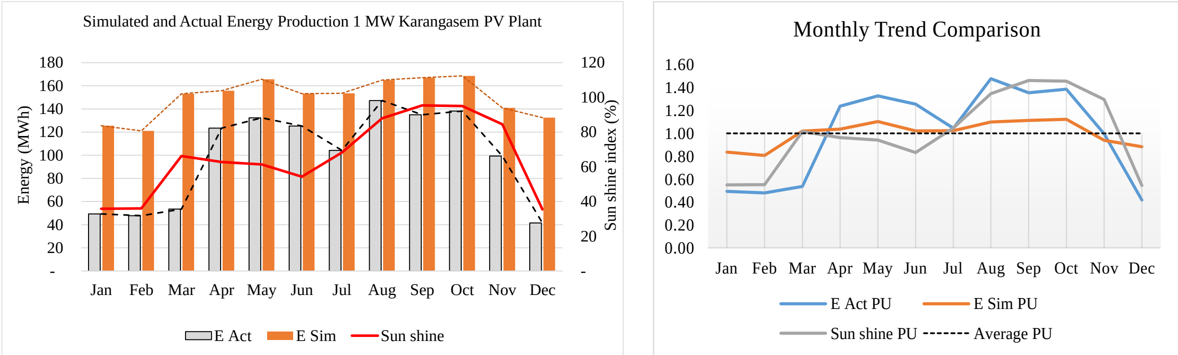


Figure 38 Actual and simulated energy production and trends

Although the power plant is already equipped with a monitoring system, the utility also installed metering at the point of connection between plant and distribution network. This measurement is used as a base for energy sale between the two parties. Based on data presented in Fig. 7, the annual energy injected into the grid is shown in Fig. 9.

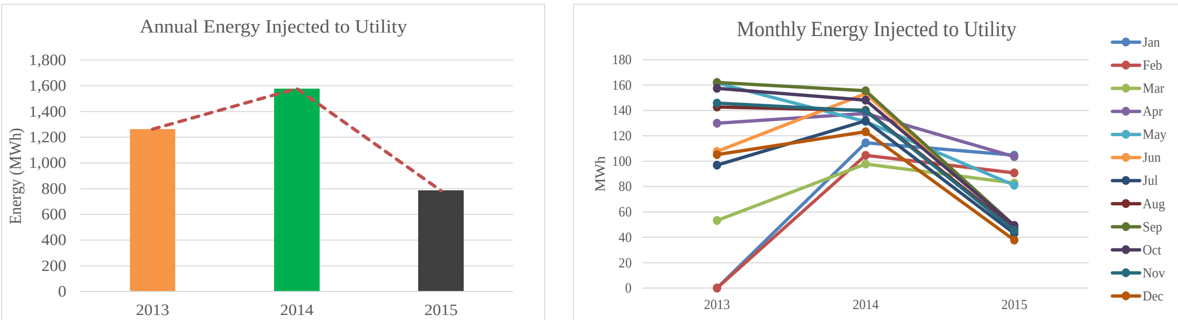


Figure 39 Actual energy injected to utility grid

It is shown that annual energy produced fluctuate significantly during the three years operation although weather condition and the environments have seen little changes. This could be largely associated with the reliability of the plant due to either technical or non-technical problems. During nearly three years operation, the plant has experienced various problems such as lightning strikes, faults on inverters, power outages, and other problems. These have caused a reduction in the energy production of the power plant.

This paper has presented simulated energy output of the 1 MW grid-connected Karangasem photovoltaics plant. Based on idealized simulated conditions, the plant produces annual energy around 1766 MWh with a monthly average of 147 MWh. Monthly output varies from minimum 120 MWh to maximum 168 MWh. Annual energy output recorded by the monitoring system in 2014 is 1180 MWh with a monthly average of 98 MWh. Monthly output varies from minimum 42 MWh to maximum 147 MWh. The actual output is lower than the simulated figure is largely caused by in absent of local environmental factors on the simulation. Energy injected to the grid measured by the utility is 1263, 1578, and 784 MWh for 2013, 2014, and 2015 respectively. The mismatch between recorded value and metered figure, where the latter is higher, suggest problems or issues on the wiring and/or on the data monitoring systems. Local environmental factors affect energy production of the photovoltaic plant. Among these factors, sun duration and volume of rainfall are two main weather parameters that greatly affect energy production. These data are useful for initial assessments on the potential for photovoltaic generation of a particular location.

4.2.3 PLTS Sumbawa

Grid-Connected System: Simulation parameters

Project :	**PLTS 1 MW Labangka**				
Geographical Site		**Labangka**		Country	**Indonesia**
Situation		Latitude	8.9°S	Longitude	117.8°E
Time defined as		Legal Time	Time zone UT+9	Altitude	41 m
		Albedo	0.20		
Meteo data:		**Labangka**	Synthetic - MeteoNorm 7.1 station		

Simulation variant :	**New simulation variant**		
		Simulation date	13/08/18 18h42

Simulation parameters

Collector Plane Orientation		Tilt	10°	Azimuth	0°
Models used		Transposition	Perez	Diffuse	Erbs, Meteonorm
Horizon		Free Horizon			
Near Shadings		No Shadings			
PV Array Characteristics					
PV module	Si-mono	Model	**ASL-M200**		
		Manufacturer	PT. Azet Surya Lestari		
Number of PV modules		In series	24 modules	In parallel	219 strings
Total number of PV modules		Nb. modules	5256	Unit Nom. Power	200 Wp
Array global power		Nominal (STC)	**1051 kWp**	At operating cond.	885 kWp (50°C)
Array operating characteristics (50°C)		U mpp	596 V	I mpp	1484 A
Total area		Module area	**6710 m²**		
Inverter		Model	**Sunteams 15000**		
		Manufacturer	KLNE		
Characteristics		Operating Voltage	380-800 V	Unit Nom. Power	15.0 kWac
Inverter pack		Nb. of inverters	70 units	Total Power	1050 kWac
PV Array loss factors					
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss		Global array res.	7.0 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss				Loss Fraction	1.5 %
Module Mismatch Losses				Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization		IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
User's needs :		Unlimited load (grid)			

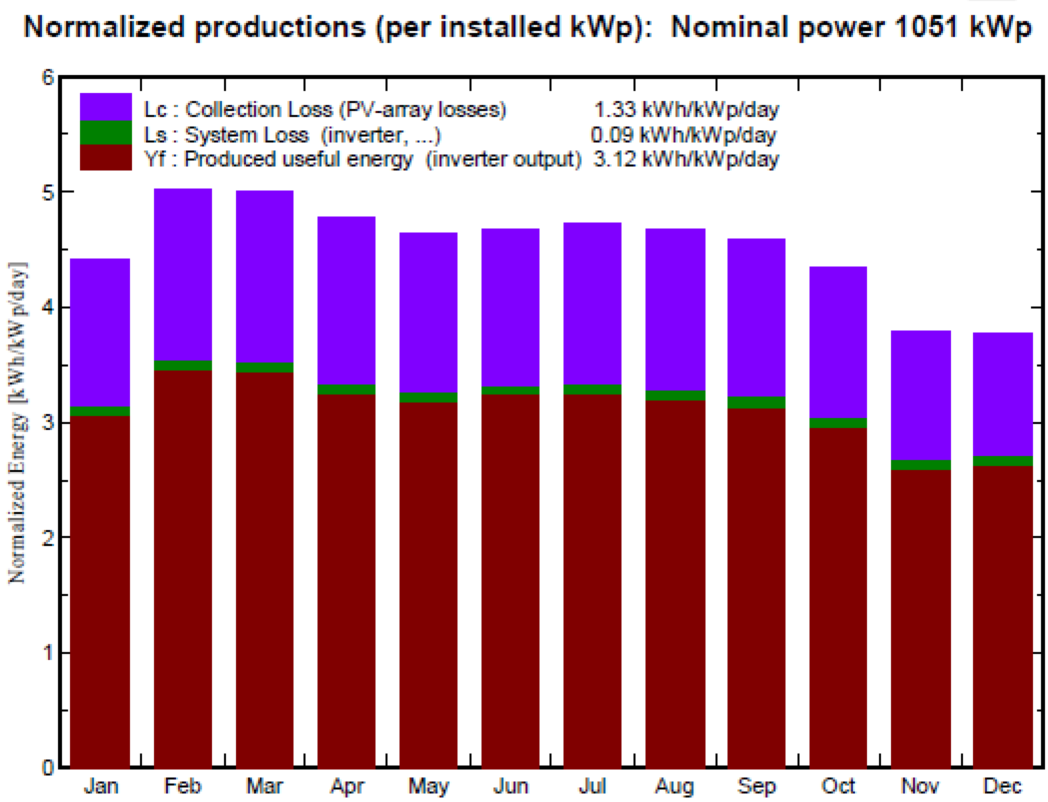
Figure 40 Performance of PLTS Sumbawa

Utara, 10 derajat

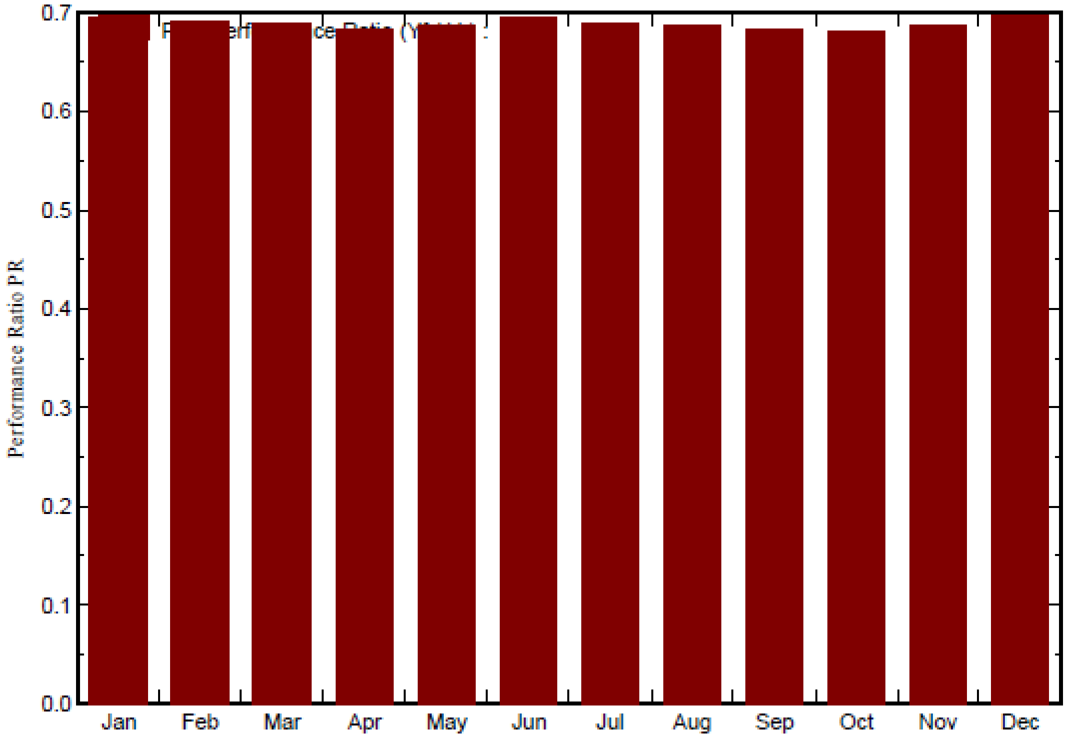
Energy use and User's needs

	E_Grid MWh
January	99.9
February	102.0
March	112.2
April	102.7
May	103.8
June	102.4
July	106.2
August	104.6
September	99.1
October	96.3
November	82.0
December	85.6
Year	1197.0

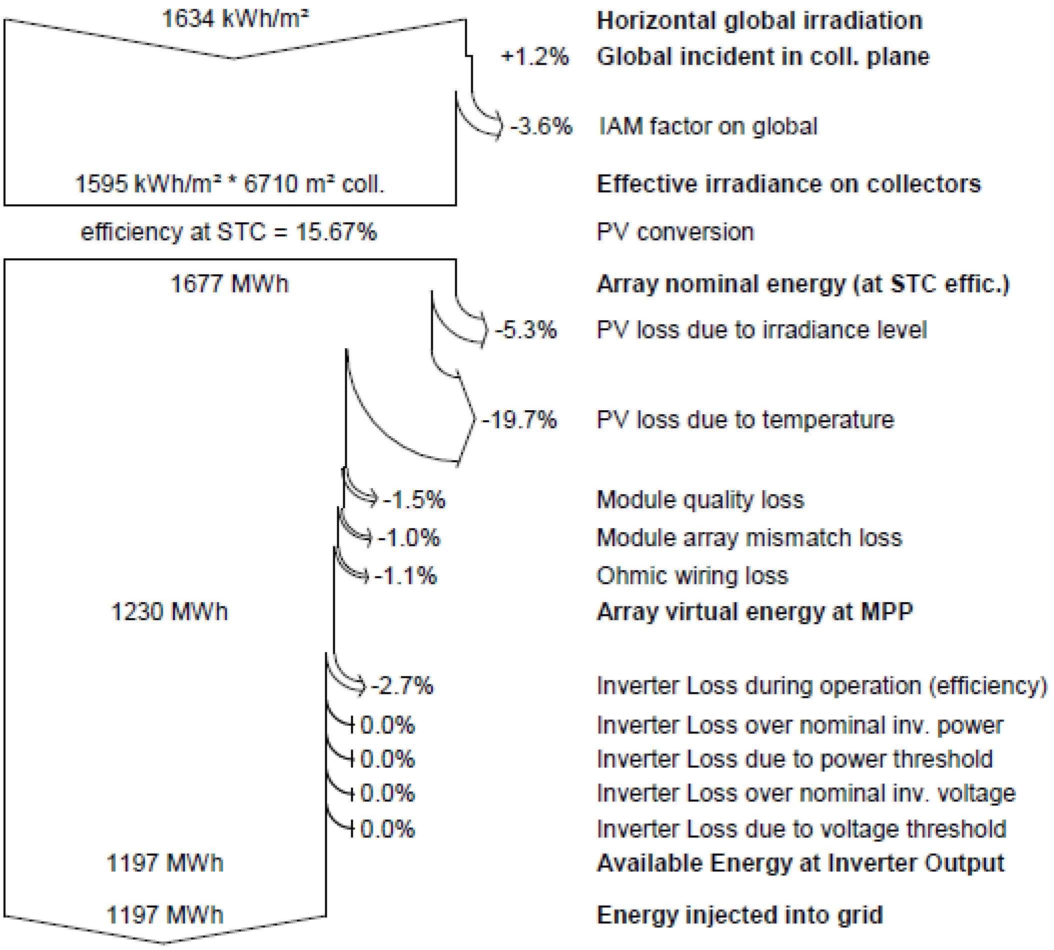
Legends: E_Grid Energy injected into grid



Performance Ratio PR



Loss diagram over the whole year



4.3 Sustainability of Grid-connected PV Plant Indonesia

4.3.1 Bangli PV Plant

4.3.2 Karangasem PV Plant

4.3.3 Sumbawa PV Plant

The results of site visit or survey on the location of Labangka PV plant is shown below. The power plant has been abandoned as it is not very clear who is responsible for the operation and maintenance of the power plant.


PEMBANGKIT LISTRIK TENAGA SURYA
TERKONEKSI JARINGAN (GRID CONNECTED PV)


Sunteams


KLNE
KLNE

4.4 PV Development in Southeast Asian Countries (ASEAN)

ASEAN menargetkan 23% EBT pada tahun 2025.

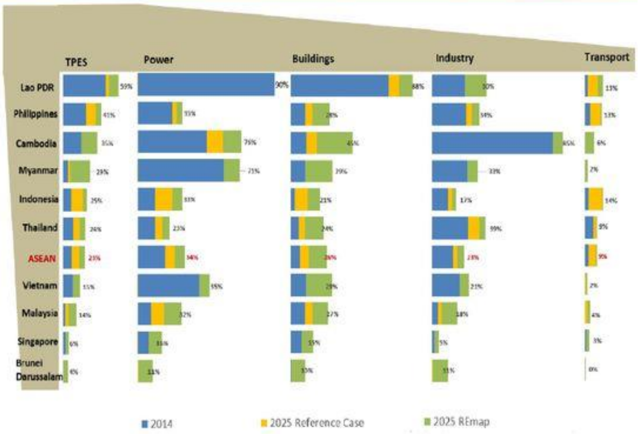
Indonesia tertinggal dibandingkan negara-negara tetangganya di Asia Tenggara dalam mengembangkan sumber daya energi terbarukan seperti sinar surya, angin, dan biomassa. Sumber: Artikel ini telah tayang di Kompas.com dengan judul "ADB Kucurkan 1,1 Miliar Dollar AS untuk Sektor Energi Indonesia", https://ekonomi.kompas.com/read/2017/09/14/160000826/adb-kucurkan-1-1-miliar-dollar-as-untuk-sektor-energi-indonesia. Penulis: Sakina Rakhma Diah Setiawan.

Renewable Energy Share by Country (2014-2025)

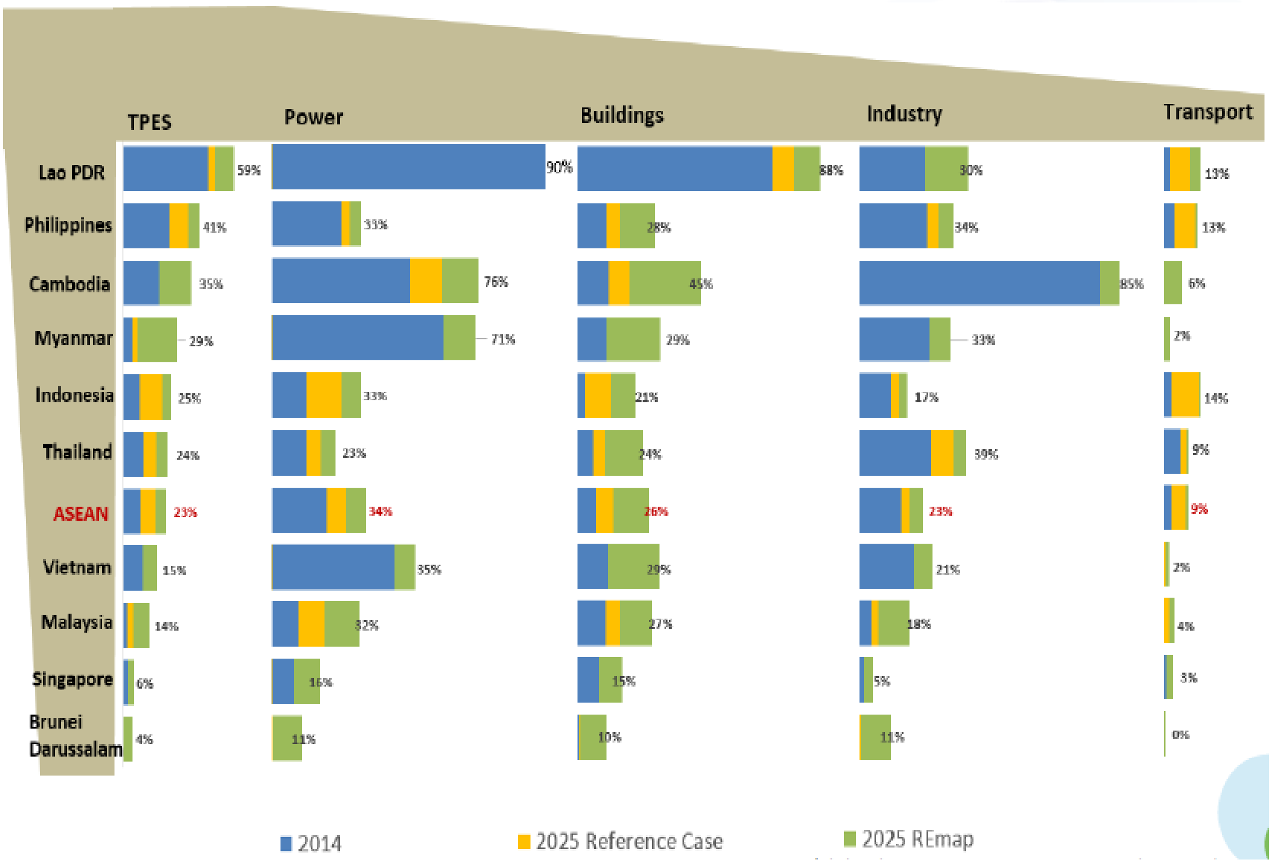
Renewables share ranged from 4% - 59% under TPES . . .

1

- Large variations exist in the distribution of RE use amongst the ASEAN countries – ranging from 4% in Brunei Darussalam to 59% in Lao PDR.
- Across the ASEAN, share of RE use by Sector shows:
  - Power sector (34%), has the largest share, followed by
  - Buildings (26%),
  - Industry (23%) and
  - Transport (9%) in that order.



Source: IRENA – ACE, 2016



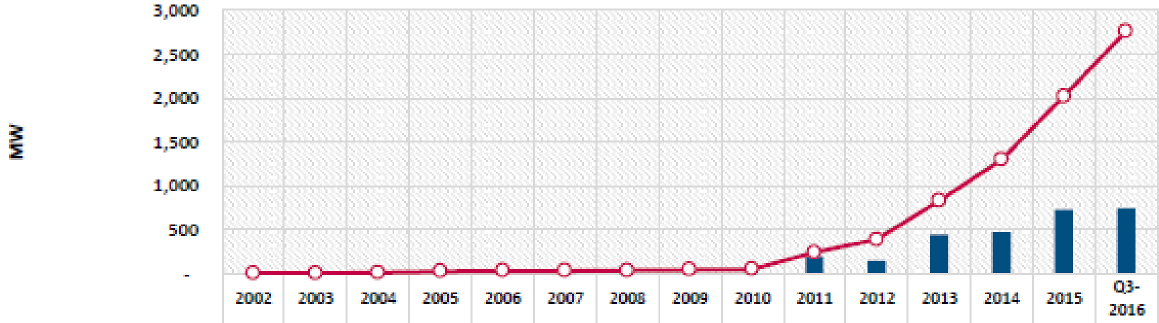
Malaysia possesses an abundance of energy resources, both conventional and renewable. Its primary energy demand was 98,315 ktoe in 2013. The share of conventional energy resources is very high at 97%, while Renewable Energy (RE) resources still play a very small role in the national energy mix. The installed capacity of Solar PV in Malaysia is 249.61 MW (June 2016).

Malaysia's National Energy Policy was established in 1979, consisting of three objectives: (1) securing a sufficient supply of energy in a cost-efficient manner, (2) promoting efficient use of energy, and (3) ensuring environmental protection in energy uses and productions. The Fuel Diversification Policy (1981 and 1999) was introduced to ensure the country is not overly dependant on a single source of energy. The four fuels initially defined include oil, natural gas, hydro and coal. The 8th Malaysia Plan 2001-2005 included RE as a fifth fuel, thereby adjusting the four fuel policy to five.

Renewable Energy Installed Capacity Malaysia 2017

Year	Biogas	Biogas (Landfill / Agri Waste)	Biomass	Biomass (Solid Waste)	Small Hydro	Solar PV	Geothermal	Total
2012	2	3.16	36.9	8.9	11.7	31.53	0	94.19
2013	3.38	3.2	0	0	0	106.97	0	113.55
2014	1.1	0	12.5	0	0	63.92	0	77.52
2015	0	5.4	12	7	6.6	60.34	0	91.34
2016	0	15.46	19.5	0	12	77.63	0	124.59
2017	0	22.54	0	0	0	31.87	0	54.41
2018	0	2.4	0	0	0	0.23	0	2.63
Cumulative	6.48	52.16	80.9	15.9	30.3	372.49	0	558.23

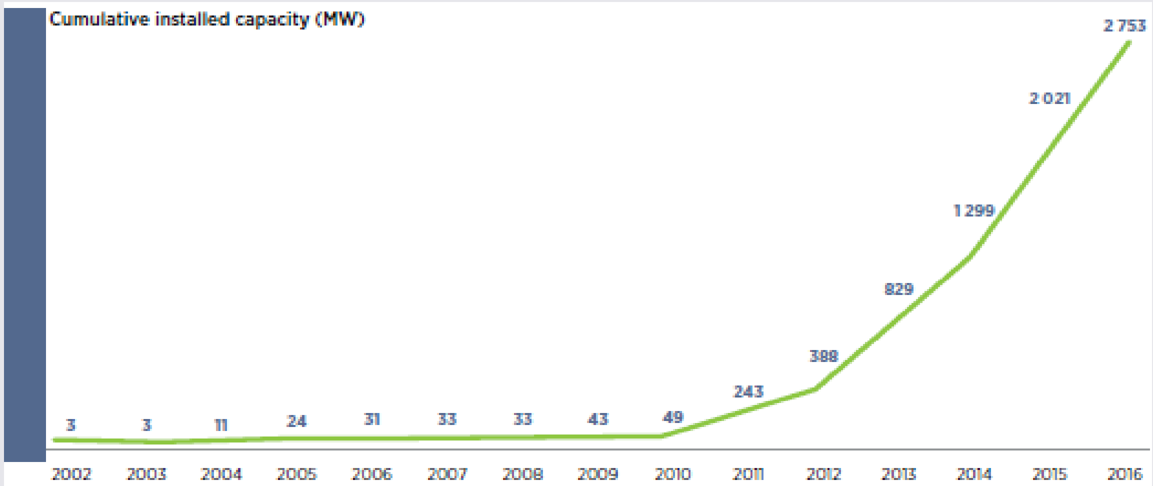
Figure 1. Thailand's Solar PV Installed Capacity



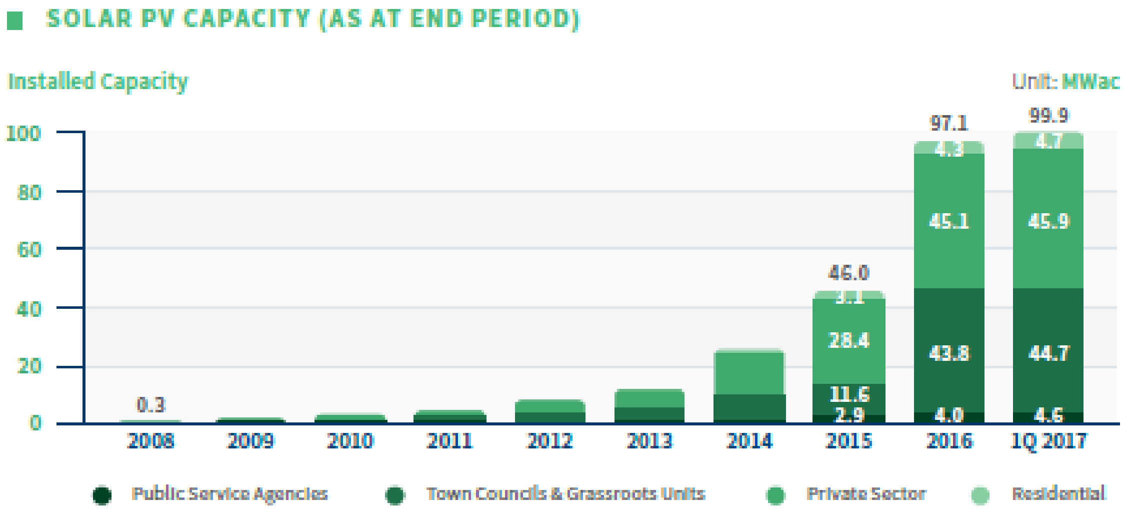
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Q3-2016
Annual Installed Capacity (MW)		1	7	13	7	2	1	10	6	193	145	441	470	722	740
Cumulative Installed Capacity (MW)	3	4	11	24	31	33	33	43	49	243	388	829	1,299	2,021	2,761

Source: 2002-2014 data from DEDE (Link), 2015&2016 data from ERC

Figure 14. Thailand's cumulative solar PV installed generating capacity, 2002-2016



Based on data from DEDE and ERC
Note: 2016 data as of September



Solar Singapore from 2008 - 2017

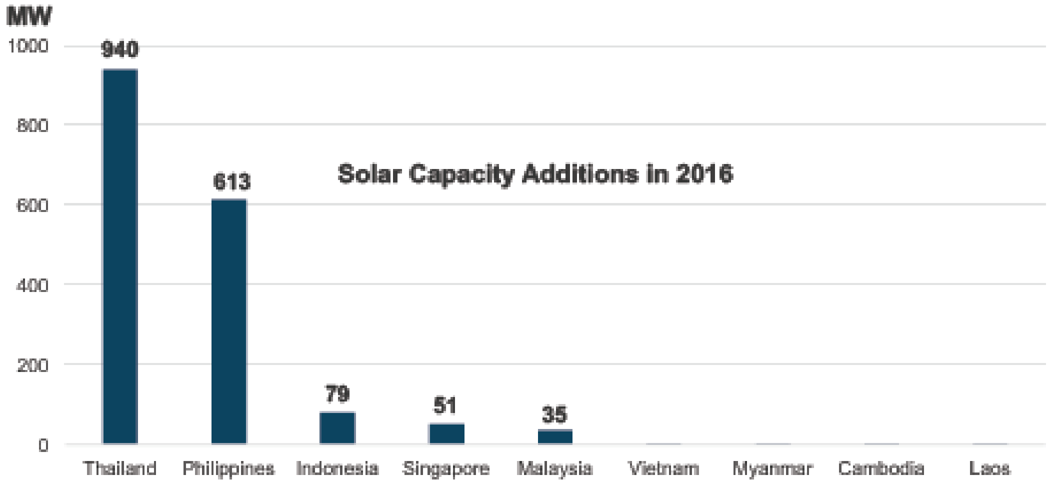
The Philippine

Installed Power Generation Philiphine

Technology	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Coal	3,958	3,967	3,967	4,177	4,213	4,213	4,277	4,867	4,917	5,568	5,568	5,708	5,963	7,419	8,049
Oil Based	3,604	3,669	3,663	3,602	3,616	3,353	3,193	3,193	2,994	3,074	3,353	3,476	3,610	3,616	4,153
Natural Gas	2,763	2,763	2,763	2,763	2,834	2,831	2,831	2,861	2,861	2,862	2,862	2,862	2,862	3,431	3,447
Renewable Energy	4,799	5,149	5,226	5,261	5,277	5,284	5,309	5,437	5,391	5,521	5,541	5,898	6,330	6,958	7,079
Geothermal	1,932	1,932	1,978	1,978	1,958	1,958	1,953	1,966	1,783	1,848	1,868	1,918	1,917	1,916	1,916
Hydro	2,867	3,217	3,222	3,257	3,293	3,291	3,291	3,400	3,491	3,521	3,521	3,543	3,600	3,618	3,627
Biomass	0	0	0	0	0	0	30	38	83	119	119	131	221	233	224
Solar	0	0	1	1	1	1	1	1	1	1	1	23	165	765	885
Wind	0	0	25	25	25	33	33	33	33	33	33	283	427	427	427

Overview of 2016 SE Asia Solar Energy

- **About 1.7GW of solar power was build in SE Asia in 2016**
  - Focused on two countries – Philippines and Thailand
  - Solar capacity additions in Taiwan is 368MW in 2016



Sources: Taiwan Bureau of Energy, Ministry of Economic Affairs statistic data, The Lantau Group material

CHAPTER 5 PLAN FOR NEXT STAGE

Writing analysis of PV development of Indonesia, the current progress, the future plan, and identify potential application of solar PV to achieve 5000 MW PV by 2025

Analysis of performance 3 x 1 MW PV plant of Indonesia; factor that affect performance/ failures

Analysis of Thailand achievement (how Thailand can achieve 2700 MW in very short time; policy, implementing regulation, stake holder targeting and response, industry

CHAPTER 6 CONCLUSION AND RECCOMMENDATION

Based on the current findings, the following conclusions are drawn:

1. Solar PV Indonesia has started from 1977 and continue to 2017 and will continue to reach target as set by National Energy Policy. The current solar PV capacity is 155 MW installed throughout the country.
2. Simulation of performance index of PLTS Kayubihi is 70% while its actual performance is changing from 72.5% to 48.4% which suggest problems occurred.
3. Simulation of performance index of PLTS Karangasem is 85% while its actual performance is changing from 69% to 87% to 43% and finally to 29% which suggest problems occurred.
4. Simulation of performance index of PLTS Labangka is around 70% while its actual performance is 0% as the power plant never connected to the PLN's grid.
5. Among ASEAN member Indonesia is in the fourth place in the total installed solar PV capacity. Solar PV ASEAN is led by Thailand with around 2.7 GW solar capacity by the end of 2017. The implementation of adder and feed-in-tariff is two major policy/regulation that bring Thailand as the leader of solar PV in ASEAN

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ATTACHMENTS

Implementation of Grid-connected PV Plant in Remote Location in Sumbawa Island of Indonesia: Lesson Learned

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Abstract—**The National Energy Policy (NEP) set 23% renewable energy target in the generation mix by 2025, where solar PV has identified as one of the feasible resources. There are many solar programs implemented in Indonesia. A large-scale grid-connected solar PV (1 MW) project in Indonesia is analyzed in this study. The power plant is installed on Sumbawa island. The project is analyzed to investigate the performance of PV systems in a tropical climate. The performances were analyzed on project development, plants technical specification, energy production and performance index, and its current status. Data is collected through site visit and observations, documents review, and discussion with relevant stakeholders. PVSyst is used to simulate the potential of annual energy production and performance. Our audit found that the main components of the power plant are certified from reputable international organizations including Indonesian national standards. The simulation showed the power plant could generate 1,195 MWh annual energy with an average of 8% monthly variation which leads to an average performance index of 68.9%. Since the commissioning tests, the plant has not been operated. Consequently, no energy has been injected into the grid nor supplied to local load. Currently, the power plant is an inoperable condition due to non-technical problems. The problems are discussed, and a recommendation is presented in this paper.**

Keywords*— *renewable energy, grid-connected, solar PV, photovoltaics, energy production, performance index, project development

I. Introduction

The government of Indonesia has stated in the National Energy Policy (NEP) that it sets to reach 23% renewable energy in the national energy mix by 2025 [1]. The renewable energy consists of energy sourced from geothermal, biomass, hydropower, solar, wind, and ocean resource. The potential of renewable resource of the country is abundant. However, the current progress of renewable energy has reached only 12%. Therefore, lots of works need to be done to achieve the target.

Solar PV has identified as one of the components of the renewable energy portfolio of Indonesia. The country has the abundance potential of solar electricity generation. It westimated that the country has 208 GW electric power available from the solar energy conversion technology.

Sumbawa 1 MW solar PV plant was developed as one of the first pilot projects of large-scale grid-connected plant in Indonesia. The commercial operation date (COD) of the plant was in early 2013. However, since the commissioning in early February 2013, the power plant has not been connected to the utility distribution network nor connected to any local loads. However, there is little information available with regards to this project. Meanwhile, the government has planned to develop more large-scale PV plants in the future. Therefore, it is critical that lesson learned can be drawn for this project to prevent the occurrence of a similar project. This background has motivated our research to help the community or stakeholder in understanding the status of the project. The research comprises review on the development of the project including the relevant policy and regulation related to grid-connected PV development of the country. The paper also reviews the technical information of the power plant, its energy potential through simulation, and factors which affect its energy production, including the status of local electrical distribution network where the PV plant would inject its power.

The objective of this paper is to obtain the potential of energy generated by the Sumbawa 1 MW PV plant to get insight into its performance. It also reviews the development of the project and then draws lesson learned in developing government-financed large-scale grid-connected PV plant in the context of Indonesia. The paper is organized as follows. Section II discusses the material and methods of the research, section III contains results and discussion, and finally, section IV discusses the conclusion and followed by references.

II. Methodology

The methodology of the research is shown in the following flowchart as shown in Fig. 1. It mainly comprises literature reviews, computer simulation, and analysis. At the end, recommendation is presented should the power plant is revitalized.

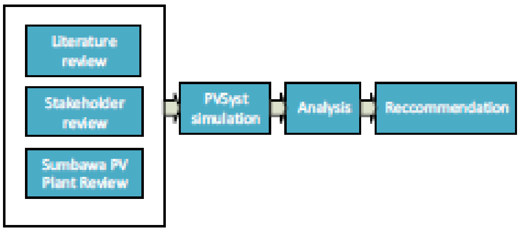

Fig. 1 Methodology of research

The literature review is carried out to obtain information related to the project development. It also undertaken to understand procedure and mechanism of government project development especially on asset management and ownership transfer of ministerial-built project to local government grant recipient. The review is also undertaken to understand demographic of the location, in getting insight of power plant impact to the local community. A stakeholder review is undertaken to evaluate the process of choosing the location of the power plant, technical requirements of grid-connection for distributed generation, condition of local electricity grid, and the role of central and local government.

Review on Sumbawa PV plant is undertaken to obtain technical information about the power plant, components and systems, installation, and including site protection and site safety access. To simulate the performance of solar PV systems PVSyst simulation tool, developed by University Geneva. Data and information are then analyzed to identify the reasons why the project could not achieve its goal. Recommendation for revitalizing the project is proposed as part of the research conclusion.

III. Description of the System

The first pilot project of 1 MW grid-connected PV system built by the Government of Indonesia in Sumbawa island in the eastern area of the archipelago. The schematic of the PV plant is shown in Fig. 2. The plant comprises of PV arrays, inverters, and medium voltage step up transformers. The site is protected from lightning strike using lightning protection systems. The site weather parameter is measured using Kipp & Zonen weather station. Electrical parameters of the power plant are monitored using KLNE Remote Monitoring System.

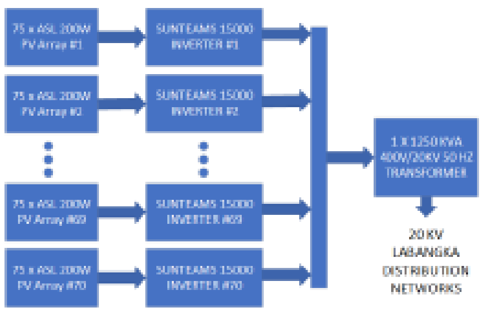

Fig. 2 Schematic of Sumbawa 1 MW PV plant

The on-site weather parameters are recorded using KLNE remote monitoring system which consists of a pyranometer, anemometer, and temperature measurement device for the module and ambient. The system consists of 70 PV arrays and each array is consist of 75 PV modules totaling to 1 MWp. PV modules are connected to 70 unit inverter. This system supplies electricity to the consumer in Labangka sub-district which is connected to the local electricity distribution network.

PV module of the power plant is ASL-M200 with 200-watts maximum power output. The module consists of 72 monocrystalline cells. It has a nominal voltage of 24 V, open circuit voltage of 45.3 volts, a maximum current of 5.32 A, and short circuit current of 5.72 A. The power tolerance is lower than 3%. The power plant uses 5,250 unit of modules. The module is manufactured by a local company which has been certified by Indonesian national standard SNI and TKDN [2].

Inverter of the power plant is a grid-connected type Sunteams 15000 manufactured by KLNE China. Its maximum DC power is 15,550 W with a nominal output of 15,000 W. The power plant uses 70 unit of Sunteams 15000. Hence, the power plant could produce the maximum DC power output of 1,050,000 watts. The MPPT voltage range is 250V – 800 V. Nominal DC voltage input is 650 V. The voltage AC output is 230/400 V 50 Hz with THD of less than 3%. The maximum efficiency is 98.0% with temperature operating range of -25°C to +/-60°C and humidity of 0 to 95%. It has a working altitude of 2000 meter. The cooling is forced air cooling type with enclosure of IP65 protection degree. The inverter is certified by VDE, SAA, CE, GC G59/2 [3].

The transformer is 380 V/ 20 KV distribution, oil-cooled type, to increase voltage output of the plant into 20 KV level so that it can be connected with the PLN's distribution networks. The transformer is manufactured locally by a reputable company and certified by IEC 76, SPLN, ISO 9001, ISO 14001, and TKDN > 40% [5].

IV. Results and Discussion

A. Profile of Plant's Location

Subdistrict Labangka is one of the 24 subdistricts in District Sumbawa in the West Nusa Tenggara province of eastern Indonesia. The map of the island is shown in Fig. 3. The power plant is located at the coordinate 8°55'13.3"S 117°46'29.0"E. The population of the subdistrict in 2016 was 10,702 with a population density of 44 people/km^2 and with total administrative area of 243.08 km^2 [4].

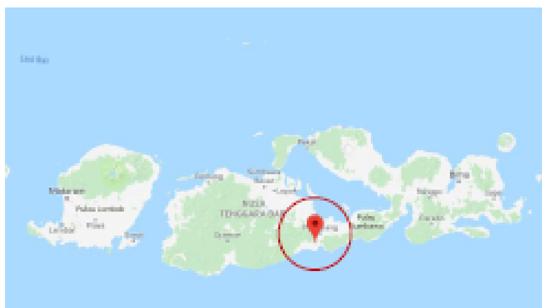

Fig. 3 Sumbawa island part of West Nusa Tenggara islands

Almost 90% of the population's livelihood relies on agriculture. The agriculture crops include corn, green been, ground peanuts, rice, cashew nuts and cattle such as cows and bulls. Industries also develops such as red brick or concrete bricks fabrication, rice milling, handicrafts of bamboo, wood and rattan [4].

B. Plant's Technical Information

Fig. 4 shows the PV modules installed on the ground. The module was installed using fixed structure with tilt-angle of around 15°. The arrays faces north as the location is in the south of the equator. From tilt-angle and orientation perspective, the plant has been installed in the position to capture maximum of the sun energy. Generally, the surrounding area is free from tall structures or plantations. So, there is no effect of shadows on the arrays.

Fig. 4 Sumbawa 1 MW PV plant

From the system data analysis, it has been seen that the reliability and the efficiency of the inverter are good which has a significant impact on the energy production of the power plant. By comparing the technical specification of the inverter and the location of the environmental profile, it was found that the environmental conditions of the plant location are still within the inverter's operating conditions. For example, the temperature varies between 30°C to 34°C which still within the inverter's limit. The humidity of the area is also within the range specified in the datasheets of the inverter. Therefore, the inverter should be able to deliver its output with high reliability.

In general, the technical specification and the equipment at the Sumbawa PV plant are good. The equipment and wiring material has been certified. The wiring has complied with the Indonesian electrical wiring standards PUIL 2000. The site also protected by Helita Pulsar 45 lightning protection system with protection radius of 105 meters.

C. Plant's performance

The energy produced by the power plant is estimated using PVSyst. The tool was originally developed by people at the University of Geneva. The tools simulate energy production of solar PV plant to provide insights on plant's performance. The tools use meteorological data as input to estimate sun energy and then converted into electrical power based on the technical specifications of the power plant including and location characteristics. The results of the simulation are presented in TABLE 1, Fig. 5, and Fig. 6.

TABLE 1 Estimated energy production of Sumbawa 1 MW PV plant

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
97	100	112	104	106	105	109	106	99	95	80	83
Total	1,195	Min	80	Max	112	Avg	100				

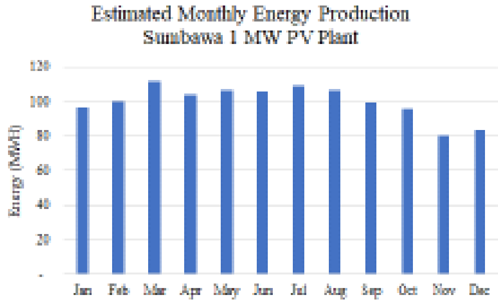

Fig. 5 Monthly output of Sumbawa 1 MW PV plant

TABLE 1 shows monthly energy production of the power plant. It can be seen that monthly production varies from month to month. Energy max is 112 MWh, energy minimum is 80 MWh, and with a monthly average of 100 MWh. If we compare energy production of Sumbawa PV plant with the energy consumption of the West Nusa Tenggara area the energy could supply 966 residentials as described in the following calculation. According to PLN, the energy consumption of residential type customers in West Nusa Tenggara area in 2016 was 1026.96 GWh. The total number of residential customers was 1,032,862. Hence the average energy consumption per household is 2.76 kWh per day. Assuming the PV plant produces minimum monthly energy of 80 MWh, then the electricity could be supplied to 966 residential customers.

TABLE 2 Weather profile of Labangka subdistrict

Month	Number of Rain (days)	Rainfall (mm)	Avg Rainfall (mm)	Max Rainfall (mm)	Avg Temp. (°C)	Avg Humidity (%)
Jan	11	102	3.29	78	27.5	83
Feb	19	303	10.82	68	26.8	88
Mar	9	128	4.13	67	27.5	84
Apr	7	69	2.30	36	27.8	78
May	8	226	7.29	97	28.2	79
Jun	8	226	7.53	97	27.3	79
Jul	9	204	6.58	157	26.9	78
Aug	2	48	1.55	43	26.9	73
Sep	4	108	3.60	59	27.8	74
Oct	13	205	6.61	91	28.1	76
Nov	8	226	7.53	176	28.3	79
Dec	13	306	9.87	153	27	86

Rainfalls in Labangka subdistrict vary from month to month with maximum rainfall of 226 and 306 mm occurred during November and December as in TABLE 2. The maximum rainfall was recorded in November and December are176 mm and 153 mm respectively. The high volume of rainfall explains the low energy production during these two months as shown in Fig. 5.

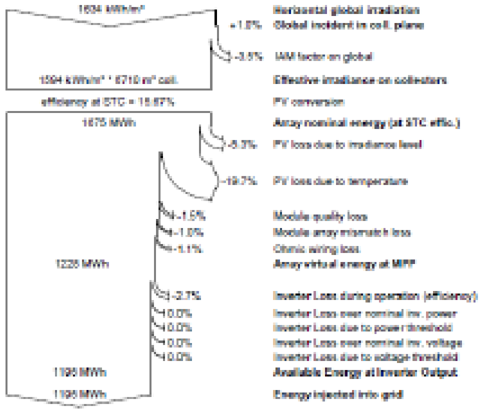

Fig. 6 Simulation of energy flow of Sumbawa 1 MW PV plant

The loss diagram of the energy flow obtained from the Pvsyst is shown in Fig. 6. The largest loss component is associated with the temperature at 19.7%.

Based on data in TABLE 2, it is shown that maximum temperature near the power plant location is relatively high with monthly average temperature of 27.5°C. This ambient temperature is slightly higher than the STC condition of the ASL-M200 which measured at 25°C. Meanwhile, the output power temperature coefficient of the monocrystaline M200 is -0.432/°C. There was no data for the actual module temperature of the plant but the temperature of module will be much higher than the ambient. Reports [6] [7] [8] show that module's temperature is higher than ambient and could reach 50°C above its ambient. Using this assumption, the temperature difference of the module in Labangka to STC condition is 52.5°C. This temperature rise could reduce output of the module by 23% from its STC condition. This explains the high energy loss of the power plant at 19.7% which is associated with temperature loss. The performance ratio obtained from PVsyst simulation of the power plant varies from 68% to 69% and with an annual average of 68.9%.

The simulation shows that Sumbawa district has good potential of solar PV application but at the same time the area has high temperature with annual average of 27.5°C although daily temperature is reported between 32 to 34°C. The effect of high temperature is reduction of module's output. Therefore, consideration in choosing PV module technology should include temperature profile of the plant's location. Mono-crystalline Silicon has been known to perform well in cool weather but not in hot ambient which also shared by poly-crystalline based module. The use of thin film such as Amorphous Silicon, Cadmium Telluride (CdTe), or Copper Indium Gallium Selenide solar cell (CIGS) are suitable for application in high temperature environment as thin film technology have lower temperature coefficient and particularly for CdTe and CIGS which have zero temperature coefficient and low impact on output due to low irradiance [9].

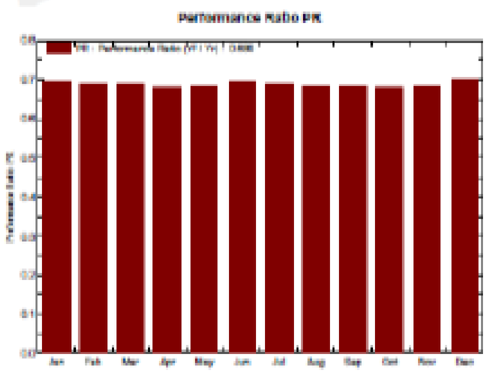

Fig. 7 Monthly performance ratio of Sumbawa PV plant

There was no actual energy production from the power plant due to the fact that since the completion of the project and after the commissioning period, the plant has never been connected to the grid. During the commissioning, a very brief test was conducted according to the commissioning report. The test was carried out on April 20, 2013. During the test, the weather was reported in cloudy condition. The power plant showed the voltage of 17.7 KV as measured at the plant's cubicle with current measured at 9.039 A which gave a power output of 160 KW or 16% of its peak power output. The one-time measurement was taken from 12:00 to 13:00 Indonesian Eastern Time [6]. No other tests were reported. According to the international standard IEC 62446 Grid Connected PV Systems, there are minimum requirements for system documentation, commissioning tests, and inspection to verify the safe and proper operation of PV systems.

D. Electrical Power System of Sumbawa Island

Sumbawa electrical power system is a radial 20 KV distribution system comprises 20 KV feeders and 220/380 low voltage networks to supply the customers. As of 2015, the power plants comprised diesel-powered plants with total capacity of 76.5 MW and a coal power plant of 14 MW capacity. Details of generating stations of Sumbawa power system is shown in TABLE 3. Currently, there are no renewable power plants in operation, although plan for micro hydro has been drafted. The power system serves a population of 1,461,454 distributed in an area of 15,414 square kilometers [7].

TABLE 3 Generators of Sumbawa power system

No	Generator	Capacity (MW)	Location
1	PLTMG Sumbawa	50	Northwest Sumbawa
2	PLTU Sumbawa Barat	14	West Sumbawa
3	PLTD Labuhan	13.4	Northwest Sumbawa
4	PLTD Taliwang	5.3	Southwest Sumbawa
5	PLTD Bima	7.8	Bima
	Total	90.5	

TABLE 4 Electricity customer of Sumbawa Island (2017)

Customer type	Number of Customer	Percentage
Residential	137,291	94.6%
Business	4,098	2.8%
Social	2,552	1.8%
Public/Government	1,086	0.7%
Industry	107	0.1%
Total	**145,134**	**100.0%**

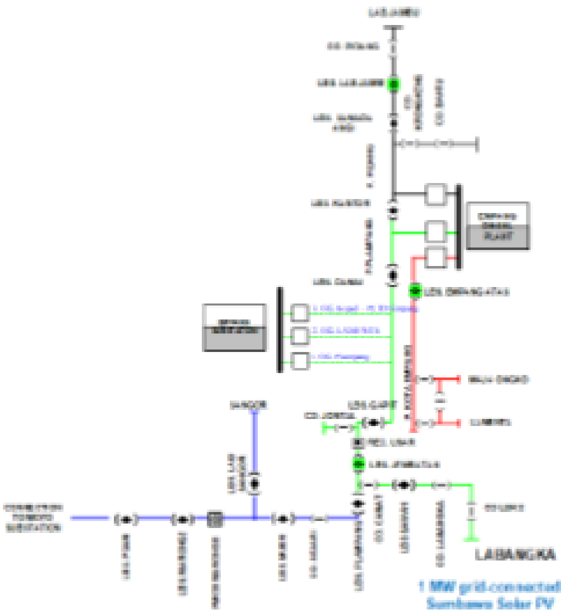

Fig. 8 Electricity distribution networks for Labangka

Based on data provided by the Sumbawa utility company the load of the feeders is shown in TABLE 5. The Labangka subdistrict is served by Kota Empang feeder. The peak load of the feeder was 900 KW during daytime and 1,900 KW during evening time.

TABLE 5 Loading condition of feeders near Labangka

Feeder	Area	Load Condition	
		Daytime peak (KW)	Evening time peak (KW)
Kota Empang	Serving customer in Empang area	900	1400
Pidang	Serving customer in Pidang area	700	950
Plampang	Serving customer in Plampang area	1900	2100

If we compare daytime peak load of Kota Empang feeder at 900 KW and peak capacity of Sumbawa solar PV at 1,000 KW, it is clear that the Distributed Generation could inject power at 110% of the current maximum feeder load. According to the PLN regulations, any DG should not inject power greater than 25% of the feeder capacity. However, due to the change of insolation, hence power output of the plant, the solar PV plant generation affect the operation of the diesel-powered generator connected to the grid which in turn affect the stability of the distribution systems. For example, during the commissioning test, the Labangka solar plant generated 160 kW power during the one-hour test. The test indicates that Labangka PV plant's output could vary from 160 kW to its peak capacity of 1,000 kW. The change of weather and cloud could occur instantly hence the output of PV plant is intermittent. The high-power ramping rate the solar PV plant requires the power systems be able to respond to the sudden change of the injected power. However, with comparable output capacity, compared to the feeder's maximum capacity/ load, then it could lead to unreliable operation of the power systems.

E. *Project Development and Current Status*

Indonesian Electricity Law enacted in 2009 (UU No 30/2009) [8] states that the business of supplying electric power consists of power generation, transmission, distribution and the sale of electricity to the customer. The law has opened an opportunity for other entity to participate in the provision of electric power in the country. The entity can be in the form of Independent Power Producer (IPP), cooperative, state enterprises both provincial and district governments' enterprises or business enterprises owned by village government or locally known as *Badan Usaha Milik Desa* (BUMDES) [9]. Consequently, the state-owned utility company PLN no longer has the legal monopoly of the electric power provision of the country. However, the company owns and operate the transmission and distribution networks and own the majority of the generation facility in the country.

In the context of injecting power generated by Distributed Generation especially those that come from renewable technology, plant developer needs to establish contract with the PLN as the electricity infrastructure is owned by PLN and PLN is the sole electrical energy buyer in Indonesia. The main contract is through Power Purchasing Agreement (PPA) which set the price per kWh energy that PLN will pay to the power producer. Without the PPA, PV developer will not be able to sell the energy to the grid [10]. According to Sumbawa utility [11] and District Government of Sumbawa [12], the PPA between Sumbawa utility and District Government or government enterprise assigned by District Government has not been signed. One of the main reasons for unsigned PPA is the fact that the project is developed not by the District Government but a project grant from the ministry. For the local government to register the power plant as their asset, the central government needs to formally handover the power plant to the District Government according to current government regulation (PP No 27/2014) [13]. Through this process, the power plant can be registered under the local government assets. Consequently, the use of the asset and its maintenance can be included in the local government administration. Without this step, district government cannot proceed to initiate any contract using this object. And the process of handing over project of this scale of investment will need to comply with central government regulations which one of the steps is handover permit obtained from highest government leader as described in the regulation of Ministry of Finance (PMK No: 52/2006) [14]. Discussion with officers from the District of Sumbawa [12] suggested that the local government hasn't received the formal handover from the central government which developed the power plant. Although, the local government had started the preparation for to expand the scope of existing enterprise business area to include power generation that would be responsible for maintaining the power plant including selling the energy into the grid. However, according to the district officer, the formal decree has not been issued by the head of district government [12].

The power plant was completed in early 2013 and tested in February 2013. The project cost was reported at IDR 31.8 billion. In 2014, the plant was under commissioning by the contractor. In 2015, the plant was under investigation by the authority due to the concern related to the quality of the project. In 2016, the authority continued the investigation and including acquiring experts from universities and engineering agencies in reviewing the project. In 2017, the authority stopped the investigation upon the allegation that the contractor had installed sub-standards equipment. The authority decision was taken after hearing witness from BPPT, an independent government agency, that stated the power plant was built using components as specified in the contract.

Currently, the 1 MW Sumbawa PV plant is in the inoperable state. The pictures below give insights into the current state of the power plant. All of the components of the plant such as inverters, control panels, weather station, cabling, and wiring are damaged and in non-usable condition. Many of the components and cabling has been vandalized and looted because the project has been left unattended as the location is in remote area. Trees and shrubs have grown on the site. Most of the solar module are still in good condition although will require thorough cleaning and tests should they are re-used. Such conditions occur due to uncertainty over which party should maintain the plant after the commissioning period. The developer scope is until the completion of the project. The local government which acts as the grant recipient through its enterprise would have been responsible for the operation and maintenance of the plant including selling the energy to the utility, but this could only be done after the official handover from the developer. The PLN as the utility under the current regulation will buy the power from the government enterprise. To inject power to their grid, the power plant needs to comply with the technical standards of PLN and plant's operator has signed the Power Purchasing Agreement.

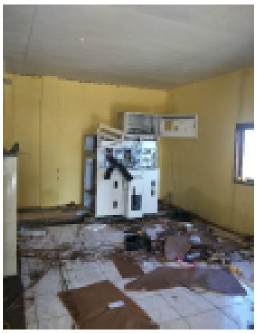

Fig. 9 Current condition of PV arrays and control room of Sumbawa PV plant

V. Conclusion

This paper has reviewed a grid-connected large-scale 1 MW solar PV plant in Sumbawa island of Indonesia. Inspection of the equipment revealed that the components such as inverters, solar modules, transformer, and weather station all are certified by CE, EU, SNI, and TKDN. In general, the technical specification of the plant is high hence its expected reliability. Pvsyst simulation shows the power plant could generate an annual energy output of 1,195 MWh and with an average performance ratio of 69%. The notable loss is attributed to temperature loss at 19.67% and is the largest component of the losses. The high loss is associated to the location climate and weather condition which has high ambient temperature and humidity. The high module temperature could have affected voltage or power output of the module which in turn affect its efficiency. The high humidity could affect the electronics components of the power plant and in the case of Sumbawa plant the effect of humidity is not compensated for.

Currently, the power plant is in non-working condition and has been abandoned due to non-technical problems. Based on our field inspection and survey, revitalization of the power plant will require substantial re-investments. All of the power plant's components will need replacement except the solar module, arrays mechanical supports, and the medium voltage step up transformer. The PV modules can be re-used as still have 20 years lifetime but requires thorough cleaning. The cabling requires complete re-wiring. However, revitalization of the power plant should only be implemented when the non-technical problems have been fully solved as described as follows:

- For DG injection to a grid, it should comply with PLN's guidelines which states DG should not inject power of greater than 25% from the maximum of feeder capacity unless a special circumstance which will require further assessment by the utility. Therefore, preliminary study is necessary to review the status of electrical distribution network prior nominating location of DG.
- In government-financed project, the developer should prepare a formal handover of the power plant after commissioning period to the district government to allow local government to comply with the national regulation concerning government assets and its management.
- District government as the recipient of power plant should establish an enterprise to manage the plant including selling energy to the grid after signing the power purchasing agreement with PLN. Although the feed-in-tariff is set by the central government but in this case the local government is not involved in the financing of the project except providing the land, therefore, the tariff should be based on mutual agreement between PLN and the local enterprise.

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