"Developing a Framework to Increase Solar Photovoltaic (Solar PV) Microgrid Penetration in a Tropical Region: A Case Study in Indonesia"

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Declaration

I declare that this dissertation is my own account of my research and contains as its main-content work which has not previously been submitted for a degree at any tertiary education institution.

Abstract

Although tropical regions receive a significant amount of solar radiation throughout the year, most tropical countries have low solar photovoltaic (PV) penetration. Indonesia has around 208 gigawatts of solar potential but less than one percent of this potential has been harnessed. This research combined both quantitative and qualitative research to develop a framework for increasing solar PV microgrid penetration in Indonesia.

A techno-economic evaluation was performed to identify the performance of a solar PV microgrid in Indonesia and to evaluate its economic potential based on two different land acquisition scenarios. Additionally, surveys and interviews were conducted to obtain some perspectives from key stakeholders regarding the policy landscape of the country. The study shows that although high solar radiation is great to produce higher power, the performance ratio can be quite low. The economic evaluation shows that the land purchasing scenario can give a higher profit while the land leasing scenario can provide a quick return. This study also found out that the declining investment costs and the presence of a Power Purchase Agreement are the drivers for the development of solar PV microgrid in the countries. In contrast, the unstable grid connection and the insufficient technical knowledge are some barriers to this development.

The development of solar PV microgrid in Indonesia is a complex issue because of a complex relationship between different technical, financial, social and regulatory aspects. The financial aspect, particularly the presence of a solar PV market, has been seen as the top priority to be resolved in the country. After determining the priority, a framework for successful implementation of solar PV microgrid in Indonesia is being developed. The developed framework has four stages in which each key stakeholder has different roles in each stage. Successful implementation of the framework can increase solar PV microgrid penetration in Indonesia.

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List of Abbreviations

Abbreviation	
^oC	Degree Celsius
^oE	Degree East
^oN	Degree North
^oS	Degree South
a-Si	Amorphous Silicon
AC	Alternating Current
ASEAN	Association of Southeast Asian Nations
BPP	Electricity Supply Cost
C	Coulomb
c-Si	Crystalline Silicon
CdTe	Cadmium Tellurium
CIGS	Copper Indium Gallium Selenide
CSR	Corporate Social Responsibility
DC	Direct Current
EPC	Engineering, Procurement, and Construction
FF	Fill Factor
FiTs	Feed-in-Tariffs
GHG	Greenhouse Gases
GW	Gigawatt
GWh	Gigawatt-hours
HIT	Heterojunction with Intrinsic Thin-Layer
IEC	International Electrotechnical Commission
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency

Abbreviation

IRR	Investment Rate of Return
J	Joule
K	Kelvin
kW	Kilowatt
kWh	Kilowatt-hours
LCOE	Levelized Cost of Electricity
m-Si	Multi Crystalline Silicon
m^2	Square meter
mm	Millimetre
MoEMR	Ministry of Energy and Mineral Resources
MoI	Ministry of Industry
MTOE	Million Tonnes of Oil Equivalent
MW	Megawatts
NDC	Nationally Determined Contributions
NPV	Net Present Value
O&M	Operation and Maintenance
PLN	Indonesia State-owned Electricity Company
PP	Payback Period
PPA	Power Purchase Agreement
PR	Performance Ratio
PV	Photovoltaic
REC	Renewable Energy Certificate
RUPTL	Power Supply Business Plan
SDG(s)	Sustainable Development Goal(s)
SHS	Solar Home System

Abbreviation

SNI	Standard National Indonesia
STC	Standard Temperature Condition
TKDN	Local Content Requirement

List of Definitions

Term	Definition
Enabling Mechanism	The factor that can help to reduce the barriers in the development of technology. There are two different types of mechanism. A market-based instrument is a mechanism that will directly stimulate the market, such as the presence of incentives. A non-market-based mechanism is an instrument that will enhance technology implementation without direct intervention on the market, such as capacity building as well as technology research and development.
Microgrid	A localized small network of the electricity system with a local source of supply that is usually attached to a centralised/decentralised grid but able to function independently. This microgrid is relatively smaller compared to a traditional/conventional electricity grid system.
Performance Characteristic	A measurement of how effective or efficient a system works, such as performance ratio. The performance ratio is the ratio of the actual power generated from the system over its theoretical value.
Solar Photovoltaic (PV)	A technology which converts solar radiation into electricity by utilizing the photovoltaic effect of a semiconductor such as crystalline silicon.

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Chapter 1: Introduction

1.1 Background

To limit global warming to 1.5 degrees Celsius (^{o}C), renewable energy has been seen as one measure that can be implemented in both developed and developing countries (Coninck et al. 2018). It is in accordance with Sustainable Development Goals (SDGs) 13 to take urgent action to combat climate change. The increase of renewable energy share can also help the governments addressing SDG 7 by facilitating access to clean energy (United Nations Development Programme 2019). Additionally, this deployment of clean energy technology can lead to multiple SDG dimensions including poverty eradication and reducing inequalities (Roy et al. 2018).

There is a remarkable increase in the installation of renewable energy in the last couple of years. In 2018, an expansion of 181 gigawatts (GW) renewable energy capacity was installed within the power generation sector (REN21 2019). Interestingly, more than half of this installed capacity was accounted for solar photovoltaics (PV) technology (REN21 2019). This technology has been seen as the promising solution to overcome the energy crisis because of its simplicity, environmentally friendly, and abundance potential in nature (Farhoodnea et al. 2015, Ismail, Moghavvemi, and Mahlia 2013, Humada et al. 2018, Kumar, Sudhakar, and Samykano 2019, Khatib, Sopian, and Kazem 2013, Li et al. 2018). The growth in photovoltaic markets is also driven by both technological advancements and policy-related actions, such as the promotion of rooftop solar projects and rural electrification programs (Kichou et al. 2018, Necaibia et al. 2018, REN21 2019).

The countries situated in the equator with tropical climate receives the highest amount of solar radiation throughout the year because the region experiences almost no seasonal variation (Baharin et al. 2016, Dobaria, Pandya, and Aware 2016, Quansah et al. 2017). It can be seen from Figure 1 that the power photovoltaic potential in tropical region is greater than 3.2 kWh/kWp (World Bank Group 2019). In the Köppen–Geiger climate classification system, a tropical climate is characterised by an average temperature greater than 18°C all months (Pidwirny 2006). Additionally, based on its precipitation, there are three distinct varieties within the tropical climate zone, namely tropical rainforest (Af), tropical monsoon (Am), and tropical savanna (Aw) climates (Pidwirny 2006).

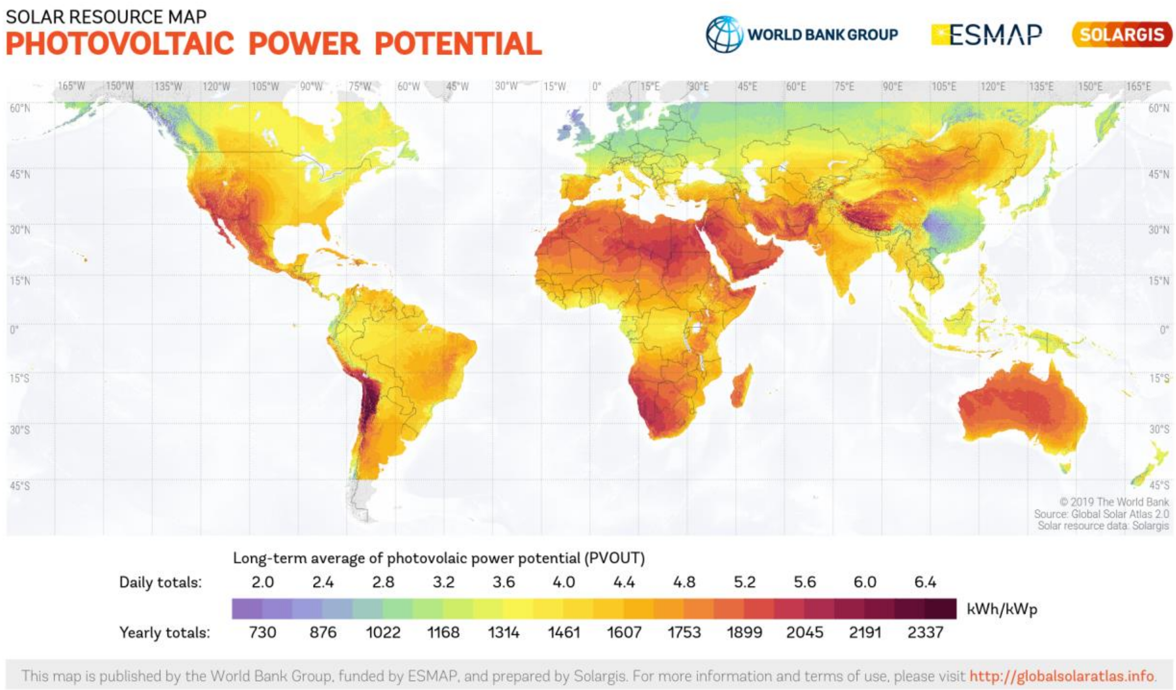


Figure 1 Power Photovoltaic Potential. Source: World Bank Group 2019.

The tropics not only make up about 36% of the Earth's landmass but also are home to around 40% of the world population (National Geographic 2019, World Population Review 2019). It is also estimated that by the late 2030s, half of the world population will reside in this tropic region spreading over 90 countries (World Population Review 2019). Unfortunately, only 15 countries are categorized as high-income countries while 22 countries are designated as low-income countries, and the rest is middle-income countries (World Bank 2019b). Almost 20% of people in tropics have no electricity access consisting of 212 million people in Asia, 468 million people in Africa, and 28 million people in Central and South America (REN21 2019). Because the region has an abundance of solar radiation, solar PV microgrid can play a key role to fulfil the energy needs of millions of people living in this region, particularly in remote areas (REN21

2019). However, only four countries in this region have installed solar PV systems with a total capacity greater than one gigawatt, which are India, Brazil, Mexico, and Thailand (IRENA 2019).

While the development of solar PV microgrid can improve electricity access in rural and semi-urban areas in the tropics region (Ismail, Moghavvemi, and Mahlia 2013, Quansah et al. 2017, Tossa et al. 2016), this development needs meticulous planning. The solar PV performance may determine the economics of the system, including its funding and energy market (Farhoodnea et al. 2015, Limmanee et al. 2017). Yet, the output power of a solar system strongly depends on solar radiation availability which varies with location and is affected by other environmental factors, such as ambient temperature and shadowing effects (Humada et al. 2016, Ismail, Moghavvemi, and Mahlia 2013, Khatib, Sopian, and Kazem 2013, Limmanee et al. 2017). This variation happens because each location is subjected to different climate and weather conditions. Furthermore, the environmental conditions in the same region may differ at the same time because of different microclimates (Baharin et al. 2016, Daher et al. 2018, Ferrada et al. 2015).

Generally, tropical climate is characterised by high humidity, a significant amount of rainfall, high vegetation density, and high ambient temperature (Athokpam and Deshmukh 2018, Ogbomo et al. 2017, Saber et al. 2014). The high ambient temperature can raise the module temperature resulting in the performance degradation of a solar PV. This degradation can be worsened by the presence of cloud and vegetation which block the sun (Ogbomo et al. 2017, Saber et al. 2014). Furthermore, this performance reduction may significantly contribute to the variation in the Levelized Cost of Electricity (LCOE) which can make the investment in solar PV unattractive (Limmanee et al. 2017). Therefore, a study on the performance characteristic of solar PV is required to help to design a suitable system for a particular tropical location (Baharin et al. 2016, Humada et al. 2018).

Low solar PV diffusion can also be worsened by the absence of supportive policy landscapes in the tropical region. For example, only half of the countries in tropics have been considering renewable energy as a measure to reduce greenhouse gases (GHG) in their Nationally Determined Contributions (NDC) submission (REN21 2019). Additionally, less than a quarter of the tropic countries have a renewable energy target (REN21 2019). Regarding market-based mechanism policies, from 90 tropic countries, only 20 countries have implemented feed-in-tariff, eight countries have adopted renewable energy quota, and only one country has executed renewables energy certificate (REC) trading scheme (REN21 2019). Hence, it is necessary to study the opportunities and barriers as well as the enabling mechanisms in a particular country or region to understand its policy landscape for developing solar PV microgrid.

The low solar PV penetration also happens in Indonesia, the fourth most populous country in the world. The country had reached renewable energy share, around 13%, by 2016 and electrification ratio, about 95%, by 2017 (REN21 2019, World Population Review 2019). The implementation of solar PV microgrids not only is suitable for Indonesia's geographical situation but also can help to accelerate the country's effort to achieve its renewable energy target, 23% by 2025 (Republic of Indonesia 2017). Situated in the equator region with tropic climate conditions, almost 50% of renewable energy potential in Indonesia comes from solar energy, up to 208 GW (National Energy Council 2016, Republic of Indonesia 2017). However, less than one percent of this solar potential, or around 78.5 megawatts (MW), that has been utilized in Indonesia from a projection of 6.5 GW by 2025 (National Energy Council 2016, Republic of Indonesia 2017). Thus, the development of a framework, integrating both technical and non-technical aspects, is required to help the country increasing its solar PV penetration on Indonesian electricity grids.

1.2 Research Objectives

The objectives of this research are:

- To identify the performance characteristics of a solar PV microgrid under tropical climate conditions;

- To evaluate the potentials, constraints, and mechanisms for implementing solar PV microgrids; and
- To develop a framework, incorporating both technical and non-technical issues, to implement this solar PV microgrid for meeting a country's energy transition target.

1.3 Research Questions

The main research question underpinned in this study is

What is the 'best practice' integrating both technical and non-technical aspects in order to increase solar PV microgrid penetration in a tropical region, particularly in Indonesia?

To address this question the following sub-questions are posed:

i. How do environmental conditions affect the performance of solar PV in a tropical region?
ii. What are the main opportunities and barriers to implementing solar PV microgrids and how to overcome those constraints?
iii. How should these technical and non-technical factors be combined to determine a framework for solar PV microgrids implementation?

1.4 Research Boundaries

Because this study needs to be manageable, determining the research boundary is an important process. The scope area for the study is solar PV microgrids implementation undertaken in Indonesia. Microgrids can be defined as a localized small network of the electricity system with a local source of supply that is usually attached to a centralised/decentralised grid but able to function independently. This microgrid is relatively smaller compared to a traditional/conventional electricity grid system. The solar home systems (SHS) and solar rooftop systems are excluded from this study. The reason for selecting this country was the author's familiarity with the Indonesian energy sector. This tropical country has a large and growing electricity demand as well as has made substantial progress in increasing the electrification ratio. The country also has a significant amount of untapped solar energy potential. Yet, the country is still on early progress in the adoption of solar energy due to its reliance on coal for its electricity.

1.5 Research Importance

Compared to the other renewable energy source potential, solar energy penetration in Indonesia is relatively small. This low diffusion of solar PV within Indonesia's electricity mix is influenced by both technical and non-technical factors. This research not only will address those factors but also will attempt to overcome those challenges by developing a framework for solar PV microgrids so that their penetration on Indonesian electricity grid can be increased.

The relatively large body of existing literature considers the technical and non-technical issues separately. Additionally, much of the previous research has not assessed the challenges and the potentials associated with solar PV microgrids from the perspective of different stakeholders. To develop a comprehensive framework, this research incorporates both technical parameters as well as financial and regulatory issues obtained from various stakeholders involved in Indonesia. This research will help developers, researchers, and policymakers in Indonesia to identify the factors for developing solar PV microgrid in Indonesia.

Furthermore, the procedures and approaches given in this research are reproducible. This research can be adapted to the other tropical regions whether on a regional scale, such as ASEAN or even on a municipal scale, like Darwin in Australia.

1.6 Structure of the Dissertations

The preceding sections of this chapter have outlined the background, stated the objectives and questions of the present research, set the research boundaries, and presented the importance of the research. Chapter 2 will investigate the literature review related to this research followed by Chapter 3 that will discuss the methodology used in the study consisting of desktop research, techno-economic evaluation, as well as survey and interview. Chapter 4 will present the result and analysis of this study based on a case study in Indonesia including the performance evaluation of a solar PV microgrid followed by the survey and interview appraisal on the opportunities and barriers in implementing this technology. The framework development will be discussed in Chapter 5. Lastly, Chapter 6 will provide conclusions and recommendations.

Chapter 2. Literature Review

The purpose of this chapter is to provide background information for the dissertation. The first section of this chapter gives an overview of the tropical region. An introduction to the techno-economic analysis of solar PV is given in the second section followed by the summary of policy landscape from different tropical countries. The last section reviews Indonesia's policy landscape.

2.1 Tropical Region Overview

2.1.1 Geographic and Demographic Situation

The tropics are a region of the Earth situated roughly in the middle of the globe between the tropic of Cancer in the Northern Hemisphere and the tropic of Capricorn in the Southern Hemisphere, at latitude 23^{o} North (^{o}N) and 23^{o} South (^{o}S) respectively (National Geographic 2019). The tropics get more exposure to the sun so that this region is relatively warm throughout the year and only experiences two seasons, namely the wet season and the dry season. The tropical climate has an average temperature greater than 18^{o}C and precipitation greater than 1500 millimetres (mm) per year (Pidwirny 2006).

World Population Review (2019) states that more than one-third of the surface of the planet is situated in the tropical region. Around 90 countries are located in this tropics spreading all over Asia, Africa, as well as Central and South America (World Population Review 2019). In Asia, there are 10 tropical countries dominated by Southeast Asia Nations (ASEAN) countries. Around 40 countries in Africa have tropical climates and the other 40 countries are spreading over Central and South America.

World Population Review (2019) claims that more than one-third of the Earth's population lives in a tropical region with a projection that half of the world population will reside in tropics in 2030. Approximately 3.4 billion people are living in the tropics region (World Population Review 2019). Table 1 shows the top 10 countries with the highest population in the tropical region. Those 10 countries are home for around 2.6 billion people where half of this number resides in India. Unfortunately, none of these highly populated countries are categorized as high-income countries. There are only 15 countries in the tropics categorized as high-income countries where most of them are located in the Caribbean Sea (World Bank 2019b).

Table 1 The top 10 countries with the highest population in a tropical region.

Country Name	Area (km2) (World Population Review 2019)	Population (World Population Review 2019)	Population Density (People/km2) (World Population Review 2019)	GDP Per Capita ($) (World Bank 2019)	Income Group (World Bank 2019)
India	3,287,590	1,366,417,754	416	1,981	Lower middle income
Indonesia	1,904,569	270,625,568	142	3,837	Lower middle income
Brazil	8,515,767	211,049,527	25	9,881	Upper middle income
Nigeria	923,768	200,963,599	218	1,969	Lower middle income
Mexico	1,964,375	127,575,529	65	9,281	Upper middle income
Ethiopia	1,104,300	112,078,730	101	768	Low income
Philippines	342,353	108,116,615	316	2,982	Lower middle income
Vietnam	331,212	96,462,106	291	2,366	Lower middle income
Thailand	513,120	69,625,582	136	6,578	Upper middle income
Tanzania	945,087	58,005,463	61	1,005	Low income

Source: World Bank 2019, World Population Review 2019

2.1.2 Electrification, Renewable Energy, and Solar PV Status

Some people in tropical countries have limited access to electricity. According to data from REN21 (2019), only five countries in the region have an electrification ratio of 100%, namely Singapore, Barbados, Mexico, Thailand, and Mauritius. Interestingly, those countries are categorized as high-income and upper-middle-income countries (World Bank 2019b). On the other hand, around 28 countries have an electrification ratio of less than 50% (REN21 2019). From 28 countries, 27 countries are located in Africa (Figure 2) characterised with low-income and lower-middle-income conditions (World Bank 2019b). In total, around 708 million people in tropics have no access to electricity, particularly those who live in rural and remote areas (REN21 2019). It happens mainly due to the high cost of grid expansion, especially to a small density community (Diouf, Pode, and Osei 2013).

Additionally, most tropical countries have a limited share of clean energy in their power generation sector. From 90 countries in the tropic region, only 20% of tropical countries have renewable energy share greater than 50% in 2015 (World Bank 2015). Interestingly, most renewable energy generation is dominated by hydropower, such as in Paraguay and Ethiopia where hydropower accounted for 99% and 92% of total electricity generation in 2015 respectively (World Bank 2015). Figure 3 illustrates the renewable energy share in tropics.

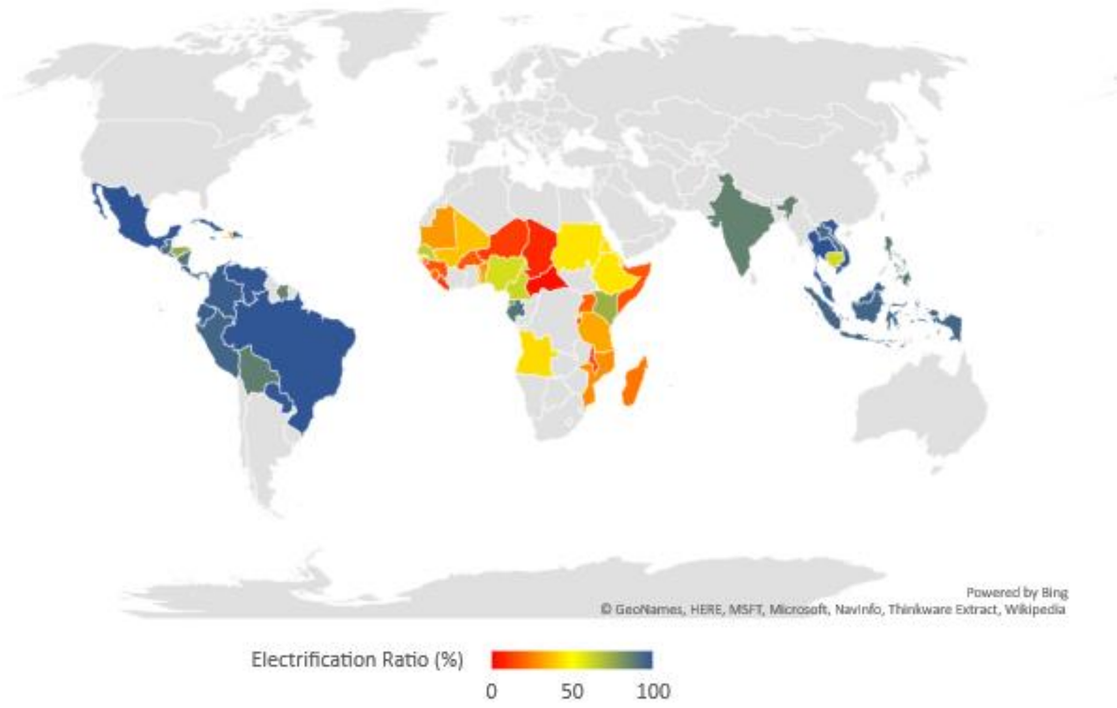


Figure 2 Electrification ratio status in tropical countries.

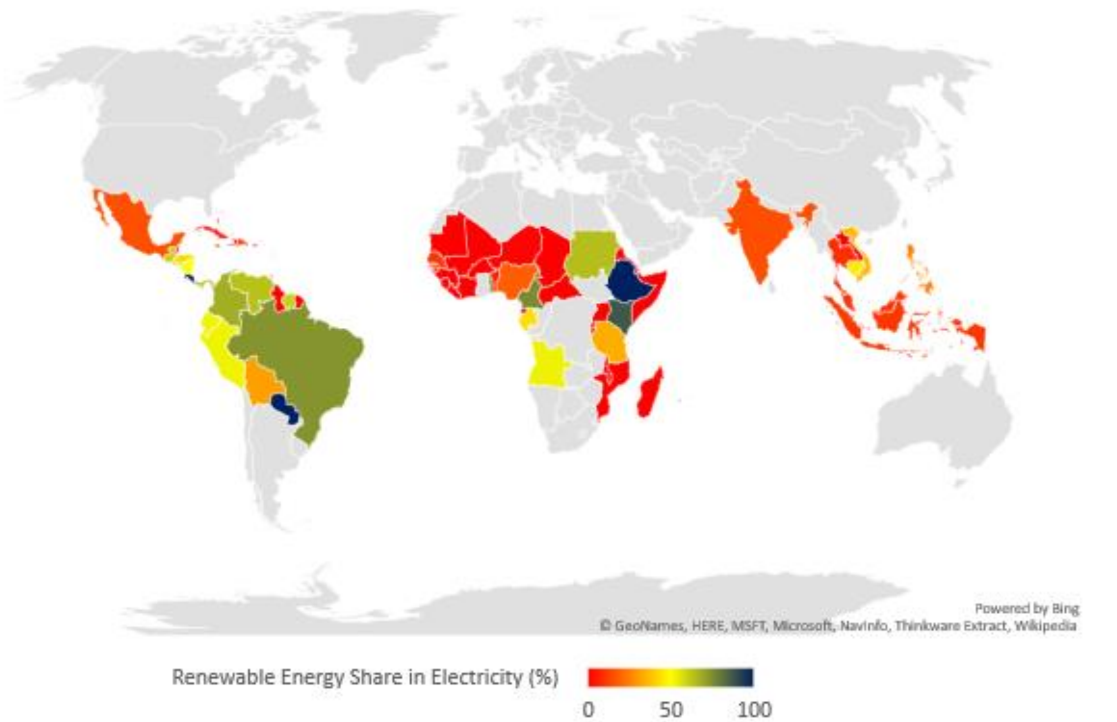


Figure 3 Renewable energy share in tropical countries.

Although some tropical countries rely on hydropower, there is some significant progress in solar PV implementation in this region. Table 2 shows 15 tropical countries with the highest solar PV installation. India becomes the top player in the region with an installed capacity of around 26.8 GW (IRENA 2019). It happens because India has launched a Jawaharlal Nehru National Solar Mission program to ensure energy security, energy access, and energy affordability (Dobaria, Pandya, and Aware 2016). Within the ASEAN region, Thailand becomes the leader in this technology implementation followed by the Philippines, Malaysia, Singapore, and Vietnam (IRENA 2019). Mexico, Brazil, and Senegal are also the key players within Central America, South America, and Africa respectively (IRENA 2019). In Senegal, solar PV microgrid has been seen as a solution for the electrification in rural areas of the country (Diouf, Pode, and Osei 2013). Meanwhile, the low bid prices of solar PV generation were seen as the driving force in Brazil (REN21 2019). These drivers will be discussed further in section three.

Table 2 The list of countries that have the highest solar capacity in the tropical region.

Country Name	**Electrification Ratio (%)**	**Renewable Energy Share in Electricity (%)**	**Solar Capacity (MW)**	**Renewable Energy Capacity (MW)**	**Solar Fraction (%)**
Data Year	2017	2015	2018	2018	2018
Source	(REN21 2019)	(World Bank 2015)	(IRENA 2019)	(IRENA 2019)	(IRENA 2019)
India	87	15.34	26,869	117,919	23
Thailand	100	8.53	2,720	10,411	26
Mexico	100	15.39	2,541	22,128	11
Brazil	99	73.96	2,296	135,674	2
Philippines	90	25.41	886	6,482	14
Honduras	75	42.27	516	1,692	30
Malaysia	98	9.95	438	8,157	5
Peru	95	52.73	345	6,252	6
El Salvador	96	57.82	184	1,250	15
Dominican Republic	97	11.63	166	1,017	16
Singapore	100	1.82	150	279	54
Panama	92	65.32	147	2,261	7
Senegal	65	10.41	134	234	57
Guatemala	92	60.39	114	2,995	4
Vietnam	99	36.73	106	18,523	1

Source: IRENA 2019, REN21 2019, World Bank 2015

2.2 Techno-economic Evaluation of Solar PV

A well-designed solar PV project will optimally use an integrative process that carefully considers multiple spectra of analysis. Technical assessment, such as resource assessment and technological performance simulations, as well as economic assessment, like financial simulation and comparative analysis, must be performed in designing a system (Baharin et al. 2016, Farhoodnea et al. 2015, Good and Johnson 2016, Humada et al. 2018).

2.2.1 Performance Characteristic

2.2.1.1 Current versus Voltage (I-V) Curve

Khatib, Sopian, and Kazem (2013) explained that a solar cell can be expressed by a current source, a diode, a shunt resistance, and a series resistance. They also mentioned that the character of a solar cell can be expressed by its current and voltage relationship (I-V) at specific temperatures and solar radiation levels. According to Humada et al. (2018), a solar cell has a similar function to a semiconductor diode in the absence of sunlight which can be represented by

$$I = I_L - I_o\left[exp\left(\frac{q(V+IR_s}{nkT_c}\right) - 1\right] \qquad (1)$$

where I is the output current, I_L is the photocurrent, I_o is the reverse saturation current, q is the electron charge value (1.602 x 10^{-19} C), k is the Boltzmann constant (1.381 × 10−23 J/K), T_c is the cell temperature, R_s is the series resistance, and n is the ideality factor between 1 and 2. Meanwhile, an ideal cell under an illuminated condition is expressed by a current generator connected in parallel with a diode and can be characterised by

$$I = I_L - I_o\left[exp\left(\frac{q(V+IR_s)}{nkT_c}\right) - 1\right] - \frac{V+IR_s}{R_{sh}} \qquad (2)$$

where R_{sh} is the shunt resistance.

A typical I-V curve indicates the current and voltage at the different operating conditions. When a PV module is connected without load, a very high current (I_{sc}) is passing during this short-circuit condition. In contrast, there is no current to pass when a PV module is not connected to any load, but a very high voltage (V_{oc}) occurs during this open-circuit condition. The short-circuit current I_{sc} can be considered equivalent to the photocurrent I_{ph} proportional to the solar irradiance at normal levels (Ndiaye et al. 2014). The knee of this I-V curve indicates the operating condition in which the product of current and voltage result in maximum power point (P_{max}).

Another way to visualise a PV module characteristic is by presenting the power and voltage relationship (P-V) curve. During open-circuit and short-circuit conditions, the power equals to zero. The power reaches its maximum power point P_{max} at the current and voltage values referred to as I_{MP} and V_{MP} respectively, where

$$P_{max} = I_{MP} \, x \, V_{MP} \qquad (3)$$

2.2.1.2 Fill Factor

Another important performance indicator is the fill factor (FF) representing the rectangularity of the I-V curve. The formula of this fill factor can be written as

$$FF = \frac{V_{MP} \, x \, I_{MP}}{I_{SC} \, x \, V_{OC}} \qquad (4)$$

An ideal PV module will produce a perfectly rectangular I-V curve where the maximum power point concurs with the short-circuit current I_{sc} and open-circuit voltage V_{oc} for a fill factor of 1. The arrays with higher fill factor value will produce more power if these arrays have the same values of I_{sc} and V_{oc}.

2.2.1.3 Efficiency

The efficiency of a cell or module can be defined as the fraction of power output P_{out} over the power input P_{in} which can be written as

$$Efficiency = \frac{P_{out}}{P_{in}} x100\% = \frac{I_{SC} \, x \, V_{OC} x FF}{GxA} x100\% \qquad (5)$$

where G is solar radiation in W/m^2, and A is the module area in m^2.

2.2.1.4 Array, Reference, and Final Yields

The system yield can be categorized into three types, namely array yield, reference yield, and final yield (Dobaria, Pandya, and Aware 2016, Farhoodnea et al. 2015, Quansah et al. 2017). These yields are indicating the actual array operation relative to the array's rated capacity. The array yield Y_a is defined as the energy output from the PV module E_{DC} normalized by the PV rated capacity P_{rate}. This array yield can be interpreted as the time taken by solar PV to operate at a standard temperature condition (STC) so that it generates nominal DC energy, where

$$Y_a = \frac{E_{DC} \, [kWh \, DC]}{P_{rate} \, [kW \, DC]} \qquad (6)$$

The reference yield Y_r is defined as the ratio of the total in-plane daily solar radiation H_t in kWh/m² to the array reference irradiance G_r (1 kW/m²). This reference yield can also be interpreted as the number of peak sun hours (Farhoodnea et al. 2015).

$$Y_r = \frac{H_t}{G_r} = \frac{H_t\ [kWh/m^2]}{1\ [kW/m^2]} \quad (7)$$

The final yield Y_f is defined as the AC energy generated E_{AC} by PV power plant divided by the PV rated capacity P_{rate} indicating the full sun hours that PV plant would operate at an ideal condition or STC (Dobaria, Pandya, and Aware 2016). It can be expressed as

$$Y_f = \frac{E_{AC}\ [kWh\ AC]}{P_{rate}\ [kW\ DC]} \quad (8)$$

2.2.1.5 Performance Ratio

Performance ratio (PR) is a dimensionless parameter that measures solar PV quality as a ratio between the actual and theoretical energy output of a PV plant. It measures how effectively a system converts the collected sunlight into delivered energy and quantifies the overall losses effect due to inverter inefficiency, component failures, as well as wiring mismatch (Dobaria, Pandya, and Aware 2016, Farhoodnea et al. 2015, Quansah et al. 2017). The performance ratio is also the ratio of final yield to reference yield.

$$Performance\ Ratio\ (PR) = \frac{Y_f}{Y_r} = \frac{E_{AC}/P_{rate}}{H_t/G_r} \quad (9)$$

2.2.1.6 Capacity Factor

One of the most confusing aspects of renewable energy is the difference between installed capacity and the actual output that is obtained from these systems. The capacity factor (CF) is simply the ratio of energy generated over a time period, typically a year, divided by the energy output that would have been generated if the system were operated at full capacity for the entire period (Farhoodnea et al. 2015, Humada et al. 2016, Necaibia et al. 2018, Quansah et al. 2017). The capacity factor varies for solar PV systems depending on the location. The annual capacity factor can be determined as

$$Capacity\ Factor\ (CF) = \frac{Energy\ Generated\ in\ a\ year\ (kWh)}{Installed\ Capacity\ (kW) x\ 8760\ hours} \qquad (10)$$

2.2.1.7 Degradation Rate

In a long-term performance assessment, degradation is also one important issue. Degradation can be defined as the outcome of performance loss progression happened at the cell, module, or system levels (Ndiaye et al. 2014). Ndiaye et al. (2014) defined that global degradation (GD) is the parameter value considered from the first installation to the respective period which can be written as

$$GD\ (\%) = \frac{X(t_n) - X(t_0)}{X(t_0)} x\ 100 \qquad (11)$$

where $X(t_n)$ and $X(t_0)$ are respectively the parameter value in the STC condition at time t_n and t_0. t_0 represents the initial time when the solar module puts into service while t_n represents the time when the test is carried out. Hence, the degradation rate (DR) can be expressed as

$$DR\ = \frac{GD}{t_n - t_0} \qquad (12)$$

2.2.2 Factors Affecting the Performance

Several studies have been conducted to see both environmental and technical parameters on the performance of solar PV. The performance of a PV system is not merely depending on geographic position, cell technology, and installation configuration but also depending on environmental factors, such as global radiation, ambient temperature, and soiling loss (Al-Otaibi et al. 2015, Dabou et al. 2016, Daher et al. 2018, Dobaria, Pandya, and Aware 2016, Farhoodnea et al. 2015, Ferrada et al. 2015, Necaibia et al. 2018, Osma-Pinto and Ordóñez-Plata 2019).

2.2.2.1 Solar Radiation

Solar radiation determines the power output. The increasing radiation intensity generates a positive increase in the current and power output (Humada et al. 2016). The rise in the number of photons striking the solar PV module leads to an increase in electron-hole pair generation and a higher photocurrent. Thus, the higher the radiation intensity, the higher the current value resulting in an increase in its power output. The irradiance value is also affected by the orientation and tilting of the module's surface. Portolan dos Santos and Rüther (2014) compared multiple solar modules at different array positions. The irradiance value is higher if the solar panel is directly facing the sun.

2.2.2.2 Temperature and Wind Speed

The PV system's performance is also affected by the module's temperature. The module temperature rises with the increase in solar radiation. This temperature increase reduces the bandgap so that the photocurrent slightly increases. However, this situation also decreases the open-circuit voltage significantly. Consequently, the total power output decreased with the increment of temperature (Dobaria, Pandya, and Aware 2016). It happens due to the high injection of electrons from the valence band to the conduction band of a semiconductor material (Humada et al. 2016). The increase in temperature not only reduces performance ratio and efficiency but also increases degradation rate and system loss (Dabou et al. 2016, Al-Otaibi et al. 2015, Luo et al. 2019).

The presence of wind can have a substantial and highly dynamic influence on PV module temperatures. Several studies have been conducted to study the impact of wind speed on the PV module. Al-Otaibi et al. (2015) reported that with the help of the wind, the modules in Kuwait are cooled rather quickly. Osma-Pinto and Ordóñez-Plata (2019) claimed that the air velocity is more influential on the performance of the PV panel in Colombia particularly when the solar irradiations are high. Hence, the wind has a strong cooling effect on PV modules.

2.2.2.3 Shading, Cloudiness, and Soiling

PV modules will experience loss when the modules are shaded by trees, buildings, or other objects in the proximity to the modules. A reduction in solar irradiance as a result of complete or partial shading will have an impact on the module performance (Maghami et al. 2016). It happens because there is a nonlinearity between the voltage and current under the partially shaded condition. Maghami et al. (2016) stated that there are two types of shadings, namely soft shading and hard shading.

Soft shading causes a current reduction, yet the voltage remains the same. Meanwhile, hard shading reduces the voltage while the current remains the same. In the case of soft shading, the shaded cells are unable to produce the same amount of current that unshaded cells generate. Because of the series connection, the weakest (shaded) cell dictates the total current of the module causing the reduction in current. In addition to that, the shaded cell acts like a load where the current passes through this unshaded cell causing no current passes through the system. In a hard-shading case, the object covers some of the cells. As a result, the string cannot produce a similar amount of voltage. Hence, voltage losses happen. However, because some unshaded cells are receiving solar irradiance, the current remains constant.

The presence of clouds indicated by the clearness index also affects the performance of solar PV. A study conducted by Dabou et al. (2016) revealed that there were some irregular forms and some peaks on the PV module, inverter, and system efficiency during the cloudy days. They claimed that this variation naturally happens because of the changing in solar radiation due to the presence of clouds cover. The other studies also found out that the presence of cloud might also reduce the energy yield as well as performance ratio of the system particularly during rainfall season (Athokpam and Deshmukh 2018, Baharin et al. 2016, Dobaria, Pandya, and Aware 2016, Ogbomo et al. 2017).

The presence of particles that cover the surface of the PV modules such as snow, dirt, and dust can also cause performance loss. Dust can be generated from many sources, such as volcanic eruptions and air pollution. The module's glass transmittance is affected by the dust because the dust absorbs and scatters the light radiation. The loss caused by the presence of dust may vary depending on the dust's particle size, chemical composition, and layer's thickness (Ferrada et al. 2015). Daher et al. (2018) observed that losses due to soiling can be as high as 14.23% during dry dusty periods and as low as 0.03% following rainfall events. Hence, they suggest that regular cleaning needs to be scheduled to maintain the modules' performances.

2.2.2.4 Cell Technology

Cell technology itself has a significant impact on the performance of solar PV. Regarding efficiency, some cell technologies perform better than others. Polman et al. (2016) compared the efficiency of different cell technology. They found out that the monocrystalline silicon (m-Si) and the multi-crystalline silicon (mc-Si) have higher efficiency than the amorphous silicon (a-Si). The other thin-film technologies, such as Cadmium Tellurium (CdTe) and Copper Indium Gallium Selenide (CIGS), also have low efficiency although it is larger than the a-Si one.

Additionally, five intrinsic losses cannot be avoided in an idealised solar cell (Hirst and Ekins-Daukes 2011). Firstly, the photons with energy below the bandgap cannot be absorbed because there are differences between the mono-energetic absorption of a single bandgap and the broad solar spectrum. Secondly, the strong interaction between lattice photons and exciting carriers causes thermalisation losses. The emission losses also happen due to the emission of energy from some absorber. The Carnot loss might happen because the solar cell might work following the heat engine principle. Finally, due to the inequality between the absorption and emission angle, the Boltzmann loss might occur resulting in the generation of entropy from photon expansion (Hirst and Ekins-Daukes 2011).

The performance characteristic of a solar module can be affected by its temperature. However, some cell technologies have a better capability to adapt to the temperature. For example, although the monocrystalline silicon (m-Si) module has a better performance ratio compared to the amorphous silicon (a-Si) one, some thin-film modules might reach a higher performance ratio than m-Si one (Ferrada et al. 2015).

2.2.3 Characteristic Comparison

Several studies have been done to compare different performance parameters in tropical regions. Table 3 summarises the performance comparison cited in Daher et al. (2018), Farhoodnea et al. (2015), Humada et al. (2018), and Necaibia et al. (2018).

Table 3 Characteristic comparison from the various countries in tropical regions.

Location	PV Type (mounting)	Capacity (kWp)	Final Yield (kWh/kWp)	PV Module Efficiency (%)	Performance Ratio (%)	Capacity Factor (%)	Cited In
Singapore	p-Si(rooftop, BIPV)		3.12	11.8	81		Daher et al. (2018)
Gandhinagar, India	p-Si (ground)		2.79-5.14	11.07	75.3		
Gandhinagar, India	a-Si (ground)		2.62-4.84	6.56	70.8		
Karnataka, India	mc-Si (ground)		3.73	10.1-13.25	70	15.69	
Sohar, Oman	p-Si (rooftop)		5.14		84.6	21	
Abu-Dubai	p-Si		4.51-5.57	10.3-11.1			
Kuwait	CIGS (rooftop)		4.5		70-85		
Nouakchott, Mauritania	a-Si (ground)		4.27		67.96		
Maseru, Lesotho	p-Si (ground)		3.43	10.93	67	17.2	
Fortaleza, Brazil	p-Si (ground)		4.6	13.3	82.9	19.2	
Sivagangai, India	a-Si (ground)		4.81	6.08	89.15		
Rajkot, India	p-Si (rooftop)		4.49		74		
Malaysia	c-Si	5.76	2.97	8.8	64	24.7	Farhoodnea et al. (2015)
Malaysia	mc-Si	0.26	3.2	9.7	61	26.6	
Malaysia	mc-Si	5	2.5	12.8	73	10.5	
Malaysia	p-Si	1.92	3.3	11.8	78.2	27.5	
Malaysia	a-Si	6.08	3.8	6.9	94.6	31.6	
Malaysia	c-Si	27	3.2	11.7	81	26.7	
Malaysia	c-Si	6	0.7	3.4	20	10.3	
Malaysia	c-Si	2	2.1	10	59	29.4	
Malaysia	c-Si	2	2.4	11	65	32	
Malaysia	p-Si	3	3.8	10.1	77	15.7	
Thailand		11		10.41	73.45		Humada et al. (2018)
Brunei		5.25		12.9	50		
Singapore		142.5		11.2	81		
Indonesia		5.4		8	75.4		
Malaysia		3		10.11	77.28		
Malaysia		5		10.92	70.88		
Thailand		500	2.9-4.0		70-90		Necaibia et al. (2018)
Singapore	p-Si	142.5	3.12	11.8	81		
India	p-Si	11.2	3.67	13.42	78		
India	a-Si	110	2.67-3.36		71.6-79.5		

Source: (Daher et al. 2018, Farhoodnea et al. 2015, Humada et al. 2018, Necaibia et al. 2018).

The performance ratio is one key parameter that can be used to compare multiple datasets to analyse how different factors, such as cell technology and environmental factors, affects the PV module or the PV system (Dobaria, Pandya, and Aware 2016). It can be seen from Table 3 that the performance ratio is ranging from 61% to 95%. The module efficiency is ranging from 6% to 14% depending on cell technology. The a-Si modules have the lowest efficiency. The capacity factor in this tropical region is ranging from 10.3% to 32% (Daher et al. 2018, Farhoodnea et al. 2015, Humada et al. 2018, Necaibia et al. 2018). Limmanee et al. (2017). Investigated different degradation rate values for multiple modules in Singapore and Thailand.

They found that thin-film technologies have a higher degradation rate compared to the crystalline silicon and Heterojunction with Intrinsic Thin-Layer (HIT) ones. From the study, a CIGS module has a degradation rate of around 6% per year.

2.2.4 Economic Evaluation of a Project

The long-term PV module performance, such as energy yield, performance ratio, capacity factor, and degradation rate might have a significant impact on the economic feasibility of a PV system. Several studies have been conducted to analyse the techno-economic evaluation of solar PV systems. There are multiple indicators that can be used to determine the economics of the project, namely net present value (NPV), payback period (PP), investment rate of return (IRR), and LCOE (Haramaini et al. 2019, Ismail, Moghavvemi, and Mahlia 2013, Astriani et al. 2019, Ketut Sugirianta, Giriantari, and Satya Kumara 2016, Pranadi et al. 2019).

NPV can be defined as the value of future cash flows in today's currency discounted at the discount rate. The NPV can be expressed in the mathematical formula as

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t} \qquad (13)$$

where B_t is the benefit at year-t, C_t is the cost at year-t, i is a discount rate, and n is project lifetime (Haramaini et al. 2019, Ketut Sugirianta, Giriantari, and Satya Kumara 2016, Pranadi et al. 2019). A project is economically feasible if its NPV is greater than zero (Ketut Sugirianta, Giriantari, and Satya Kumara 2016).

Another economic parameter that can be used to determine the feasibility of a project is the payback period. This parameter calculates how long that it takes for a project to recoup its own initial cost. The quicker the investment cost can be recovered, the more desirable is the investment (Ketut Sugirianta, Giriantari, and Satya Kumara 2016). The payback period can be calculated using the following formula.

$$\sum_{t=0}^{PP} \frac{B_t - C_t}{(1+i)^t} = 0 \qquad (14)$$

where B_t is the benefit at year-t, C_t is the cost at year-t, i is a discount rate, and PP is payback period (Haramaini et al. 2019, Pranadi et al. 2019). A simplified formula can be used to find the simple payback period (SPP) which can be written as

$$SPP = \frac{C_0}{S_1} \qquad (15)$$

where C_0 is initial cost and S_1 is annual saving.

The viability of a project also can be determined by its IRR which represents the true interest yield provided by the project equity over its lifetime. The project is considered financially acceptable if the IRR is equal or greater than the required rate of return of the entity. The IRR can be calculated using the following formula.

$$IRR = i + \left\{\frac{NPV}{NPV^1 - NPV^2}(i^1 - i^2)\right\} \qquad (16)$$

where i is the interest rate, $i^1$is interest rate so that NPV^1 is positive, and $i^2$is interest rate so that NPV^2 is negative (Haramaini et al. 2019, Ketut Sugirianta, Giriantari, and Satya Kumara 2016, Pranadi et al. 2019).

The other parameter that is usually used for economic evaluation is LCOE. LCOE can be defined as the energy production cost per energy generated over the project lifetime discounted to the present value. The LCOE also represents the required electricity export rate in order to have NPV equal to zero. This LCOE can be written as follow.

$$LCOE = \frac{I + \sum_{t=0}^{n} \frac{LCC}{(1+i)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+i)^t}} \qquad (17)$$

Where I is initial cost, i is discount rate, E_t is energy produced at year-t, n is project lifetime, and LCC is lifecycle cost (Ketut Sugirianta, Giriantari, and Satya Kumara 2016).

2.3 Policy Landscape for Solar PV Implementation

The technical performances and economic feasibilities are important parameters for the project owner. However, a broader sustainability assessment including policy constraint and stakeholder analysis must be considered in designing a solar PV microgrid. A failure in assessing these important aspects in the design of any solar project will lead to a poorly performed system.

2.3.1 Opportunities, Barriers, and Drivers

It is necessary to identify barriers and drivers to formulate policies and strategies facilitating the dissemination of solar PV microgrid. Electricity market structure, political discourse, regional economic growth, land availability, regulatory and policy instruments, grid connection, and financial incentives have been looked at and studied as some factors that might influence the energy transition (Jolly 2017). Palm (2018) also exemplified that technological, social-regulatory, and financial uncertainties can be a significant barrier in the dissipation of solar PV technologies.

2.3.1.1 Technological Aspects

The abundant amount of solar energy has been considered as one driver for the development of solar PV technology (Mekhilef et al. 2012, Müggenburg et al. 2012, Newcombe and Ackom 2017). Solar energy is the largest energy resources in the world (Perez et al. 2016). However, high penetration of solar can cause a problem to the grid connection because of its intermittency. Consequently, some technical solutions such as electrical storage, curtailment optimization, and demand response must be taken into account to enabling high penetration of solar PV while maintaining the grid reliability at the same time (Perez et al. 2016).

Regarding the supply chain of the technology itself, the mass production of the PV module in China has been seen as the key driver for the rapid development of solar PV in the world. The oversupply of cells and modules drives down the panel prices making solar PV technology more affordable (REN21 2019). However, some scepticisms on the solar PV product from Asia have been observed. For instance, Müggenburg et al. (2012) stated that not only the products have poor quality but also the product does not suit the preference of the people in Ethiopia. It appears that design and quality criteria must be adjusted to the local needs and conditions of the users.

The lack of technical expertise also becomes a significant barrier in some countries. This condition can lead to the design and operational failure due to limited maintenance and quality control which may consequently induce unexpected costs. For example, many technical issues, such as poor wiring and controller failure, were discovered in the solar PV projects in Myanmar because of the variation in experience levels (Newcombe and Ackom 2017). Therefore, the after-sales support, such as warranty and training, is required to ensure the system is maintained.

2.3.1.2 Social Aspects

Rural electrification program has been seen in many countries as an opportunity to introduce solar PV technology for the community in remote areas (Müggenburg et al. 2012, Newcombe and Ackom 2017). This program not only provides modern electricity access to the relatively low-income community but also increases their economic development and their life quality. Müggenburg et al. (2012) reported that the solar electrification program in Ethiopia improves education and health quality. However, they also stated that negative effects had been reported concerning the relationships in the social community, such as jealousy and mistrust.

In this rural area, willingness to pay can also be a barrier to the implementation of solar PV technology. High prices may have a negative influence on the willingness of society to pay because of their financial condition (Müggenburg et al. 2012). This low efficiency of payment collection might be caused by political instability, lack of accountability, or poor system quality (Newcombe and Ackom 2017). However, some people are willing to pay more if the system has a higher quality or the people have a better understanding. Therefore, increasing the community awareness on PV technology through educational programs and mass media is important to encourage the rapid widespread of technology (Mekhilef et al. 2012).

Local partnership is also another key driver in the dissemination of solar technology. Having a polycentric structure with a strong local presence is fundamental to create trustworthy and reliable partnerships between stakeholders (Newcombe and Ackom 2017). For a successful solar diffusion, the trustworthiness and legitimacy of the local level institution are essentially important (Joshi et al. 2019). Additionally, understanding the local population's needs is another essential factor to make technology implementation more economic (Müggenburg et al. 2012). The provision of capacity building, maintenance assistance, and technology demonstration can raise the sense of ownership among beneficiaries (Newcombe and Ackom 2017).

The unclear institutional arrangements might also challenge the success of solar PV development. For example, the institutional arrangement in Myanmar is designed on a project-by-project basis leading to fragmented and inefficient funding (Newcombe and Ackom 2017). Newcombe and Ackom (2017) claimed that it is essential that the institutional framework can foster the penetration of solar PV sustainably and efficiently by developing a transparent program, avoiding overlap between entities, and including all relevant stakeholders.

Studying various strategies with different stakeholders is required in addition to examining the effectiveness of different policies and instruments to obtain the broader institutional context (Jolly 2017). Jolly (2017) argued that the collective action between different stakeholders during the implementation of any regulatory instruments is important for the success of regional or national initiatives. However, according to the institutional theory, the actions of the stakeholders are also influenced by both formal institutional arrangements and cultural values. The resistance from the political opposition might happens during the regulation implementation so that a continuous regulation adaptation is required as a result of rapid technological change (Jolly 2017). Therefore, research and development (R&D) is needed to cope with this rapid technological change.

2.3.1.3 Financial Aspects

The presence of the rural electrification program can have great potential to create a new market. However, because solar PV requires high initial cost while the people in the rural area have little income and spend little energy, the market is not big enough (Newcombe and Ackom

2017). Thus, financial institutions are resistant to provide loans for local manufacturers (Newcombe and Ackom 2017). Therefore, an alternative financing mechanism is needed.

The presence of subsidies can be a driver to create a competitive solar PV market. For example, the smart subsidies in Bangladesh have helped to create a market where its economics scale has a competitive price (Mekhilef et al. 2012, Newcombe and Ackom 2017). It happens because the subsidies can motivate the developer to invest in PV (Palm 2018). While subsidies can be used to build up the initial market and the elimination of subsidies in the long term is not expected to hurt the market (Newcombe and Ackom 2017), others argue that the elimination of subsidies might shrink the market size (Zhang, Song, and Hamori 2011).

The other schemes that can help in financing the solar PV development are the fee-for-service model and micro-credit scheme (Diouf, Pode, and Osei 2013). The structure of these financing mechanisms makes the system more affordable for the rural community compared to the high cost of grid expansion (Newcombe and Ackom 2017). A similar financing scheme has been implemented in Japan where the average business can generate and sell its power (Mekhilef et al. 2012). While these mechanisms seem attractive, the best mechanism to generate the lowest-cost and the fastest solar PV deployment is feed-in-tariffs (Mekhilef et al. 2012).

Feed-in-tariff (FiTs) has been seen as the most significant driver in the development of solar PV. The implementation of feed-in-tariff by the government can encourage the greater use of PV utilization (Mekhilef et al. 2012). FiTs can be defined as a premium price for grid-connected PV electricity paid by utility to the system owners guaranteed for over some period, usually 20 years. Renewable portfolio standards, tax incentives, net metering, tender, and reverse auction also have been driven to the implementation of solar PV (Mekhilef et al. 2012, REN21 2019). Unlike FiTs, net metering helps to change the consumers' behaviours gradually to use less energy (Tongsopit et al. 2016).

2.3.2 Lesson Learned from some Tropical Countries

2.3.2.1 Brazil

The electricity sector in Brazil is dominated by state-run firms and private firms that bid on electricity supply auctions. Hydroelectricity is dominating the electricity supply in the country (World Bank 2015). However, a social movement has questioned the reliance on hydropower plants because of their large environmental impact causing the government to diverse its electricity supply (Frate and Brannstrom 2017).

Brazil has an ideal condition for solar energy production because of its large proportion of sunny days, large geographic area, and optimal radiation intensity. According to Frate and Brannstrom (2017), 44 utility-scale solar PV plants had been operating, 21 plants were under construction, and 90 plants were in planning stages in 2017 comprising a total of 3 GW capacity. The drivers for the development of solar PV in Brazil are the decreasing cost of solar PV globally and the rising of externality cost from the usage of conventional fuels causing the relatively low bid price for solar PV (Echegaray 2014, Frate and Brannstrom 2017, REN21 2019). Furthermore, there are also some significant concerns regarding the environmental footprint of conventional power and a significant reception to clean form of energy (Echegaray 2014, Frate and Brannstrom 2017). Moreover, to create and expand participation in energy markets, the government uses Brazilian media as the tools to legitimize their sustainability goals (Frate and Brannstrom 2017).

While there is a significant growth in the penetration of solar PV in Brazil, the industry faces some challenges. Frate and Brannstrom (2017) found that infrastructure issues, poor community outreach, and lack of planning are the potential barriers for the diffusion of solar PV in Brazil. Additionally, the problem with the existing electricity networks, lack of workforce capability, lack of information, and expensive land purchase are the other problems that might hinder the expansion of solar PV in the country (Frate and Brannstrom 2017). Furthermore, negative incentives and financing difficulties may be an effective barrier to the development of a new generation (Frate and Brannstrom 2017, Vazquez and Hallack 2018).

2.3.2.2 Senegal

Solar PV has been seen as the solution for rural electrification in Senegal. With over 3000 hours of sunlight per annum, solar PV systems is an appropriate solution to cover the electricity needs (Diouf, Pode, and Osei 2013). The system should fit the environmental conditions, be affordable, and improve the wellbeing of the communities. Diouf, Pode, and Osei (2013) stated that currently the micro PV system in Senegal is offered to the community by private companies based on a fee-for-service model. However, this model may not have enabled sustainable growth without any further subsidies although the model can maintain a large number of systems. In some places, this fees-for-service model may appropriate if standard banking loans or microfinancing schemes are not available, yet the successful implementation needs government commitment to provide subsidies (Diouf, Pode, and Osei 2013).

2.3.2.3 India

The significant development of solar PV in India is driven by the presence of the Jawaharlal Nehru National Solar Mission (JNNSM) program. The program has been commenced by the government to reduce its reliance on fossil fuel as well as improving energy security and energy access (Jolly 2017). While the central government has done a significant initiative to increase solar penetration in India, the implementation of this sustainability initiative at the regional level is quite complex. The incentives given to the local government were quite similar to those instructed under the National Solar Mission, yet the implementation might be affected by local policies and regulations, local government commitment, and local tariffs fixed by State Electricity Regulatory (Jolly 2017). While the states in India have competed to attract investment through lobbying, simplifying bureaucracy, and providing incentives for solar PV development, some regions are successful while others are not (Jolly 2017).

One example of a region that has successfully developed solar PV in India is Gujarat. In 2014, Gujarat installed 860.4 MW out of 2753 MW total installed capacity in India in that year (Jolly 2017). Jolly (2017) reported that the success of solar PV implementation is not only because of the tremendous amount of solar potential and wasteland, but also due to the significant support from Gujarat's chief minister, Narendra Modi. The chief minister has a high commitment to climate change as well as strong political and social skills to attracts investment in the country (Jolly 2017). He not only reformed the electricity sector in Gujarat but also developed a supportive policy instrument, a business-friendly environment, and a simplified bureaucracy (Jolly 2017). This supportive environment was also supported by the presence of manpower, financial resources, as well as knowledge and physical infrastructure (Jolly 2017). Additionally, weaker stakeholders and non-elites, like poor communities and local farmers, were included during the development of solar PV projects (Jolly 2017).

In contrast to Gujarat, West Bengal is one example of a region that has not successfully implemented solar PV in India. At first, West Bengal led the Indian state in the development of solar PV by installing the first grid-connected solar PV in India in 2009 because of its adequate solar radiation and access to land (Jolly 2017). However, the development was relatively stagnant between 2009 and 2013 because of several factors. The electricity sector in West Bengal is dominated by coal power plants because of their low-cost generation (Jolly 2017). Jolly (2017) also stated that the lack of commitment from the state government and regional stakeholders caused failure in gaining the confidence of potential investors.

2.3.2.4 Thailand

Thailand is the leader in Southeast Asia for renewable energy development, particularly solar PV. There is a significant awareness that the country must reduce its reliance on fossil fuel and increase renewable energy penetration to improve its energy security (Tantisattayakul and Kanchanapiya 2017). The country then developed its first 15-year Renewable Energy Development Plant in 2008 before replacing it with the Alternative Energy Development Plan in 2011 (Ismail et al. 2015, Tantisattayakul and Kanchanapiya 2017, Tongsopit et al. 2016). Regarding solar PV development, the country had developed around 1900 MW solar capacity by

2016 in which 99% comes from the utility-scale power plants whose capacity is greater than 1 MW (Tantisattayakul and Kanchanapiya 2017, Tongsopit et al. 2016).

Several factors drive the significant penetration of solar PV in Thailand. Firstly, Thailand has a tremendous amount of solar PV potential up to 5.6-6.7 kWh/m^2 (Ismail et al. 2015). Additionally, the country has an ambitious target to develop solar PV up to 6000 MW in 2036 formulated by The Energy Policy and Planning Office under the Ministry of Energy of Thailand (Ismail et al. 2015, Tongsopit et al. 2016). Furthermore, the Department of Alternative Energy Development and Efficiency under the Ministry of Energy of Thailand also has a budget allocated for research and development which attracts international investors to build assembly plants in Thailand (Ismail et al. 2015).

While the significant amount of solar potential and the government's ambition are the drivers for solar PV development in Thailand, the major driver is the implementation of an attractive FiT policy. In 2007, Thailand implemented its first FiT scheme called Adder through three Thailand's utility companies, namely the Electricity Generating Authority of Thailand (EGAT), the Provincial Electricity Authority (PEA), and the Metropolitan Electricity Authority (MEA). This scheme guarantees additional payment on top of the normal selling price for 10 years as an incentive for renewable energy generators identical for all capacities (Ismail et al. 2015, Tantisattayakul and Kanchanapiya 2017, Tongsopit et al. 2016). The initial rate was around 8 Thailand Baht/kWh before changed into 6.5 Thailand Baht/kWh in 2010 (Tantisattayakul and Kanchanapiya 2017, Tongsopit et al. 2016).

However, because of the concern regarding the impacts on the taxpayer as well as no reflection from the actual investment cost, the premium FiTs scheme was replaced by fixed FiTs scheme in 2013 (Ismail et al. 2015, Tantisattayakul and Kanchanapiya 2017, Tongsopit et al. 2016). Within this new scheme, the rate varies depending on the installed capacity of the system within 25 years duration (Tantisattayakul and Kanchanapiya 2017, Tongsopit et al. 2016).

Although the scheme was changed, the relatively low cost of solar PV and the rising cost of electricity make the solar PV investment in Thailand attractive (Tongsopit et al. 2016).

Regarding the business model, the solar Power Purchase Agreement (PPA) model has been seen as an attractive mechanism for developers in Thailand (Tongsopit et al. 2016). Under this scheme, the utilities or customers agree to purchase the electricity from the developer for a specific number of years at a certain fixed tariff. This scheme provides a price guarantee for the companies over a contract term so that they can manage their risks. In Thailand, the developer can sell electricity directly to the customers because the structure of the power industry is partially deregulated although there is a legal uncertainty of this model (Tongsopit et al. 2016).

2.4 Solar PV Policy Landscape in Indonesia

2.4.1 Geographic and Demographic Information

Indonesia is an archipelagic country situated on the equator bordered by the Pacific Ocean and the Indian Ocean. Indonesia has over 18,000 islands spreading over an area of 1,904,569 km^2 (World Atlas 2019). Sumatra, Java, Borneo, Sulawesi, and New Guinea are the largest island in the country. Because of its position in the equator, Indonesia's climate is relatively even through the year with a hot and humid condition (World Atlas 2019). In general, the country has two seasons, a wet season which happens between November and April as well as a dry season which occurs between May and October. Under Köppen–Geiger climate classification system, almost the entire region in Indonesia is tropical, dominated by the tropical rainforest climate identified in the major islands of the country followed by the tropical monsoon climate found along the north coast of Java, the south and east coast of Sulawesi, and Bali. Some regions, such as the east of Lombok, experience the tropical savanna climate.

Indonesia is the fourth most populous country in the world. There are more than 270 million people reside in Indonesia which is equivalent to population density around 140/km^2

(World Population Review 2019). It is projected that the population will exceed 300 million people in 2030 (Wijaya et al. 2017). According to the World Bank (2019a), Indonesia is categorized as a low-middle income country with GDP per capita around USD 3,837 per person. The government has targeted not only to reduce the poverty rate below 4 percent by 2025 but also to maintain the country's GDP growth above 5 percent annually (Wijaya et al. 2017).

2.4.2 The Energy Situation in Indonesia

Both populations rise and economic growth will increase the energy demand of the country. It is predicted that the energy demand will be around 248 Million Tonnes of Oil Equivalent (MTOE) which will be supplied from around 400 MTOE of primary energy by 2025 (Republic of Indonesia 2017). According to the National Energy Policy, 23 percent of this primary energy demand will be accounted for renewables (Republic of Indonesia 2017). Regarding electricity, it is predicted that in 2025 around 135.5 GW of installed capacity is required in which 45.2 GW of this capacity is renewables (Republic of Indonesia 2017).

The electricity business in Indonesia is regulated by the 2009 Electricity Law. Under this law, the electricity supply for public demand can be carried out by one entity within one operating area or *Wilayah Usaha* in which PLN has priority rights except for certain regions (PWC 2017). The power generation in Indonesia is dominated by the state-owned electricity company, PLN, including its subsidiaries, such as Indonesia Power. In addition to PLN, the private sector also can participate in power generation through IPP appointments. The construction of coal, geothermal, hydropower, and solar power plants up to certain capacity must be undertaken by a national EPC Company before given to a consortium of a foreign company and a local company. Regarding the transmission and distribution, PLN is the sole owner of transmission and distribution assets. Consequently, PLN is the only player in transmitting and distributing electrical power as well as in the retailing of electricity (PWC 2017). Some activities involved in electrical power support such as power equipment supply, research and development, education, as well as training and certification are also becoming a part of the electricity industry in Indonesia.

While it should be acknowledged that the government of Indonesia has a significant amount of renewable energy target particularly in the electricity sector, the implementation is relatively slow. The renewable energy power plant that had been operated in Indonesia by 2017 was only around 10 GW (Republic of Indonesia 2017). As a result, to develop the additional 35 GW renewable energy power plant by 2025, a significant effort must be taken by the government. However, under the current Power Supply Business Plan (RUPTL) 2019-2028 decreed by the MoEMR in 2018, this effort is not reflected well. There is only 16 GW of new renewable energy power plant that will be installed up to 2028 (Republic of Indonesia 2018).

2.4.3 Solar Energy Implementation in Indonesia

Indonesia has a tremendous amount of solar energy potential around 207,898 MW (Republic of Indonesia 2017), particularly in Eastern Indonesia. Unfortunately, only a limited number of solar PV has been installed in Indonesia. According to the Republic of Indonesia (2017), only 78.5 MW solar PV capacity, or around 0.04% of solar energy potential, has been installed in Indonesia. This installation is lagging far behind the other neighbouring ASEAN countries, such as Thailand, the Philippines, and Malaysia (Hamdi 2019, IRENA 2019). Around 16 MW of this capacity was on-grid while the rest is off-grid (Hamdi 2019). The largest on-grid solar PV in Indonesia is a 5-MW solar PV power plant in Kupang, East Nusa Tenggara which has been running since 2016 and operated by PT LEN Industries (Hamdi 2019). Thus, solar PV in Indonesia can be considered as a microgrid. An additional of 908 MW of solar PV capacity is planned to be installed in the country by 2028 under the current RUPTL 2019-2028 (Republic of Indonesia 2018).

Having an electrification ratio of around 95% in 2017, solar PV has been seen as a solution for electrification in the rural areas, such as remote regions and isolated islands (REN21 2019, Republic of Indonesia 2018). The first procurement for on-grid solar PV took place in 2013 under MoEMR Regulation No. 17/2013 setting up for a capacity quota around 140 MW with a tariff bid around USD 0.25-0.30/kWh depending on the local content (PWC 2017). This regulation was revoked by Supreme Court in 2014 and replaced by MoEMR Regulation No. 19/2016 where around 5000 MW was to be offered with FiTs rate ranged from USD 0.145-0.25 kWh depending on the location (PWC 2017). In January 2017, this regulation was superseded by MoEMR Regulation No. 12/2017 before revoked by MoEMR Regulation No. 50/2017 (PWC 2017). Figure 4 shows the historical solar policies in Indonesia.

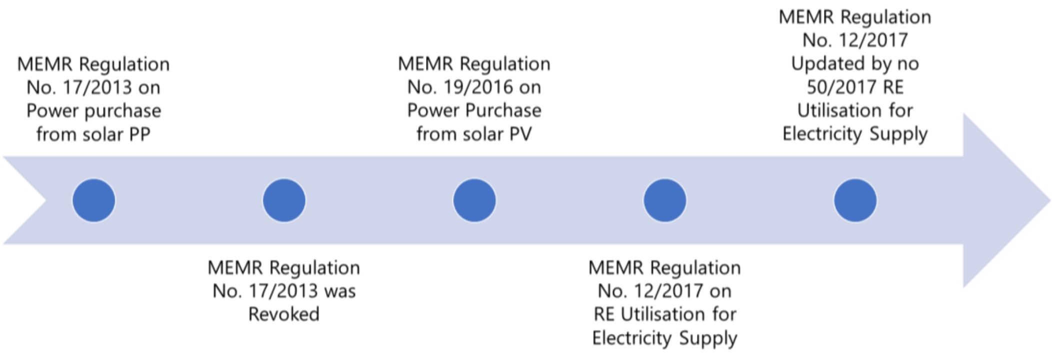


Figure 4 Solar PV Policies in Indonesia. Source: Hamdi (2019).

The regulatory changes hinder swift and steady solar PV development in Indonesia. The policy roadmap is lacking consistency which may scare away the global solar player to invest in the country (Hamdi 2019). Table 4 shows a comparison between different regulations on solar PV. The price cap under current regulation is smaller than the previous regulations which makes the investment less attractive. The current tariff ranges from USD 0.048-0.144/kWh depending on the location. This tariff should be lower than the national electricity supply cost (National BPP) or no more than 85% of the local electricity supply cost (Regional BPP). The procurement method is also different. Under current regulation, the government adopts a direct selection based on quota capacity for solar PV procurements (Hamdi 2019). Another difference between current regulation and past regulations is the presence of a Build-Own-Operate-Transfer (BOOT) scheme. Under this scheme, the IPP's facilities must be transferred into the PLN at the end of the contract, which is a maximum of 30 years (PWC 2017).

Table 4 Solar Policy Comparison. Source: Hamdi (2019).

	MEMR Regulation No. 17/2013	MEMR Regulation No. 19/2016	MEMR Regulation No. 12/2017 Updated by No. 50/2017
Price Cap	• US$ 0.25/kWh (using modules with <40% local content). • US$ 0.30/kWh (using modules with >40% local content).	Range between US$ 0.145 – 0.25/kWh depending on project location.	Tariff should be lower than National supply cost of electricity (National BPP) or no more than 85% of local electricity supply cost (regional BPP) which ranges from US$ 0.048 – 0.144/kWh depending on the location.
Procurement method	• Auction based on quota per annum. • Direct appointment allowed if only 1 company bids.	• Auction based on quota for certain predetermined regions. • Project size per developer is subject to a limit based on the available quota in the region.	Direct selection based on quota capacity.
Local Content Requirement	Yes	Yes	Yes
BOOT	No	No	Yes

The local content requirement is always incorporated into the policies where the minimum use of domestic products (TKDN) is regulated by Minister of Industry (MoI) Regulation No. 54/2012 which was amended by MoI Regulation No. 5/2017 (PWC 2017). This local content requirement is implemented to support the local manufacturing industry, such as PT Len Industry, PT Surya Utama Putra, and PT Swadaya Prima Utama (Hamdi 2019). Table 5 compares the TKDN between different solar PV systems. It can be seen that the local content requirement for the module is quite high around 60%.

Table 5 Minimum percentage of local content requirement (TKDN) for each component based on MoI Regulation 5/2017.

Solar Home System (Article 12)	Communal Solar PP (Article 13)	On-grid Solar PP (Article 13A)
Goods 39.87% Services 100% Goods and services combined 45.90% Module 60% Battery 40% Battery Control Unit 10% Mounting 42.40% Cable 90%	Goods 37.47% Services 100% Goods and services combined 43.72% Module 60% DC Combiner Box 20% Distribution Panel 40% Battery 40% Mounting 42.40% Cable 90% Protection system 42.40%	Goods 34.09% Services 100% Goods and services combined 40.68% Module 60% DC Combiner Box 20% Distribution Panel 40% Transformer 40% Mounting 42.40% Cable 90% Protection system 42.40%

In addition to regulatory and tariff barriers, there are also several challenges in developing a solar PV microgrid in Indonesia. PWC (2017) reported that greater coordination between stakeholders is required particularly for land acquisitions, grid conditions, and obtaining permits. High upfront cost, lack of awareness, challenges to grid stability, and insufficient technical knowledge and capacity are also barriers for the deployment of solar PV in Indonesia (Patunru and Rakhmah 2017). Hence, access to the right expertise as well as the technical experience on the grid stability is needed for the deployment of solar PV (PWC 2017). Moreover, political instability, low research investment, bureaucracy, lack of access to finances, as well as lack of quality control, standards, and code can also be the challenges to deploying low-carbon technology in Indonesia (Patunru and Rakhmah 2017). The presence of a framework incorporating both technical and non-technical factors is necessary to increase the development of solar PV microgrid in Indonesia.

The summaries of potentials, barriers, and mechanisms for the development of solar PV microgrid are presented in Figure 5, Figure 6, and Figure 7respectively.

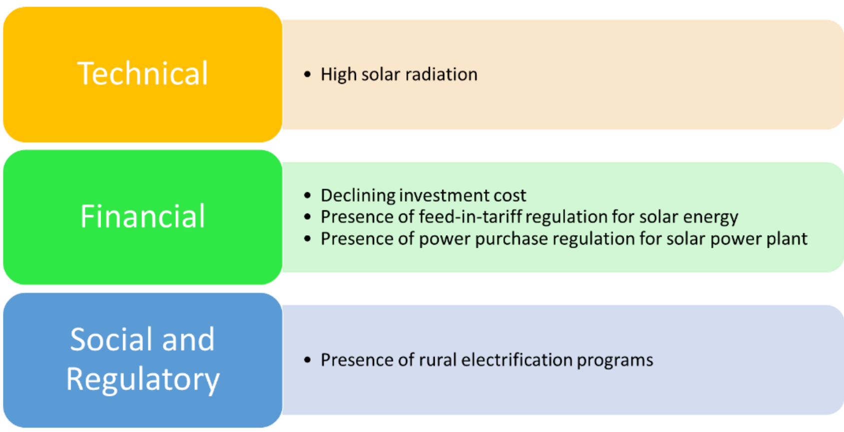


Figure 5 The potential of solar PV implementation.

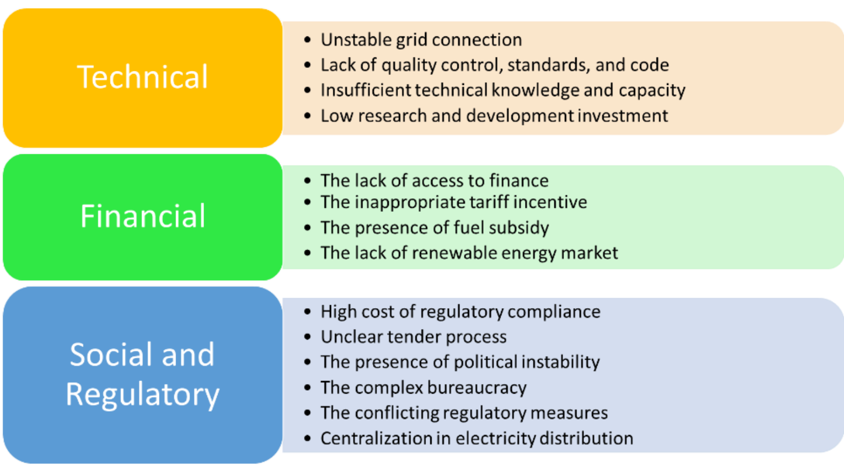


Figure 6 The challenges of solar PV implementation

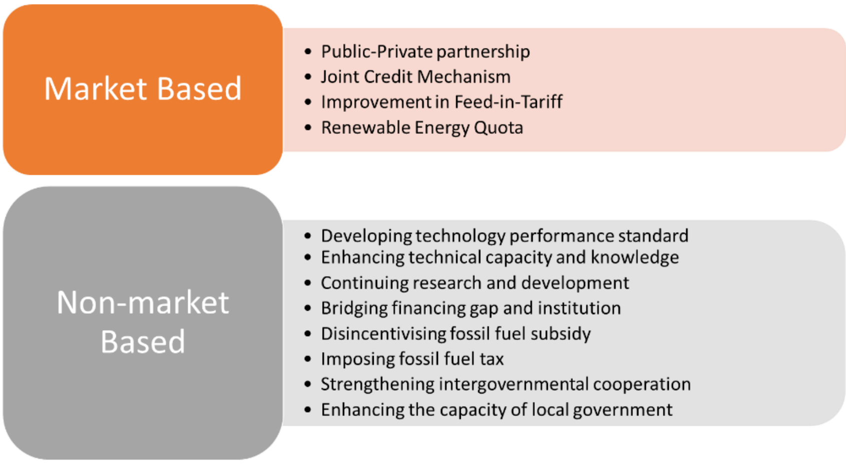


Figure 7 The enabling mechanisms of solar PV implementation

Chapter 3. Methodology and Data

The methodologies and data used to undertake this research are explained in this chapter. An interdisciplinary approach was used which enables the data gathering from multiple perspectives, quantitatively and qualitatively, and then combining this data to develop the framework.

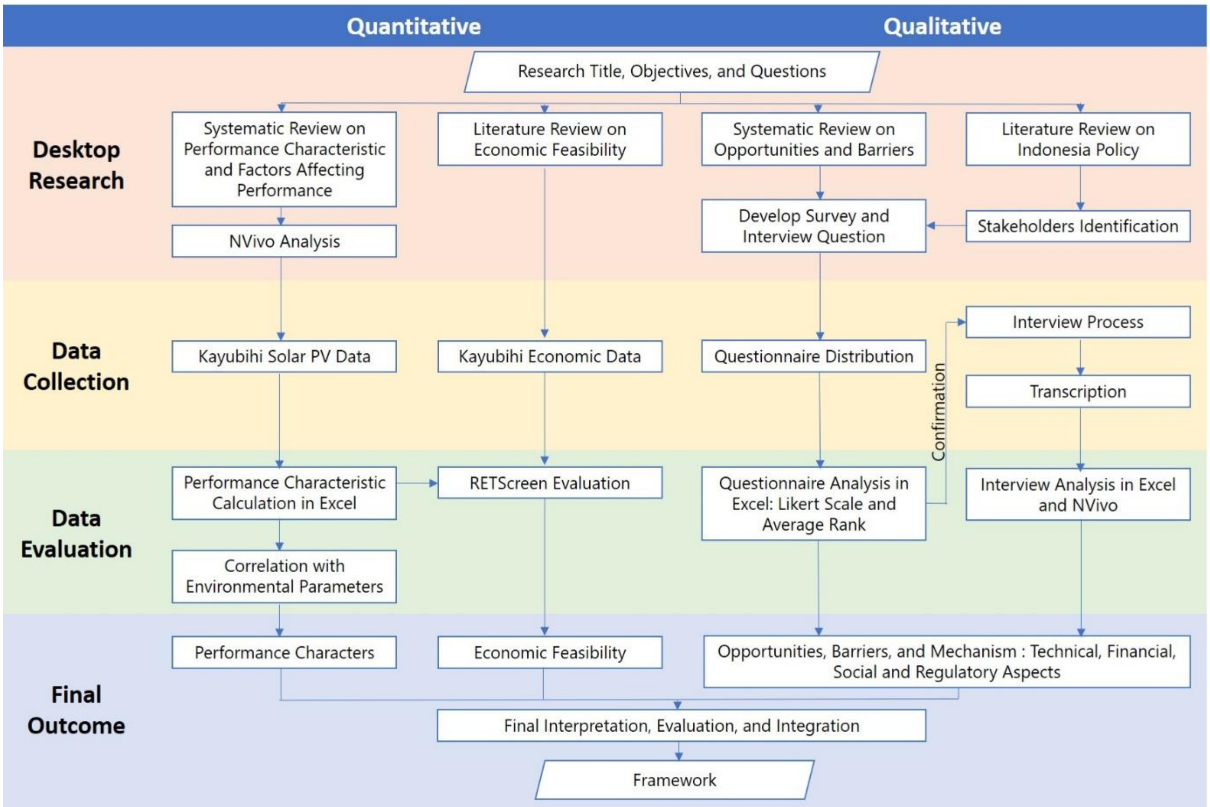


Figure 8 The Research Workflow

Figure 8 shows the flowchart of the overall research methodology including desktop research, data collection, data evaluation, and final outcome. The research started with desktop analysis studying the literature review on technical and non-technical aspects. The information from the literature review is used for developing survey and interview questions. For quantitative analysis, the solar PV data and economic data from one solar PV microgrid in Indonesia, Kayubihi was gathered before the performance characteristic and economic feasibility were evaluated. the survey was distributed for qualitative analysis and the interview was conducted to clarify the survey as well as to fill the knowledge gap. The results from both qualitative and quantitative analyses then were used for developing the framework. The details for each process were described in the following sections.

3.1 Desktop Research

A comprehensive literature review was the starting point of this study. The literature review was conducted by reviewing the literature on solar PV implementation in tropical regions. The literature review was used to obtain the background information on (i) the typical performance characteristics that can be used for evaluation, (ii) the environmental and non-environmental factors that affect these performance, (iii) the economic evaluation that have been used for the feasibility of the projects, (iv) the opportunities and challenges in implementing solar PV microgrids, as well as (v) the various strategies and approaches that have been used to overcome these barriers.

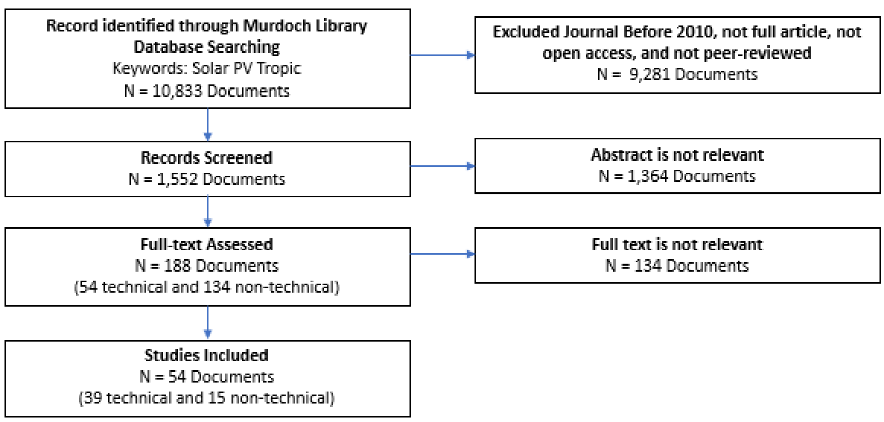


Figure 9 Literatures screening and eligibility process.

To synthesize multiple research papers clearly, a systematic review approach also has been performed. Figure 9 shows the process of screening the literature. The Murdoch Library search database is used as the database for this systematic review. The main keywords for the search were "Solar PV tropic" resulting in 10,833 results. To narrow the search, only open-access, peer-reviewed, and full-article documents were selected resulting in 1,552 results. Before assessed the full-text article, these results were screened based on the inclusion criteria, including ‘technical performance’, ‘weather and climate effect’, ‘economic evaluation’, ‘opportunities’, ’barriers’, and ‘mechanism’, resulting in 54 articles for technical and/or economic evaluation, and 134 articles for opportunities and barriers consideration. Yet, after the full article being assessed, only 39 articles were used for the techno-economic evaluation and 15 articles were used for opportunities and barriers analysis. NVivo software was also used to help to categorize the topics. The information obtained from these reviews is presented in chapter two.

3.2 Techno-economic Evaluation

The techno-economic evaluation aims to answer the following questions: how do environmental conditions affect the performance of solar PV in a tropical region? In this research, a techno-economic analysis was conducted on a 1-MW_p solar PV power plant called Kayubihi in Bangli, Bali, Indonesia. The system is one of the largest grid-connected solar PV in Indonesia and has been operating since 2013 (Kumara et al. 2013). The system is chosen because of its location almost at the centre of Indonesia with tropical climate conditions as well as due to its large capacity. Because the system also injects power into the state-owned electricity company (PLN), then the feasibility study using the tariff rate can be calculated.

3.2.1 Kayubihi Specification

Kayubihi solar PV system is located at the latitude -8.35 ^{o}S and the longitude 115.36 ^{o}E with an altitude around 870 m above mean sea level. The system consists of 5004 monocrystalline panels manufactured by PT. LEN Industry over an area of 8,700 m^2 (Ketut Sugirianta, Giriantari, and Satya Kumara 2016, Kumara et al. 2013). The panel is capable of producing 200 W_p at STC condition tilted at an angle of 15^{o} and facing north (Table 6). 18 units of PV panels are connected in series forming a string array to meet the voltage input requirement of the inverter manufactured by SUNGROW (Table 6). Then, five to six PV arrays are then connected in parallel to form a group served by a 20-kW unit inverter. There are 50 units of the inverter to make up the 1-MW_p output.

Table 6 LEN 200 W_p panel and SUNGROW inverter specifications. Source: Kumara et al. (2013).

Panel Specification		Inverter Specification	
Parameters	**Value**	**Parameters**	**Value**
Panel Efficiency (η)	15 %	Output Power (P_{out})	20 kW
Nominal Voltage (V)	24 V	Input Voltage (V_{DC})	250 V
Maximum Power at STC (W_p)	200 W	Input Current (I_{DC})	40 A
Voltage at Maximum Power (V_{max})	37.4 V	Output Voltage (V_{out})	400 V
Current at Maximum Power (I_{max})	5.3 A	Output Current (I_{out})	31 A
Short-Circuit Current (I_{sc})	5.5 A	Output frequency (f)	50 Hz
Open-Circuit Voltage (V_{oc})	44.2 A	Waveform	Pure sinusoid
Operating Temperature (T)	-40 ^{o}C to 85 ^{o}C	Operating Temperature (T)	25 ^{o}C to 60 ^{o}C
Temperature Coefficient	0.44 %/^{o}C	Total Harmonic Distortion	3
Power Tolerance	0.3 %	Number of Phase	3
Weight	16.5 kg	Weight	50 kg
Dimension	806 x 1576 x 50 mm	Dimension	648 x 695 x 237 mm

3.2.2 Kayubihi Data

The data used in this research is the data recorded between 1 January 2014 and 31 December 2014 provided by Murdoch University's research partner from Udayana University. The parameters recorded include the power output and the energy output for each inverter taken every 15 minutes from 4 am to 9 pm. The environmental monitoring data such as in-plane radiation, ambient temperature, module temperature, and wind speed were also recorded every 15 minutes. Then, the given data was used to derive the daily, monthly, and annual performance characteristics data of the system in Excel, namely final yield, reference yield, performance ratio, and capacity factor. The degradation rate cannot be calculated because of the limitation of data. The cross-correlation between environmental data and the performance characteristic data were performed to find out which environmental condition that has impacts on the performance.

For the economic feasibility using RETScreen, the following data and assumptions are used. The initial cost is around 1.2 USD/W_p (Susanto 2016), the operation and maintenance (O&M) cost are around 30 USD/kW_p/year (Ali and Shahnia 2017), while the land purchase and land lease prices in Bali are around 180 USD/m^2 and 6 USD/m^2/year respectively (Wilson 2013). Land purchasing and land leasing scenarios are examined to understand different risks in the land acquisition method due to the presence of transfer mechanisms under the BOOT regulation.

3.3 Survey and Interview

The objective of this survey and interview is to answer the following question: what are the main opportunities and barriers to implementing solar PV microgrids and how to overcome those constraints? In this research, the survey and interview were conducted for the stakeholders involved in the implementation of solar PV microgrid in Indonesia. The actor of solar PV microgrid is the Independent Power Producers (IPPs) and PLN that generates electricity from solar PV as well as the Engineering, Procurement, and Construction (EPC) company. The regulation is formulated mainly by the Ministry of Energy and Mineral Resources (MoEMR) and implemented by local authorities through the development of regulations and issuance of permits. Additionally, research institutions can call for regulations and policies that serve market development while educational units provide knowledge and technical expertise to the public.

Therefore, three key stakeholder groups were examined in this research, namely the developers, the governments, and the experts. The developers include The IPP's, PLN's, and EPC's employees, the governments include local governments and the MoEMR staffs, and the experts include the academics in universities and the researchers in renewable energy institutions.

3.3.1 Survey Design

The survey questionnaire was prepared for the participants from the literature reviews on opportunities (Figure 5), barriers (Figure 6), and mechanisms (Figure 7). The survey was used to find the information on how importance of each factor on the implementation of solar PV microgrid in Indonesia. The participants were asked to rate the importance of each factor that may influence the development of solar PV microgrid in Indonesia using a Likert-Type scale from 1 to 9, where 1 is least important, 3 is moderately important, 5 is strongly important, 7 is very important, and 9 is extremely important.

Additionally, the survey was used to find the information on which factor is the most important relative to the other factors on the implementation of solar PV microgrid in Indonesia. The participants were asked to rank in order the factors presented in Figure 10 that may significantly influence the development of solar PV microgrid in Indonesia. There were 10 factors considered for determining priorities ranging from the technical, financial, as well as social and regulatory aspects. Hence, 1 is the highest ranking while 10 is the lowest ranking. The details of the survey questionnaire can be seen in appendix I.

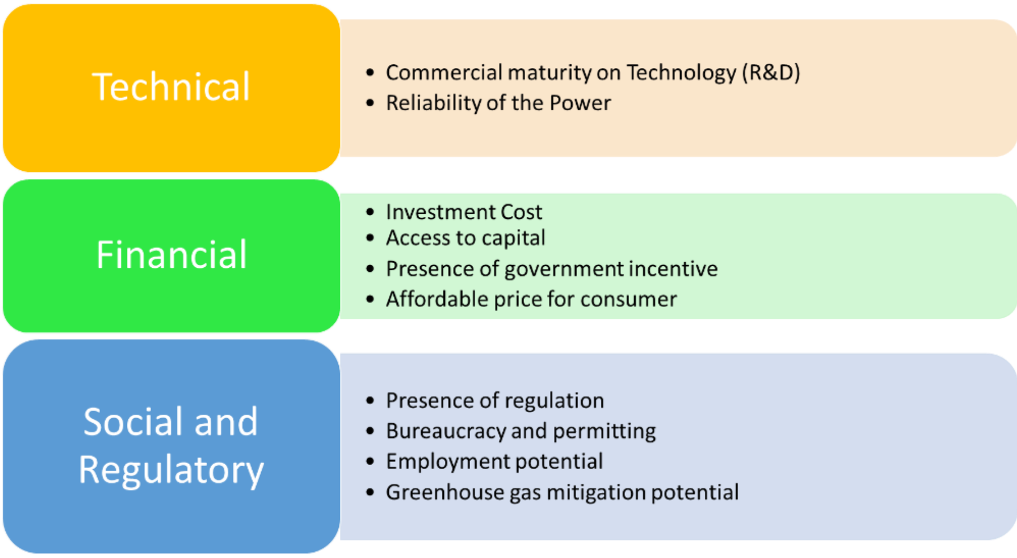


Figure 10 The priority of solar PV implementation

For conducting a survey, determining the population and sample size is important. Sample sizes are an important aspect of qualitative research because the research itself is labour and time intensive. The sample size n is calculated by using the following formula

$$n = \frac{Nx}{((N-1)E^2+x)} \qquad (18)$$

where N is the population size, E is the margin error, and x is

$$x = \left[Z\left(\frac{C}{100}\right)\right]^2 r(100-r) \qquad (19)$$

where $Z\left(\frac{C}{100}\right)$ is the critical value for the confidence level C, and r is the response distribution (Raosoft 2004).

The total population considered in this study is around 67 people. To decide the number of populations the following assumption is considered.

- The Governments: 22

  According to Ministry of Energy and Mineral Resources (2019), five (5) sub-directorates within the Directorate of Various New and Renewable Energy of the MoEMR help to regulate and to implement solar PV microgrid using the state budget. Additionally, there are around 17 provinces that have solar PV installations either developed by the MoEMR, PLN, and/or IPP (Ministry of Energy and Mineral Resources 2017).

- The Developers: 28

  There are around 12 developers in Indonesia that have run, constructed, and signed letters of intent for developing solar PV in Indonesia, including private IPP as well as PLN and its subsidiaries (Hamdi 2019). There are also around 16 National EPC companies for solar PV installation in Indonesia (PVinAsia 2018).

- The Experts (Academics and Research Institutions): 17

  It is assumed that there are approximately 17 institutions that have an interest in doing research and/or education on solar PV in Indonesia.

The lower the margin of error, the larger the sample size (Raosoft 2004). Additionally, the higher the confidence level, the higher the sample size (Raosoft 2004). In this study, the margin of error, confidence level, and response distribution were expected to be 10%, 90%, and 50% respectively. Therefore, the sample size required for this survey was 34.

3.3.2 Interview Design

Semi-structured interviews were also conducted for the data collection of this research. The purpose of the interview is to collect different perspectives from multiple stakeholders concerning the implementation of solar PV in Indonesia. Additionally, the interview was also conducted to confirm the survey result in this study in accordance with the Delphi method approach. This research method seeks experts' opinions that can be applied for policymaking (Ade Bilau, Witt, and Lill 2018). The Delphi method is also suitable for filling the knowledge gap as well as eliciting data for the development of an effective framework (Ade Bilau, Witt, and Lill

2018). Thus, the interviewee was chosen from the selected survey participants that agreed to participate in the follow-up interview process. Among experts interviewed, some were involved in the regulatory and policy process while others had experience in implementing solar PV microgrid in the society.

The interview questions were based on the desktop study as well as the initial analysis of solar PV energy implementation based on survey results. Additionally, identifying problems and eliciting solutions are the focus of Delphi's research (Ade Bilau, Witt, and Lill 2018). The duration of interviews was between 30 minutes and 60 minutes and conducted face-to-face. Each participant was asked different questions depending on their expertise. In general, the participants were asked about technical, financial, and social-regulatory issues in implementing solar PV in Indonesia as well as some mechanisms to overcome the problems. The details of some interview questions can be seen in appendix II.

Regarding the sample size for these interviews, Dworkin (2012) reported that sample size can be determined by its saturation. The data collection has been saturated enough when no longer useful information can be obtained (Dworkin 2012). Although the number of the interviewees can be as small as 4 participants or can be as much as 171 panellists, a total of 5 to 50 participants in qualitative research interviews are adequate (Ade Bilau, Witt, and Lill 2018, Dworkin 2012). Hence, at least 10 people were selected to be interviewed in this study. 5 people were representing governments, 4 people were representing developers, and 2 people were representing academic and research institutions. The interviews were audio-recorded and conducted in Bahasa Indonesia.

3.3.3 Human Research Ethics Committee Approval

An approval from the Murdoch University Human Research Ethics Committee was obtained to fulfil the research's ethical standards as well as to comply with Murdoch University codes of practice. The approval was given under the project number 2019/82 on 23 July 2019.

3.3.4 Data Analysis

3.3.4.1 Data Preparation

The survey data from each participant was captured into the Microsoft Excel spreadsheet. Subsequently, the data were coded to ensure the privacy of the participants and to comply with the Human Research Ethics Committee approval. The original survey documents are not accessible to the public. The interview recordings were transcribed to a word file and translated to English by the author. Furthermore, the transcripts were produced after the interview process and were sent back to each participant. Each participant was asked to confirm and to give additional responses or feedback until a determined deadline. After the deadline, the transcript was labelled with a unique identifier to be processed anonymously.

3.3.4.2 Data Evaluation

This research used a 9-point Likert-type scale to obtain participants' degree of importance on a given statement regarding opportunities, barriers, and mechanisms. Likert-scale was named after Dr. Rensis Likert who developed the technique to measure attitude on a proper metric scale. According to Bertram (2013), the participants' response was treated as ordinal data because although the response has its relative position, it cannot be presumed that the individuals perceive the difference between each level to be equal as in an interval data. To analyse the Likert-scale data, stacked bar charts in Microsoft Excel are used as the visualisation (Bertram 2013). Subsequently, the data is interpreted as a whole as well as a group based on three different key stakeholders, namely governments, developers, and experts.

Besides, this research also used a ranking question to obtain the information from the participants on which factor is the most important relative to the other factors. The stacked bar chart was also used to present the data distribution. In addition to that, the average ranking can be calculated by applying weight in reverse (SurveyMonkey 2019). The formula for average ranking can be formulized as follow.

$$Average\ Ranking = \frac{x_1 w_1 + x_2 w_2 + \cdots + x_n w_n}{x_1 + x_2 + \cdots + x_n} \qquad (20)$$

where x_n is the response number for the ranking-n and w_n is the weight of ranked position in which the most preferred choice has the largest weight (SurveyMonkey 2019). A spider diagram was used to visualise the result.

A Microsoft Excel spreadsheet is used to compile the interview transcript from different participants as an initial analysis. The interviewee comment based on this spreadsheet can be seen in Appendix III. The information was distributed into different issues within 4 categories. Subsequently, the summaries were created from each subcategory. Table 7 shows the categories, subcategories, and issues that are used for extracting the information from the transcript. For further analysis, NVivo software was also being used to obtain the information from the transcript interview with some categories and subcategories rearrangement. This rearrangement is needed to make a meaningful analysis to identify the priority as well as to help in developing the framework.

Table 7 Interviews transcription categories

Categories	**Subcategories**	**Issue**	**Categories**	**Subcategories**	**Issue**
Technical	**Technical Difficulty**	Weather Pattern and Solar Potential	**Social and Regulatory**	**Regulation Presence**	Rural Electrification Programs
		Grid Connection			Energy Mix
	Technical Regulation	Electrical Component			Build-Own-Operate-Transfer Scheme
		Grid Intermittency			Local Content
		Grid Code		**Bureaucracy**	Complexity
	Technical Capacity	Maintenance Issue			Local Government Participation
		Workforce Issue			Monopoly Issue
		Awareness and Willingness to Pay		**Regulation Interaction**	Conflicting Regulation
		Lifestyle			Intergovernmental Stakeholder
	Technical Research	The Presence of Research and Education			
Categories	**Subcategories**	**Issue**	Categories	**Subcategories**	**Issue**
Financial	**Financial Access**	Electricity Supply Cost	**Mechanism**	**Market Based**	Fossil Fuel/Emission Tax
		Access to Capital			Ceiling Price
		Capital Cost			Business Model
		Affordability		**Non-market Based**	Research and Development
	Financial Regulation	Feed in Tariff			Stakeholders Collaboration
		Power Purchase Agreement			Others
	Market Condition	Market Presence			
		Direct Selling			
		Procurement Process			
		PLN Tender			
		Quota Mechanism			
	Subsidy	Impact of Fossil Fuel Subsidy			

3.4 Framework Development

A framework was developed to answer the following question: How should these technical and non-technical factors be combined to determine a framework for solar PV microgrids implementation? This framework is necessary to help the key stakeholders increasing the penetration of solar PV in Indonesia. The framework itself can be defined as the interrelationships among variables in a model (Burton and The Johns Hopkins University 2007).

Several items must be considered when developing a framework. According to Center for Community Health and Development (2019), The framework must incorporate (i) the purpose of the framework, (ii) the stakeholders, (iii) the activities and the interventions, (iv) the opportunities and barriers that might influence, as well as (v) the expected outcome and impact. Additionally, arrows can be used to show the directions of influence as well as the interaction between variables. (Center for Community Health and Development 2019). The results from the literature review on Indonesia, techno-economic evaluation, as well as survey and interview analysis were used to develop the framework in this research.

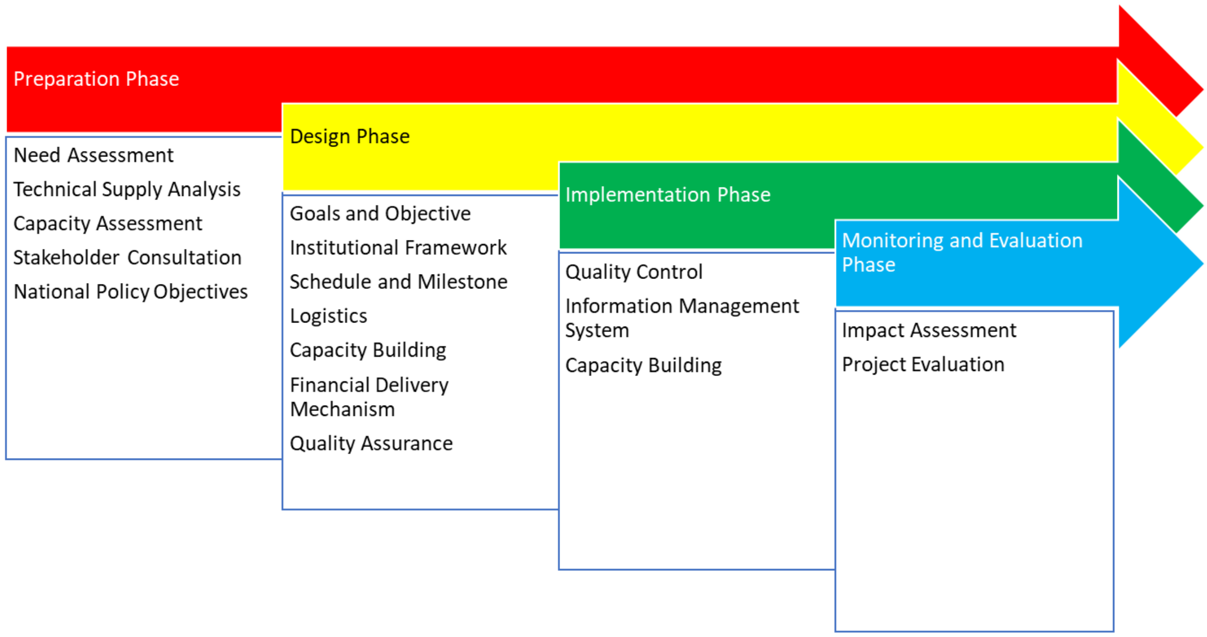


Figure 11 Phases of PV Program. Source: IEA (2003)

To increase the penetration of solar PV, a successful implementation must be performed. To achieve a good implementation, meticulous planning must be done. IEA (2003) mentioned that PV development is a multiphase challenge consisting of four stages namely, preparation, design, implementation, as well as monitoring and evaluation. Figure 11 illustrates the process of developing a PV program with more emphasis was placed on the design and preparation stages. Under the planning stage, IEA (2003) suggested assessing the needs, capacity requirements, national policies, stakeholders, as well as technical assistance requirements. During the design phase, quality assurance and capacity building are two things that must be considered. The quality control, information management system, and capacity building must be taken into consideration during the implementation stage before doing impact assessment and project evaluation in the last stage. The framework developed in this research will be designed based on these four development stages. A successful application of this framework hopefully can increase the penetration of solar PV in Indonesia.

Chapter 4. Results and Analysis

This chapter presents the results and analysis from the case study in Indonesia. This chapter is presented in two parts. The first part analyses the techno-economic evaluation from Kayubihi solar PV power plant in Indonesia. The outcomes of qualitative research, both survey and interview, are presented in the second part.

4.1 Kayubihi Techno-economic Evaluation

4.1.2 Kayubihi Performance Characteristic

The monthly average of daily weather parameters in Kayubihi in 2014 is shown in Table 8. The panel temperature, ambient temperature, and wind speed data were obtained from the monitoring data while the clearness index, precipitation, and humidity were obtained from NASA data (NASA 2014). The average temperature is greater than 18° C which is a typical characteristic of a tropical climate. The lowest average temperature was around 19.76° C in June and the highest one was around 24.26° C in March. The annual mean of panel temperature was around 26.71° C which is slightly higher than the STC condition. The average mean wind speed during that year was around 0.85 m/s with the highest average wind speed was 1.27 m/s in October.

Table 8 Monthly Average of Daily Weather Parameters in 2014

Month	Panel temp. (°C)	Amb temp. (°C)	Wind speed (m/s)	Clearness Index	Precipitation (mm)	Humidity (%)
January	25.64	22.57	0.93	0.43	11.06	83.98
February	25.81	22.74	0.93	0.52	9.53	83.02
March	28.41	24.26	0.79	0.60	3.53	79.15
April	26.28	22.99	0.60	0.59	4.57	80.17
May	28.27	23.24	0.70	0.61	1.10	80.22
June	25.54	21.45	0.78	0.62	0.27	77.69
July	24.20	20.46	0.81	0.56	1.21	77.30
August	25.04	19.76	1.20	0.61	0.27	74.83
September	28.50	21.89	1.08	0.67	0.03	71.94
October	29.80	23.21	1.27	0.64	0.41	72.79
November	26.61	22.77	0.91	0.48	14.09	83.28
December	26.42	23.19	0.23	0.45	9.14	82.30
Year	26.71	22.38	0.85	0.56	4.60	78.89

The atmosphere clearness is measured by the clearness index (NASA 2014), which can be defined as the surface radiation divided by the extra-terrestrial radiation. The lowest clearness index value was in January and the highest one was in September. Interestingly, this value was associated with the precipitation condition in that year. The high precipitation from November to February resulted in the low value of the clearness index in the same month. During these months, the average humidity is also quite high.

Five parameters are calculated from the data obtained in this study, namely the total energy produced, the average final yield and reference yield, as well as the average performance ratio and capacity factor (Table 9). In 2014, Kayubihi only generated 718.38 MWh of electricity with the lowest generation was in November. The power plant did not operate for 119 days with the longest non-operating days was in November in which the solar PV power plant did not operate for 27 days. It happened because during this period the operation and maintenance process was halted due to the absence of a clear operational scheme (Janaloka 2015).

Table 9 Monthly Performance Characteristic Data in 2014

Month	Total Energy Produced (MWh)	Average Final Yield (Hours)	Average Reference Yield (Hours)	Average Performance Ratio (%)	Average Capacity Factor (%)	Number of Days with No Production (Days)
January	88.99	2.87	3.50	82%	12%	0
February	55.93	2.80	3.68	76%	12%	8
March	75.11	3.76	4.73	79%	16%	11
April	42.45	2.83	3.48	81%	12%	15
May	85.17	3.70	3.95	94%	15%	8
June	84.70	2.82	2.97	95%	12%	0
July	73.11	2.36	2.72	87%	10%	0
August	47.99	3.00	3.27	92%	12%	15
September	65.56	3.64	4.73	77%	15%	12
October	59.01	3.28	4.64	71%	14%	13
November	5.27	1.76	2.31	76%	7%	27
December	35.08	1.67	2.61	64%	7%	10
Year	718.38	2.90	3.51	83%	12%	119

The average reference yield value in Kayubihi in 2014 varied by up to 4.73 hours in March. The monthly performance ratio varied from 64% in December to 95% in June with the average performance ratio in 2014 was 83%. This value is relatively within a similar range to the value in the other tropical countries (Table 3). Compared to the capacity factors in some tropical regions (Table 3), the capacity factor of this Kayubihi solar PV microgrid is relatively small around 12% because of the high number of non-operating days resulting in low energy generation.

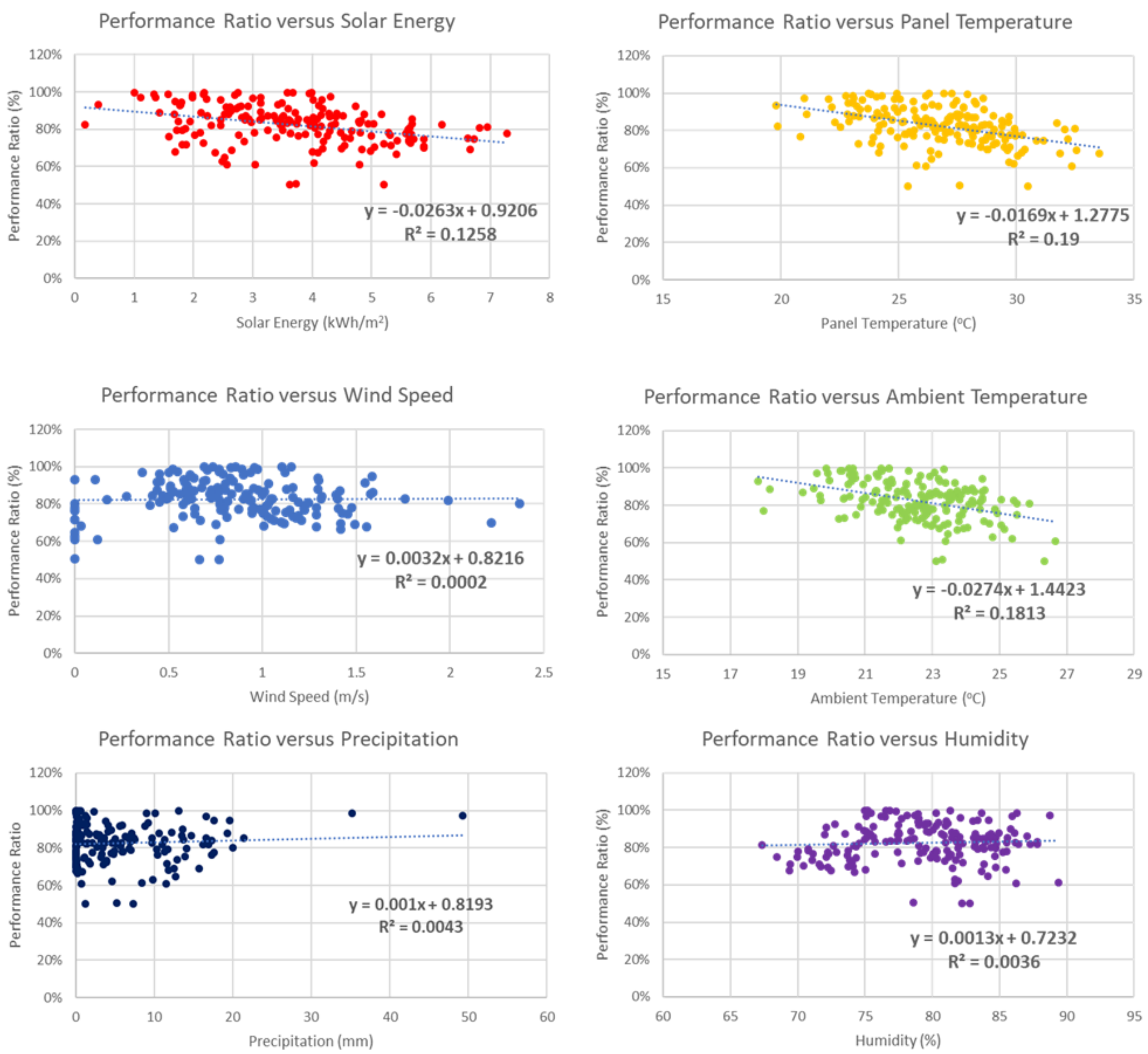


Figure 12 Correlation comparison between performance ratio and environmental parameters using all daily average data.

Due to the incompleteness of the data, it is difficult to find the correlation between the weather parameters and the performance parameters data only using the monthly average data. Hence, for the correlation purpose, all daily average data in 2014 was used. The performance ratio is one key parameter to identify the impact of weather conditions on the performance of solar panels (Dobaria, Pandya, and Aware 2016). Figure 12 compares the correlation between performance ratio and the environmental parameters. From this study, a negative correlation was observed between performance ratio and solar energy, the panel temperature, as well as ambient temperature. Panel temperature had a higher correlation coefficient followed by ambient temperature and solar energy. The higher the panel temperature, the lower the performance ratio. Meanwhile. a positive correlation was observed between performance ratio and the wind speed, the humidity, as well as the precipitation. Those three parameters provide a cooling effect which increases the performance ratio. However, in this Kayubihi area, the cooling impact can be neglected where the correlation coefficient is almost zero for these parameters.

To examine the weather effects in more detail, a monthly analysis was also performed. The month of January has been chosen due to the completeness of the data. It can be seen that there was a fluctuation in the energy yield data as well as in the performance ratio. The final yield varied from 1 to 5 hours while the reference yield varied from 1 to 7 hours (Figure 13). The performance ratio was in general greater than 70%. It is also interesting to be noticed that a high performance ratio is associated with low energy yield, such as on the 1st and on the 23rd of January.

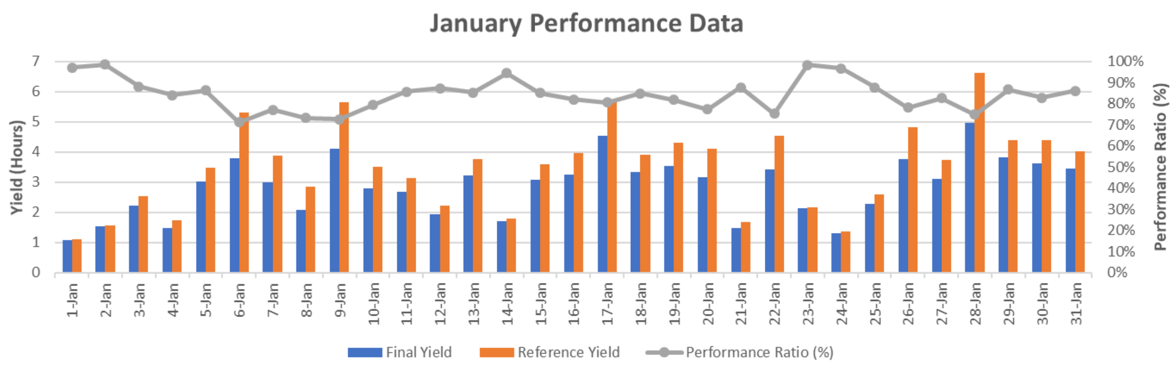


Figure 13 Performance data in January

Figure 14 depicts the weather data in January. Both the panel temperature and the ambient temperature had a similar fluctuation trend with the energy yield. Additionally, the high performance ratio on the 1st and 23rd of January is associated with the high precipitation during these days. The high precipitation was causing a cooling effect on the panel temperature resulting in high performance ratio. However, this high precipitation also reduced the energy yield. The fluctuation of energy yield was also associated to have a similar trend with the fluctuation of the clearness index. The clearness index can also represent the clearness or the cloudiness of the sky where a low clearness index is associated with high cloudiness.

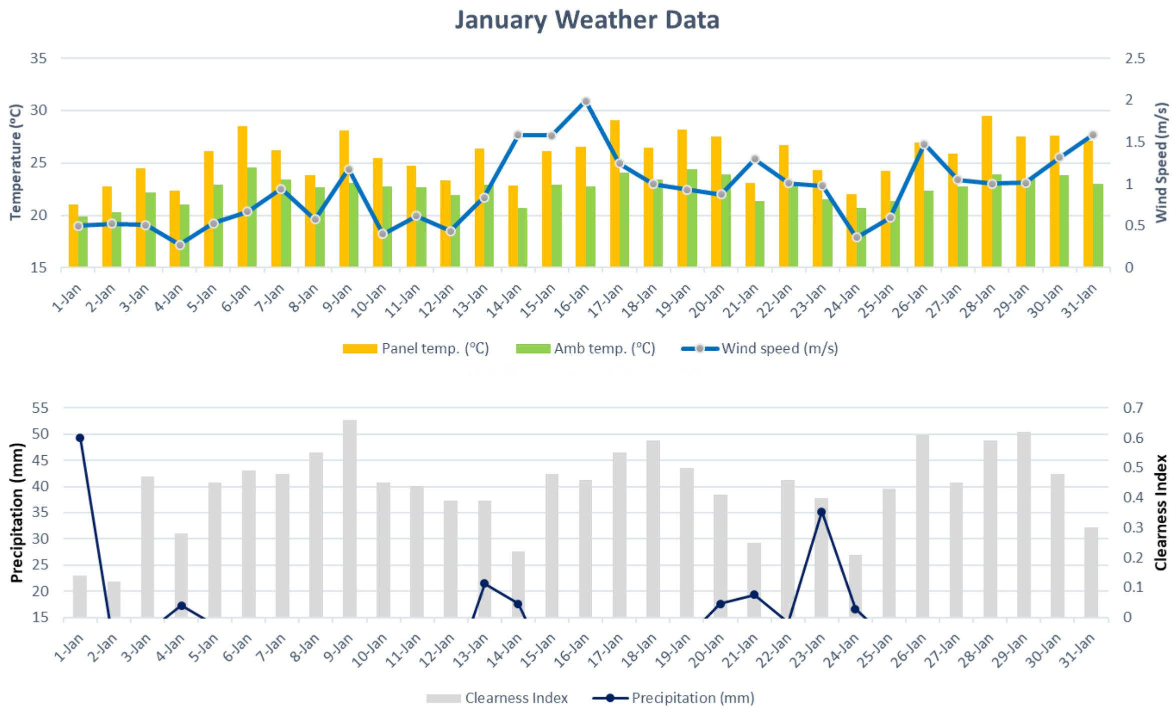


Figure 14 Weather Data in January

The correlation coefficient for this data was also calculated. Similar to the previous correlation result, a negative correlation was observed between performance ratio and solar energy, the panel temperature, as well as ambient temperature. In contrast, a positive correlation was obtained between performance ratio and the precipitation as well as the humidity. Interestingly, the correlation is stronger using this monthly data. Solar energy had the highest correlation followed by ambient temperature and panel temperature (Figure 15). Additionally, the impact of precipitation was also stronger in this month. Nevertheless, the wind speed had almost no correlation with the performance ratio. Thus, the wind speed had no impact in this Kayubihi case while solar radiation and temperature were quite impactful.

The impact of shading because of the presence of dust as well as the presence of physical objects cannot be observed in this study. However, the correlation between the performance ratio and the clearness index was able to be obtained. It can be seen from Figure 16 that there is a negative correlation between performance ratio and clearness index. The higher the clearness index, the lower the performance ratio. Additionally, the correlation coefficient value was also quite high. Hence, it can be interpreted that the presence of clouds may increase the performance ratio because at the same time the solar radiation and the temperature may decrease.

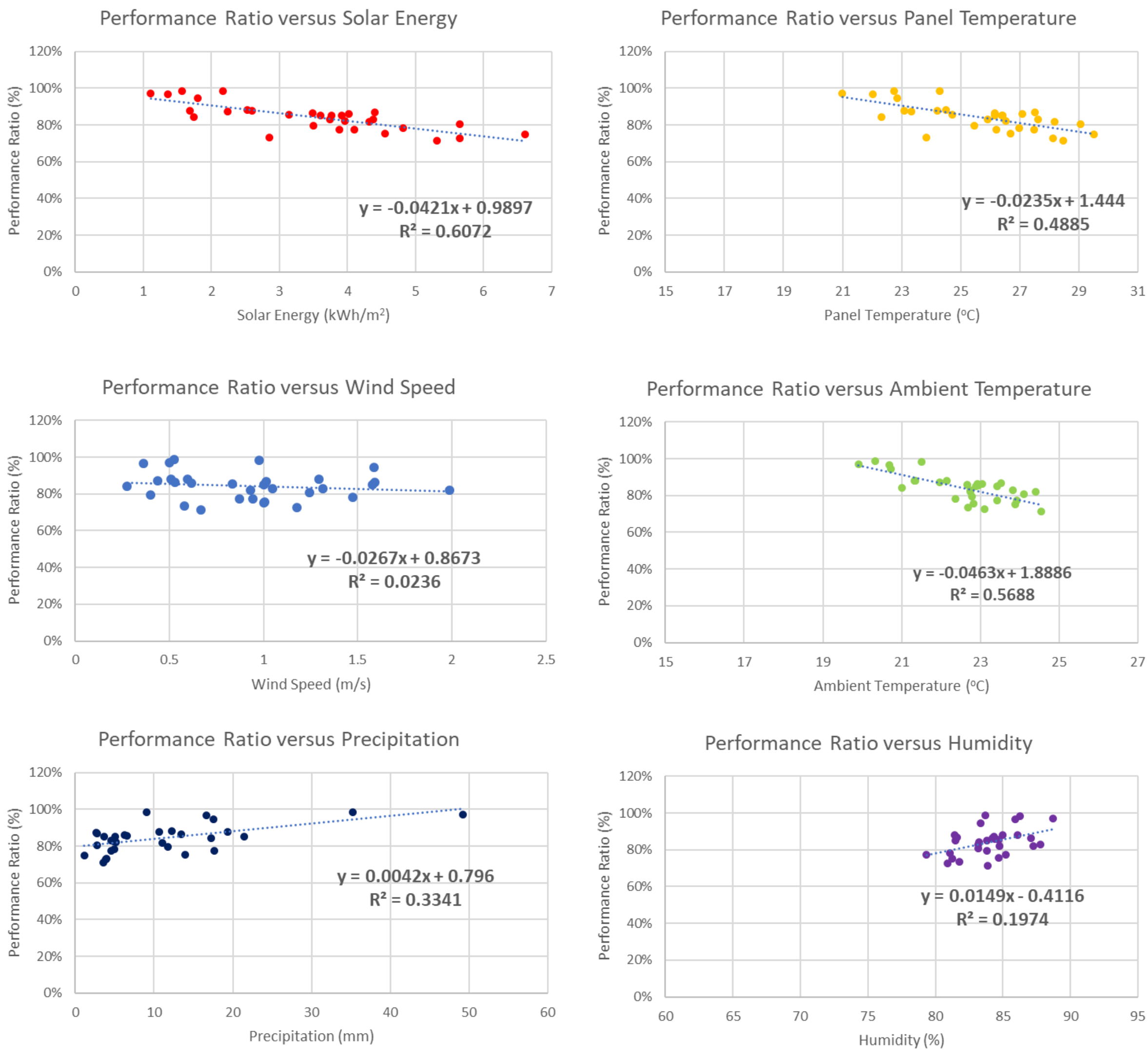


Figure 15 Correlation comparison between performance ratio and environmental parameters using January's daily average data

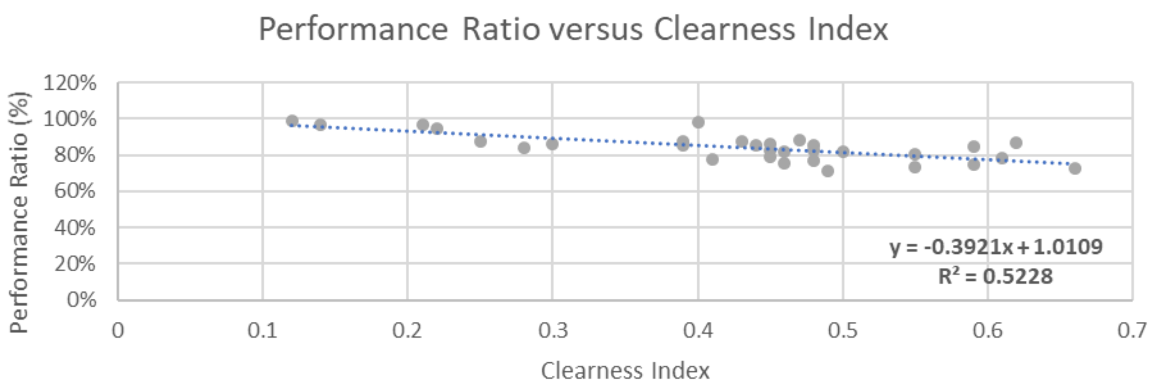


Figure 16 Performance ratio versus clearness index in January

While there is a similar correlation trend between the usage of all data as well as the usage of a specific month data, the correlation coefficient was weaker when using all data. It happened because in the tropical region the weather condition can be hard to predict. Hence, it is important to examine the daily variation for different seasons. To see the daily and seasonal variation, the average of 15-minute data from four different months are selected, which are January, April, July, and October. It can be seen from Figure 17 that there is an irregular solar radiation trend. The solar radiation value varied and overlapped each other, particularly in January and April. Interestingly, October had a relatively high solar radiation value while July had low solar radiation value. It might happen because although solar radiation value is relatively stable over the year in tropical regions, the presence of cloud and/or rain may fluctuate the solar radiation.

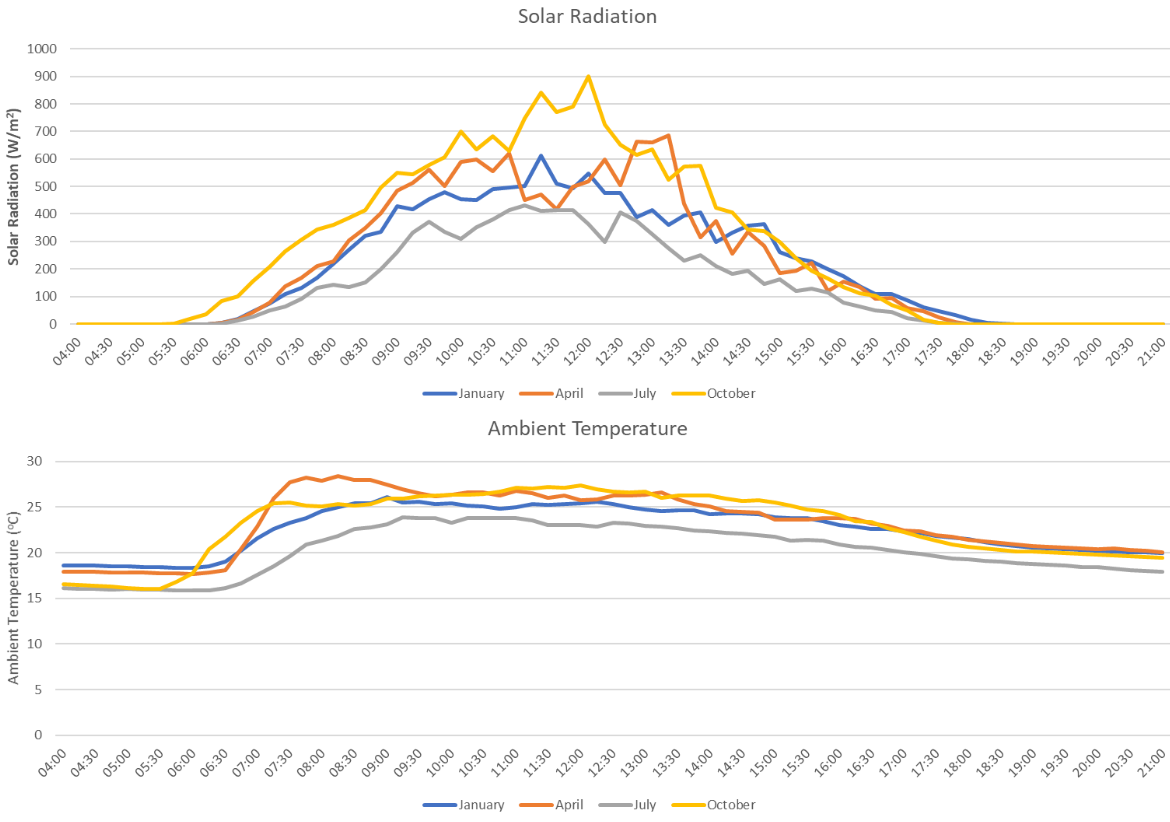


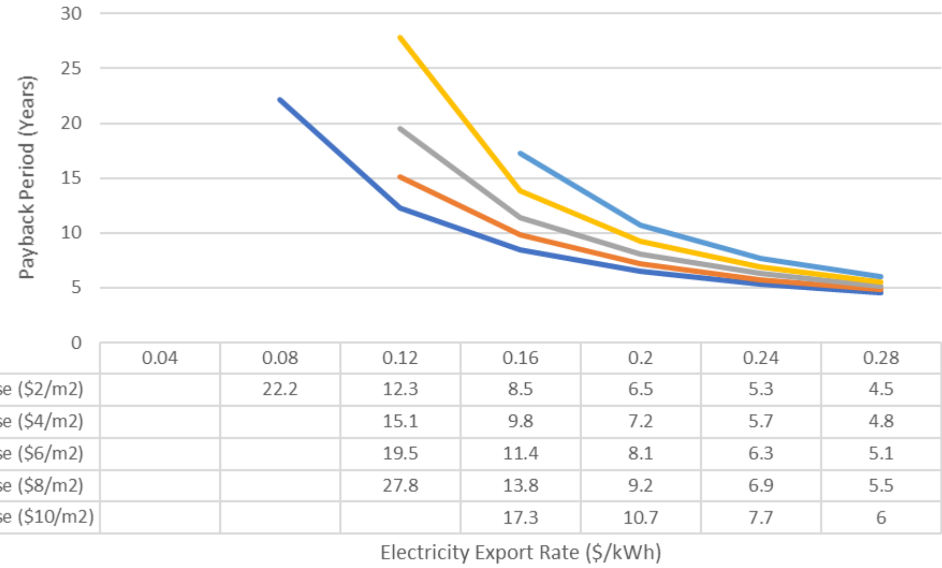
Figure 17 Weather parameter for some selected days.

The ambient temperature in this Kayubihi area also had a similar trend with solar radiation where the temperature was low in July. The low temperature and solar radiation value in July might explain the high performance ration in that month (87% from Table 9). In contrast, the high temperature and solar radiation value in October might justify the low performance ratio during that month (71% from Table 9). Therefore, solar radiation, ambient temperature, and panel temperature are three environmental factors that significantly impact the performance of a solar panel. Additionally, the presence of shading also might affect the performance by providing a cooling effect. Wind speed might also affect the performance, yet the impact can be neglected in this Kayubihi case. Due to the interaction between each parameter, it is difficult to only focus on one environmental parameter. This situation can be more complicated in tropical regions that weather conditions might vary.

4.1.2 Kayubihi Economic Evaluation

The economic evaluation was performed using RETScreen software. The level 1 energy model was used in RETScreen for a photovoltaic power plant. The power capacity was 1 MW and the capacity factor 12% was used resulting in 1,051 MWh of electricity. This value is slightly higher than the value in Table 9 because RETScreen assumed that the plant operates 365 days. For an initial analysis, it is assumed that the electricity export rate is 0.16 USD/kWh resulting in 168,192 USD revenue per year. For the cost model, the initial cost around 1.2 USD/W_p or 1200 USD/kW_p (Susanto 2016) and the O&M cost around 30 USD/kW_p/year (Ali and Shahnia 2017) were used. Additionally, the land acquisition cost was based on two scenarios.

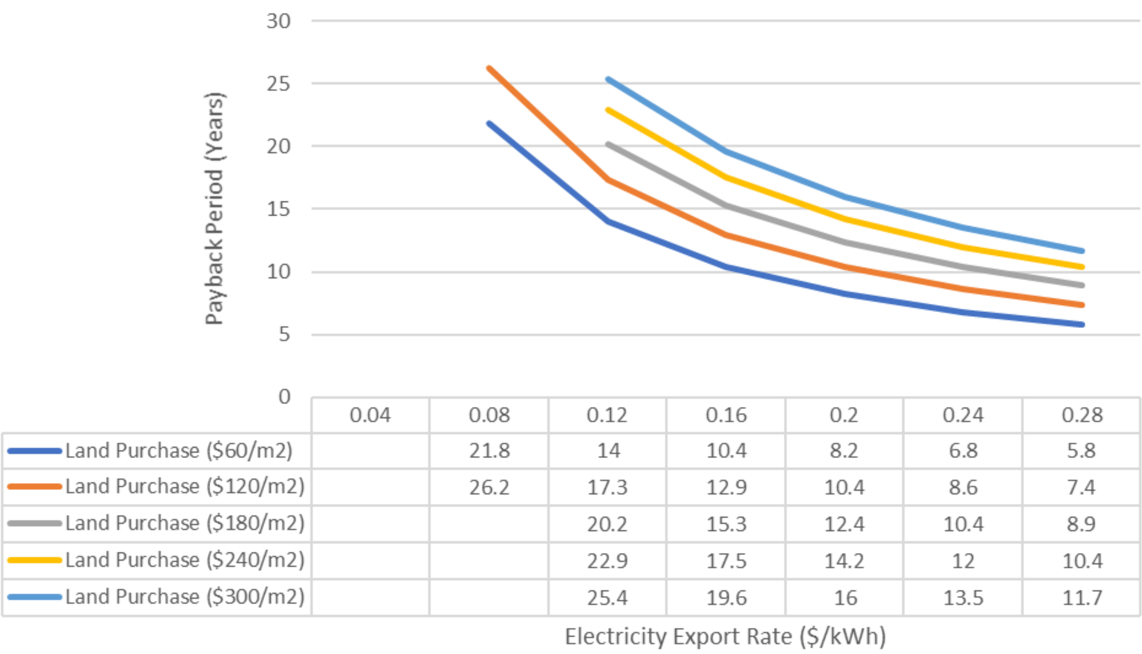
Using the level 1 financial model, it was assumed that the inflation rate was 3.2% (Plecher 2019) and the project lifetime was 30 years (PWC 2017). Purchasing the land at the beginning of the project resulted in 15.3 years of payback period, 4.2 million USD of NPV, 6.1% of IRR, and 0.14 USD/kWh of LCOE. Meanwhile, using the land-leasing scenario by paying the rent each year resulted in 11.4 years of payback period, 3.1 million USD of NPV, 9.3% of IRR, and 0.17 USD/kWh of LCOE. The payback period for purchasing land is longer than that for leasing land although the NPV of purchasing land is higher than that of renting one. Hence, the decision can be different depending on the target of the entity. If the company wants to have a quick return then land leasing is better. The sensitivity analysis was undertaken to see the impact of changing the electricity export rate (tariff) as well as changing the land acquisition cost on the project's payback period (Figure 18 and Figure 19). The land renting and purchasing costs were changed ±33% and ±66% each because of the land value variation in Indonesia. Meanwhile, the electricity export rate was in a range between 4 to 28 cents/kWh to simulate the variation of tariff under different regulations in Indonesia. When the electricity export rate is around 16 cents/kWh, the developer can get a payback period of fewer than 10 years if the land lease cost was less than 4 USD/m^2/year or at least 33% reduction from original land lease cost (Figure 18). However, under the same electricity export rate value 16 cents/kWh, the developer cannot get a payback period of fewer than 10 years even if the land purchase cost already reduces 66% (Figure 19).



	0.04	0.08	0.12	0.16	0.2	0.24	0.28
Land Lease ($2/m2)		22.2	12.3	8.5	6.5	5.3	4.5
Land Lease ($4/m2)			15.1	9.8	7.2	5.7	4.8
Land Lease ($6/m2)			19.5	11.4	8.1	6.3	5.1
Land Lease ($8/m2)			27.8	13.8	9.2	6.9	5.5
Land Lease ($10/m2)				17.3	10.7	7.7	6

Figure 18 Sensitivity analysis on land leasing scenario

If the electricity export rate is greater than 20 cents/kWh, then the payback period will be less than 10 years under the land leasing scenario. Under the land purchasing scenario, the payback period will be less than 10 years if the land price decreases and the export rate increases. Hence, land leasing seems better than land purchasing for giving a shorter payback period. Additionally, if the electricity export rate is less than 8 cents/kWh, then the project was not feasible for both land acquisition scenarios because the payback period is greater than the project's lifetime (Figure 18 and Figure 19). Under the current regulation, the electricity export tariff can be as low as USD 0.048/kWh which appears this tariff is not economically attractive.

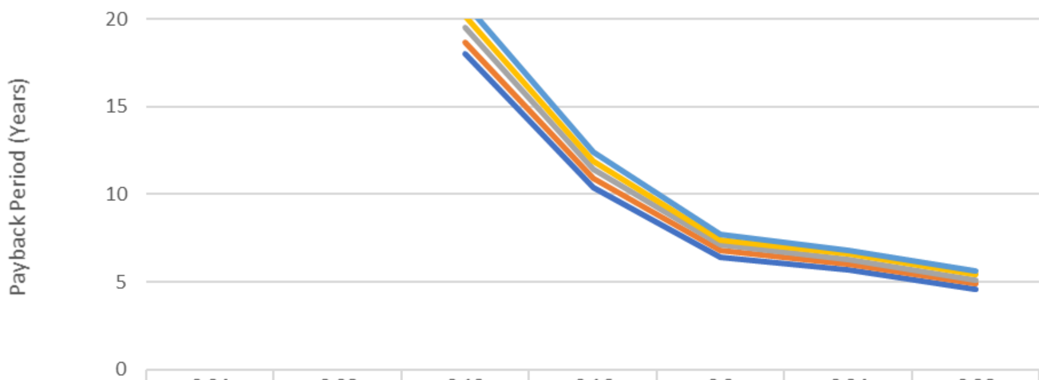


	0.04	0.08	0.12	0.16	0.2	0.24	0.28
Land Purchase ($60/m2)		21.8	14	10.4	8.2	6.8	5.8
Land Purchase ($120/m2)		26.2	17.3	12.9	10.4	8.6	7.4
Land Purchase ($180/m2)			20.2	15.3	12.4	10.4	8.9
Land Purchase ($240/m2)			22.9	17.5	14.2	12	10.4
Land Purchase ($300/m2)			25.4	19.6	16	13.5	11.7

Figure 19 Sensitivity analysis on land purchasing scenario

A similar sensitivity analysis was also performed to see the impact of changing the initial cost and O&M cost (Figure 20 and Figure 21). Both costs were changed up to ±10% because there is no significant variation in initial and maintenance costs in Indonesia. Under a condition of electricity export rate around 16 cents/kWh, the developer cannot get a payback period less than 10 years even though the initial and O&M costs were reduced by 10%. If the electricity export rate is equal to or greater than 20 cents/kWh, then the payback period will be less than 10 years for any given initial and O&M cost (Figure 20 and Figure 21). Besides, if the electricity export rate is equal to or less than 8 cents/kWh, then the project was not feasible (payback period greater than the project's lifetime) although the initial or O&M costs were changed.

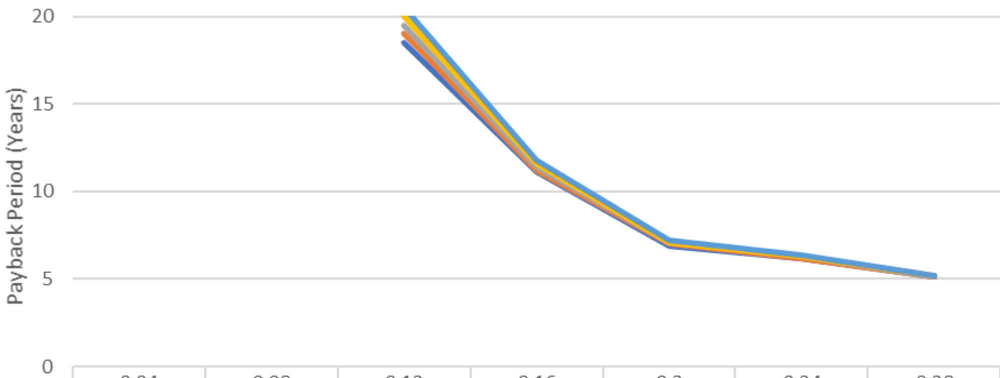
Hence, it can be inferred from this economic evaluation for both scenarios that the project seems not feasible if the utilities buy the electricity from the developers with a price less than 8 cents/kWh. This situation can be worsened if a detailed analysis was performed, particularly by incorporating the degradation rate. Also, the developer needs to understand their objectives, whether they want a quick return or high profit, because different approaches or decisions may have different outcomes.



	0.04	0.08	0.12	0.16	0.2	0.24	0.28
Initial Cost ($1.08/W)			18	10.4	6.4	5.7	4.6
Initial Cost ($1.14/W)			18.7	10.9	6.8	6	4.9
Initial Cost ($1.20/W)			19.5	11.4	7.1	6.3	5.1
Initial Cost ($1.26/W)			20.2	11.9	7.4	6.6	5.4
Initial Cost ($1.32/W)			20.9	12.4	7.7	6.8	5.6

Electricity Export Rate ($/kWh)

Figure 20 Sensitivity analysis of initial cost.



	0.04	0.08	0.12	0.16	0.2	0.24	0.28
O&M ($27/kW)			18.5	11.1	6.9	6.2	5.1
O&M ($28.5/kW)			19	11.2	7	6.2	5.1
O&M ($30/kW)			19.5	11.4	7.1	6.3	5.1
O&M ($31.5/kW)			20	11.6	7.1	6.3	5.2
O&M ($33/kW)			20.5	11.8	7.2	6.4	5.2

Electricity Export Rate ($/kWh)

Figure 21 Sensitivity analysis of maintenance cost.

4.2 Stakeholders' Survey and Interview

4.2.1 Participants

The survey questionnaires were distributed to 67 people representing the solar PV microgrid stakeholder population in Indonesia. There were three groups of stakeholders namely governments, developers, and experts. Thirty-four (34) people responded to the survey representing a 50.7% response rate. Ten (10) people (30%) were from the governments, 12 people (35%) from the developers, and the remaining 12 people (35%) from the experts. Figure 22 shows the distribution of stakeholders participated in filling a questionnaire for this research.

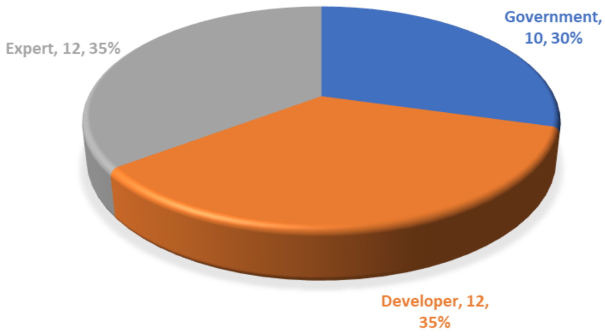


Figure 22 Survey Participants

Regarding the interview participants, 11 people were selected from the survey participants to be interviewed. Five (5) people (46%) were representing governments, four (4) people (36%) were representing developers, and two (2) people (18%) were representing the expert group (Figure 23). The summary of the results from the survey and the interview is presented in the following section.

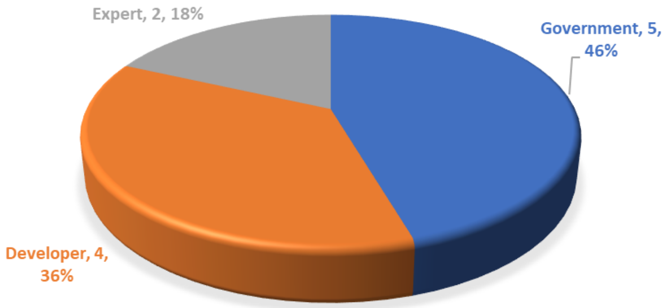


Figure 23 Interview Participants

4.2.2 Opportunities for Implementing Solar PV Microgrid

Participants were asked about their views on the opportunities for implementing solar PV microgrid in Indonesia. They were asked to rate the importance of factors that might help increasing solar PV microgrid penetration in Indonesia, including high solar radiation, declining investment cost, and the presence of the rural electrification program. According to the survey, 50% of participants agreed that the declining investment cost is extremely important followed by a power purchase agreement (41%). Figure 24 presents the detailed visualisation of potential factors for all groups. The figure shows that 58% of developers answered that this declining investment cost is extremely important. This factor is significant for developers because it may impact their capital cost.

Furthermore, 41% of survey participants mentioned that the presence of PPA regulation is extremely important. Although only 20% of the government's participants stated that power purchase regulation is extremely important, more than half of participants from experts and developers believed that this regulation is extremely important for the development of solar PV microgrid in Indonesia (Figure 24). The PPA purchase is simpler compared to the direct selling scheme from IPP to the consumers where parliament approval is required. Additionally, it provides a price guarantee for the developers. According to a participant,

//...Energy purchase policy is very important to provide certainty for investors. By knowing the price, the investors can calculate its payback and IRR...//

Only 26% of participants mentioned that the high solar radiation and rural electrification program are extremely important for increasing the penetration of solar PV microgrid. There is no doubt Indonesia has significant solar potential. Yet, without any supportive regulations or incentives, this potential cannot be harnessed. Additionally, the current rural electrification program only impacts on the increase of electrification ratio rather than the penetration of solar PV microgrid.

The FIT is claimed to be not extremely important enough, particularly from the government side because FiT is expensive for the government. According to the government participant, the parliament revoked the FiT scheme because they decided that subsidies should be given to the poor community, not to the private sector. Furthermore, the government has a lack of budget allocation for community electrification schemes hindering the deployment of PV microgrid.

//... the government itself does not have any budget allocation for the scheme ...//

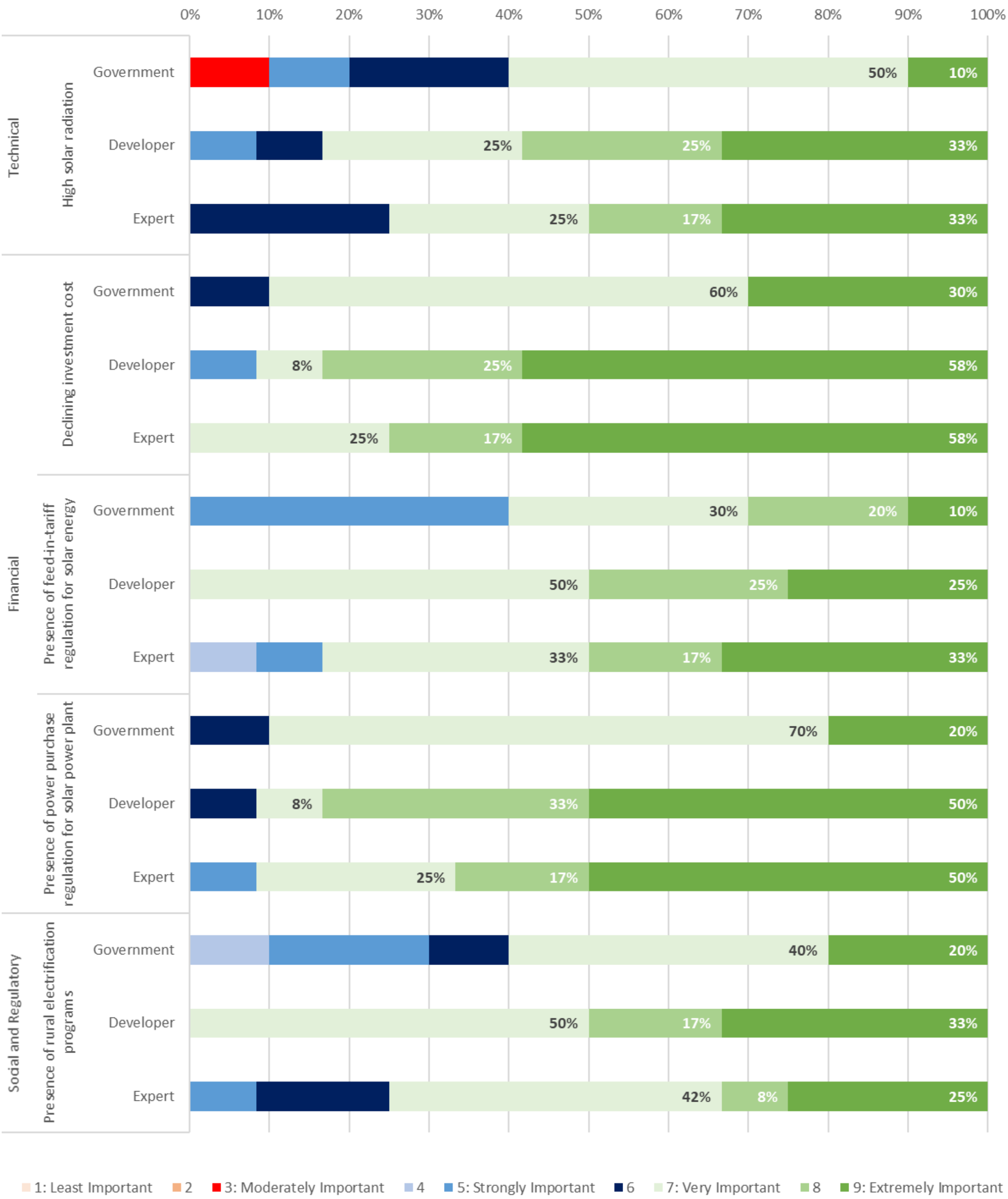


Figure 24 Survey result for potential

While governments believe that helping the developer through FiT is not extremely important, others have different views. According to the developer groups, the presence of a FiT scheme in other countries helped to attract the investment in solar PV microgrid.

//.. Malaysia and the Philippines have attractive FiTs to increase their clean energy investment, including solar PV. This FiT also attracts foreign investors to build manufacturing companies in these countries …//

4.2.3 Barriers for Implementing Solar PV Microgrid

Participants were also asked about their opinions on the barriers to implementing solar PV microgrid in Indonesia.

4.2.3.1 Technical Barriers

There are mixed opinions concerning technical factors that are extremely impactful on the development of solar PV microgrid. Both developers and experts agreed that insufficient technical knowledge and capacity are extremely impactful while governments claimed that unstable grid connection is extremely impactful.

According to Figure 25, approximately one-third of experts and developers believed that insufficient technical knowledge and capacity are extremely impactful. The developers feel that this aspect is extremely impactful because it will affect their solar PV project's sustainability.

//... some areas have highly motivated and skilled citizens, but there are some areas that do not have them. It makes the sustainability of the system vulnerable…//

No participant from the government agreed that insufficient technical knowledge and capacity are extremely impactful because the current LTSHE program owned by the government is simple and can be maintained easily. Yet, 90% of government participants still believed that it is still very impactful because in the past the government had some large PV microgrid projects.

//…When the central government entered an area to build a solar power plant, then the solar power plant was handed over to the local government or community to be managed. Unfortunately, they could not yet manage the solar PV, institutionally, as well as to operate the system. As a result, many government's assets have been damaged because the systems were not being operated and maintained properly…//

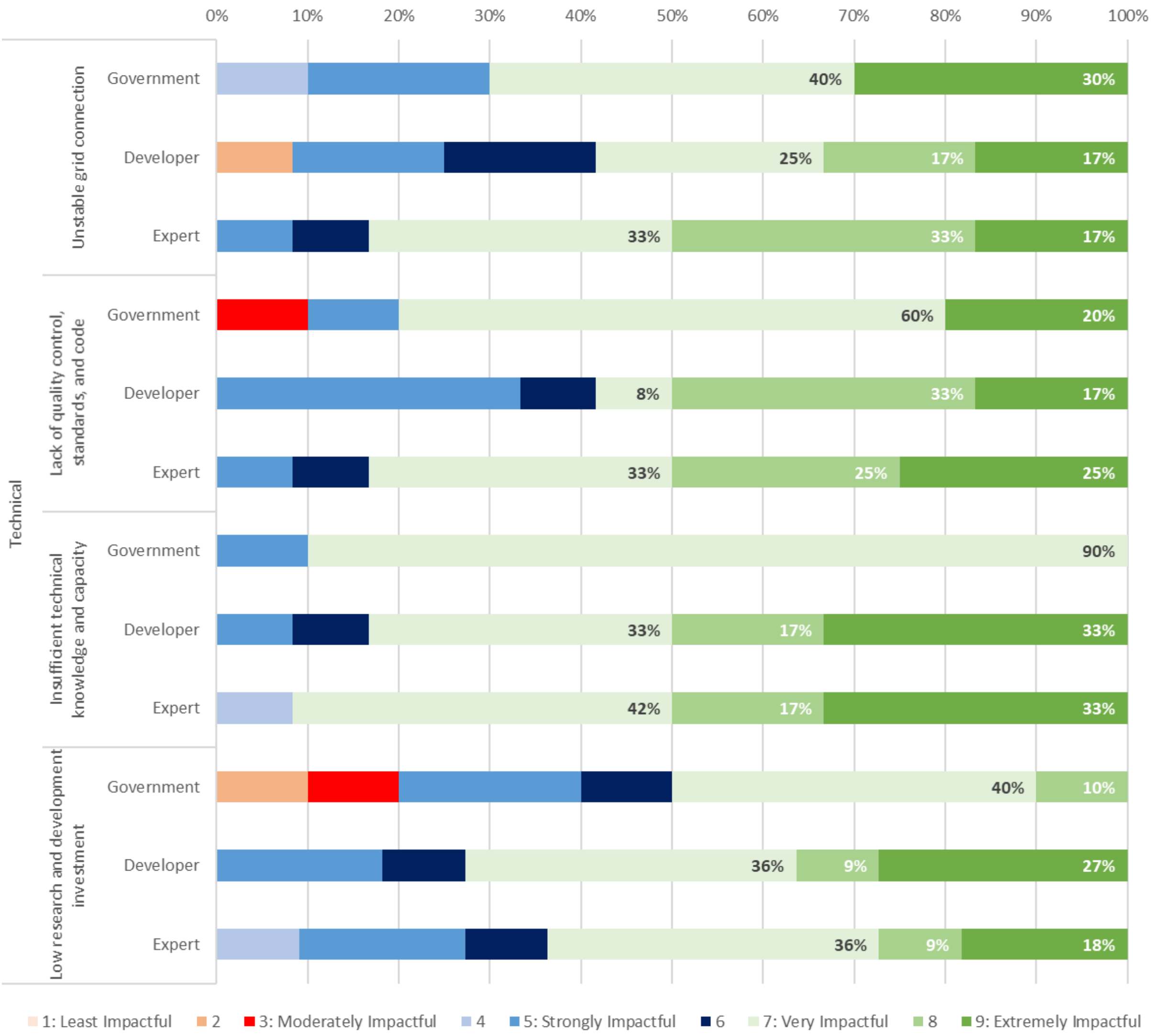


Figure 25 Survey result for technical barriers

The intermittent behaviour of solar PV becomes an issue for network stability, particularly when the penetration is quite large. Around 30% of government participants responded that it is extremely impactful (Figure 25). The unstable network condition can be a barrier to the grid. Battery or backup generation, like diesel generators, can be the solution to overcome this issue. However, the project will be less economical for the developer if these ancillary components are included. PLN must pay a high intermittent fee for a large grid-connected solar PV system. These ancillary loads might be too costly for the state company.

Regarding the standard, the project owners have fulfilled the specifications given in the tender requirement, following SNI (Standard National Indonesia) standards or IEC (International

Electrotechnical Commission) standards. Yet, the standard for the grid quality such as frequency, harmonic factors, and voltage variation is still required in Indonesia. This grid standard is called 'grid code' in Indonesia. A quarter of experts believed that the lack of grid code is extremely impactful because it might impact the grid network too. According to one participant,

//…Renewable has not been prepared for on-grid because in the past renewable is mainly used off-grid to help people in remote areas. Because there is a new policy to connect the renewables to the network, including rooftop PV, then grid code is required…//

While low R&D investment is not extremely impactful from the government's point of view, 27% of developers thought that it is extremely impactful. The solar PV development is not only hampered because of limited R&D budget but also due to limited testing centre.

//… Most current systems should have at least followed SNI because it is a pre-requisite in the tender document. However, sometimes, this pre-requisite is not mandatory because there is only one testing institution in Indonesia…//

4.2.3.2 Financial Barriers

While the government participants have not seen the other financial aspects are extremely important, both developers and experts have different views on this (Figure 26). The lack of a renewable market is seen as extremely impactful from the developers (36%) and experts (27%) perspectives. The presence of fuel subsidy was also mentioned as a problem by these two respondent groups followed by the inappropriate tariff incentive. Currently, PLN dominated the electricity sector in Indonesia from generation to distribution. Concerning generation, steam power plants are still dominating the electricity market. Consequently, this situation hinders the development of the renewable energy market.

//…there are not many renewable energy markets. Hence, many companies are not yet interested in opening solar PV's manufacturing industry in Indonesia… Consequently, the price of solar PV is more expensive than the traditional power plant… //

Furthermore, according to the survey, almost one-third of participants agreed that the lack of access to finance is extremely impactful. The developers claimed that local banks are not interested in solar PV projects because these institutions have doubts about the sustainability of the industry. Developers thought that foreign banks or private equities are more attractive.

//…At present, local banks are still less competitive because they have high-interest rates. Approaching foreign banks or development banks is a better solution for IPP because these banks provide loans for renewable energy projects with lower interest…//

However, small developers might have difficulties in accessing the capital from the bank because most small developers have no collateral.

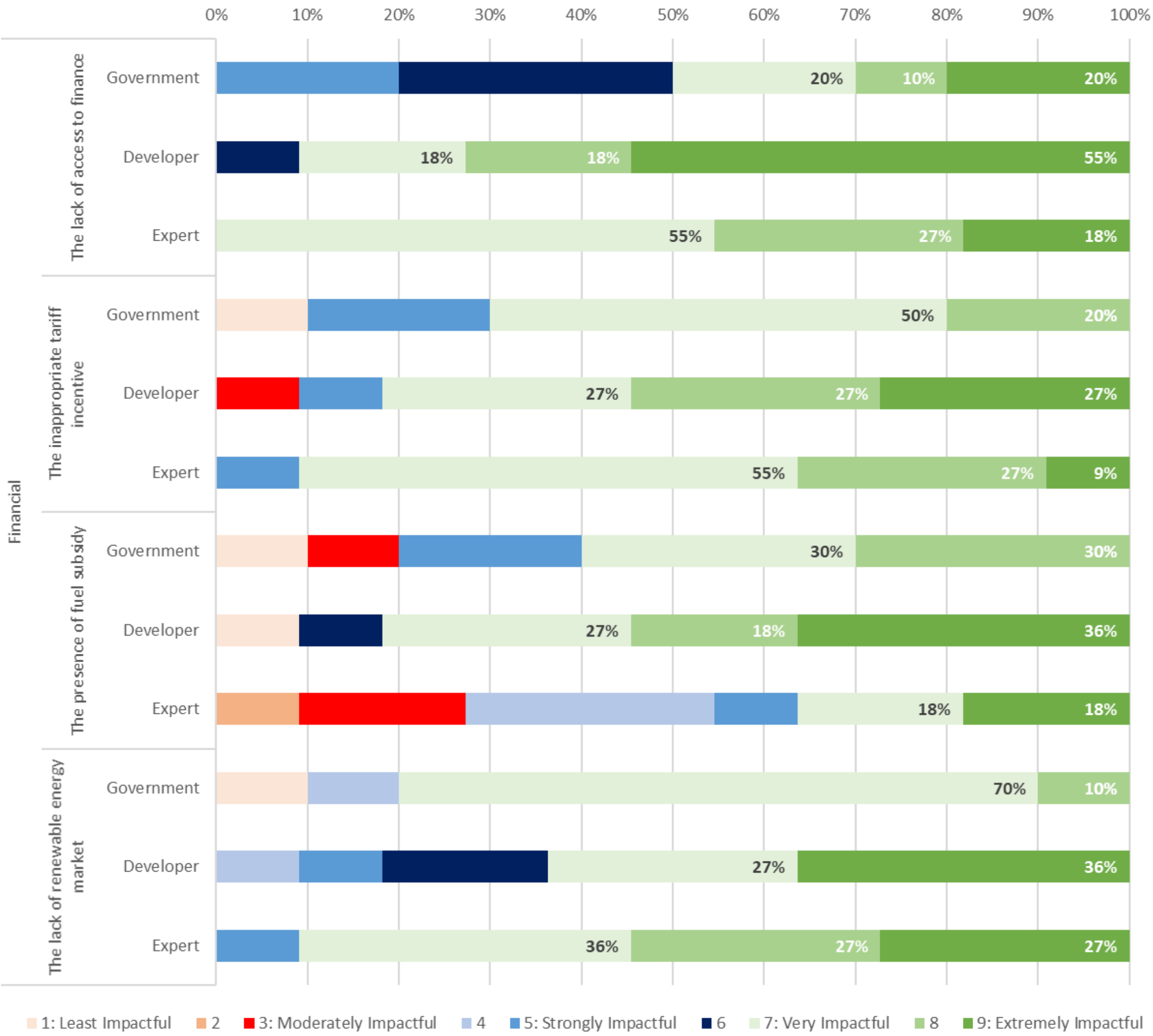


Figure 26 Survey result for financial barriers

4.2.3.3 Social and Regulatory Barriers

Figure 27 shows the survey result for the social and regulatory aspects that are potentially hampering the implementation of solar PV microgrid in Indonesia. There were different perspectives regarding the impact of each factor. Not many government participants claimed that the given factors were extremely impactful, except for the conflicting regulatory measures. This factor was also extremely impactful for developers (18%) and experts (27%). The same percentage of experts also believed that the complexity of bureaucracy is extremely impactful. Meanwhile, around 27% of developers argued that the unclear tender process is significantly impactful.

Almost 20% of participants gave a response that the conflicting regulatory measures are extremely impactful. The current renewable policy, MoEMR Regulation No. 50/2017, regulates the electricity supply cost (BPP), local content (TKDN), BOOT mechanism, as well as tender mechanism for renewable energy development, including solar PV microgrid. The presence of this regulation becomes a significant burden for developers.

The regional electricity supply cost or BPP becomes the ceiling price to determine the tariff structure under PPA. Although it may give a guarantee, the current regulation makes the selling price less attractive. The BPP regulation makes some projects are economically not feasible. Some places have a better market yet because the BPP is quite low, then the projects are not attractive, particularly for the microgrid ones.

//…in Java, BPP is less attractive because its value is low due to the presence of steam power plants. Outside Java, the BPP price is attractive but the network is not ready to get solar penetration. Yet, Java has a large market, around 70% of electricity demand in Indonesia…//

The local content regulation also hinders the development of solar PV microgrid in Indonesia. According to MoEMR Regulation No. 50/2017, the local content is based on MoI Regulation No. 5/2017. For a solar PV microgrid, the local content requirement for the module must be at least 60%. However, at this moment, Indonesia cannot locally produce solar cells. The country is only capable to assemble the imported cells in Indonesia. This situation is worsened by the lack of market as well as the lack of labour capacity which increases the module's assembly cost. Consequently, the modules become more expensive than imported ones.

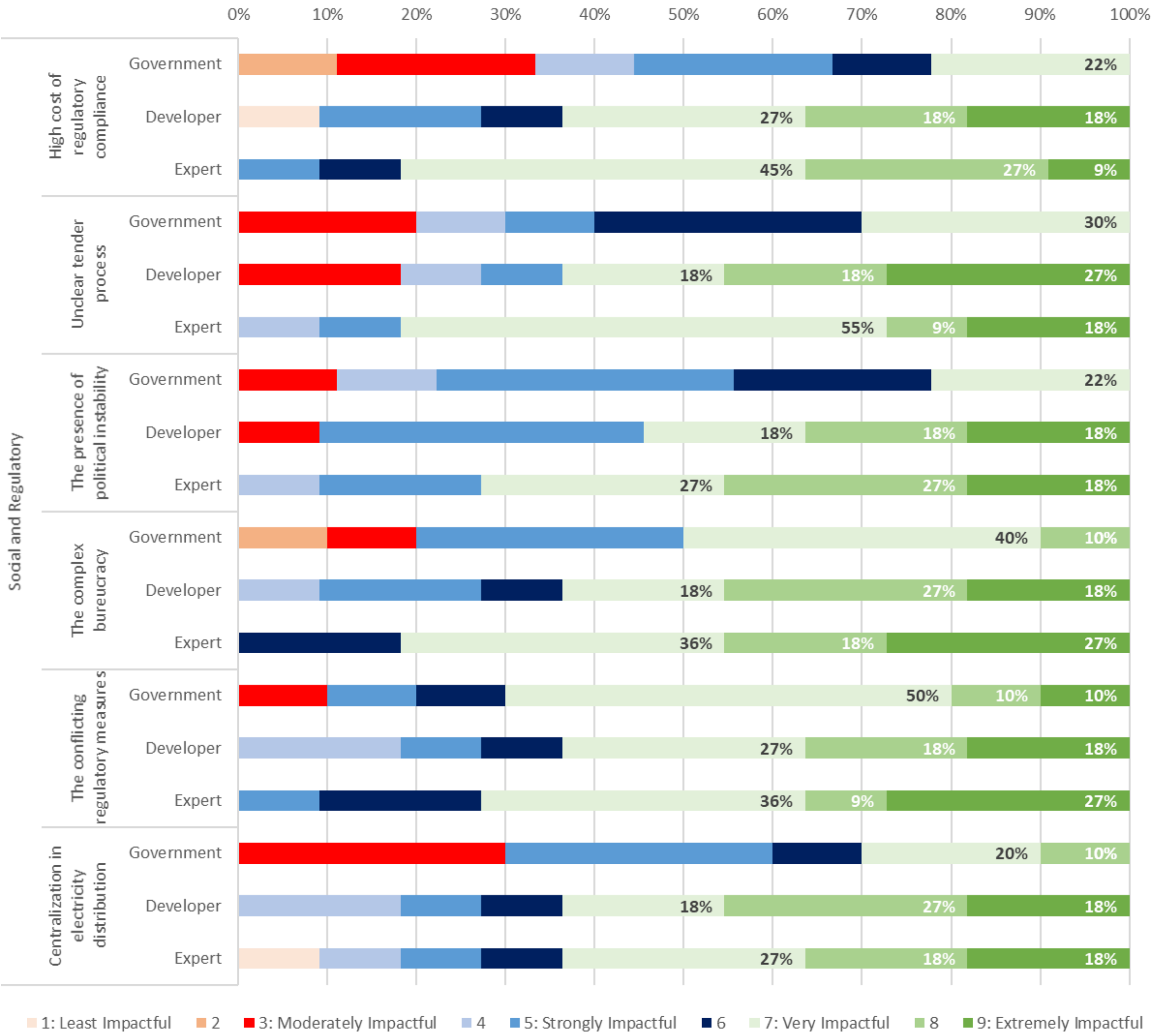


Figure 27 Survey result for social and regulatory barriers

The transfer process on the BOOT scheme is also another issue in the current regulation. The participants mentioned that the regulation is not beneficial for the IPP because they cannot use their assets as collateral for getting the loan from the banks. Additionally, public companies cannot transfer their assets to the central government without the approval from the parliament. Additionally, this scheme becomes a problem for the developers in regard to land acquisition. At the location where the land price is premium, the developers are reluctant to transfer their land to the government at the end of the contract period. The governments also do not give incentives or aids for the land acquisition process. A barren land or ex-mining land also cannot be used to develop solar PV because it may raise a conflict with environmental regulation. The transfer process in the BOOT scheme under the current regulation causes a significant issue for developing solar PV microgrid in Indonesia.

//…If the transfer in BOOT mechanism is removed, then it will have a significant impact…//

The tender mechanism was also regulated in the current MoEMR Regulation No. 50/2017. The developers are selected using direct selection based on quota capacity. Yet, to be selected the developers must be under the PLN's selected list of participants. It has been claimed that the current process is more competitive, more objective, and less risk than the previous tender because the developers were screened for their feasibility studies. However, the determined location and capacity might not be feasible for the developers. Intermittent generations are usually getting a small quota.

//…Because of the quota mechanism from PLN, IPP encounters obstacles to develop solar PV. The demand increase will be distributed partially for baseload and other generations. Intermittent generators usually get a small quota. Additionally, PLN will choose the most reliable and the cheapest baseload such as steam power plant…//

4.2.4 Mechanism for Implementing Solar PV Microgrid

Participants were also asked about their opinions on the mechanisms that enable the implementation of solar PV microgrid in Indonesia. Details summary of the survey and interview results on the mechanism are presented in the next section.

4.2.4.1 Market Based Mechanisms

The market-based mechanism was not seen as extremely important enough for the government (Figure 28). Whereas, experts (45%) and developers (27%) agreed that public-private partnership is extremely important. Meanwhile, 36% of developers claimed that renewable energy quota is extremely important supported by 18% experts. Interestingly, 36% of experts and 27% of developers claimed that feed-in-tariff is extremely important which was not agreed by the government. Joint Credit Mechanism was not picked as extremely important by many participants.

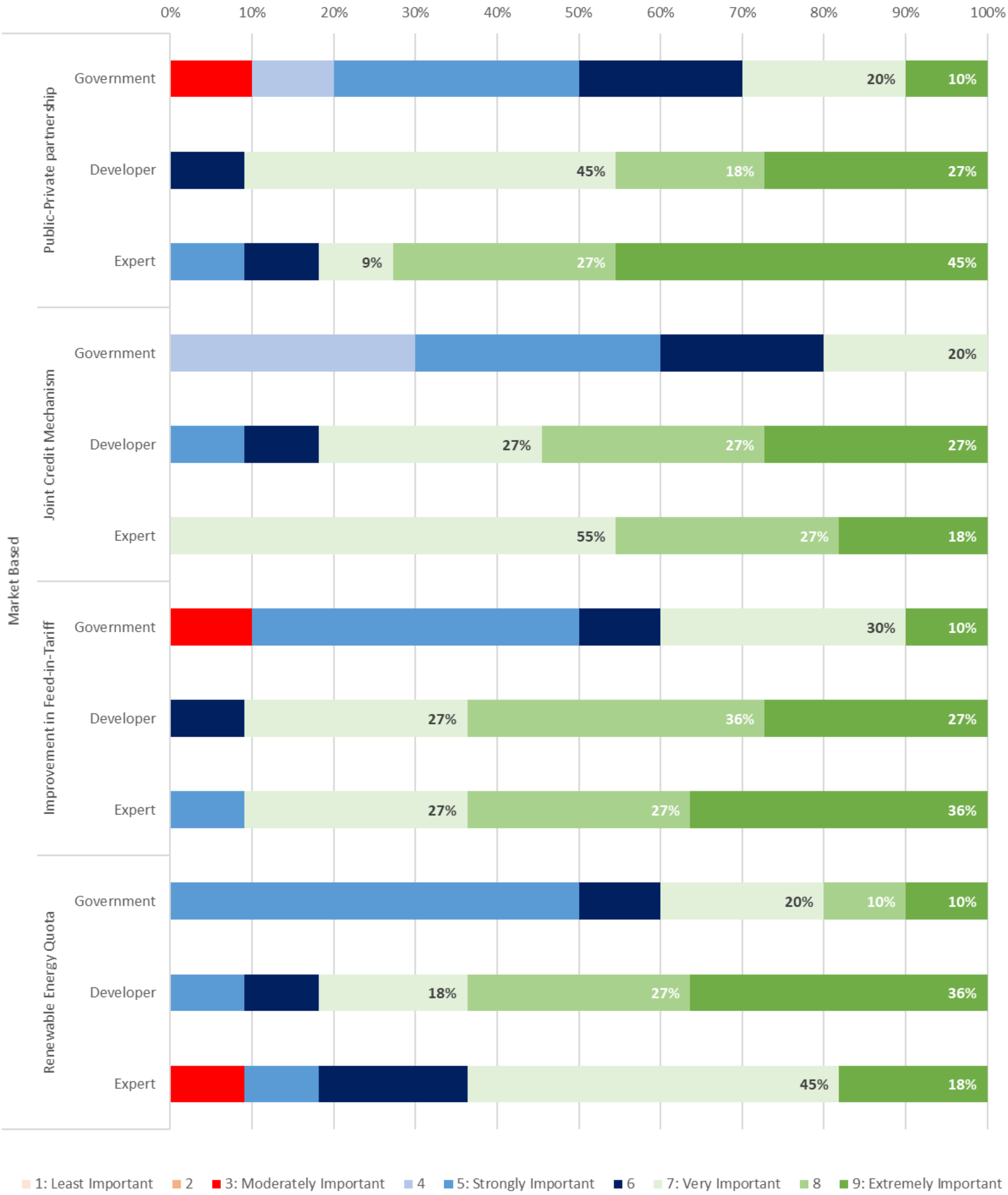


Figure 28 Survey result for market-based mechanisms

While surveying the participants, they agreed that Public-private partnership is extremely important because the collaboration between private and state enterprises might reduce the investment risk. According to the interviewee, each enterprise can contribute to the area where they have excellence capabilities. As a result, it will increase the deployment of solar PV microgrid in Indonesia. Although quota capacity has been used in the tender mechanism, the government should prioritise renewable energy, such as solar PV, in their quota capacity which was mentioned also by a participant.

//…The government should have prioritized renewable energy quotas whose prices are below the BPP before taking thermal generation into account…//

Currently, none of the solar PV microgrid projects is implanted via a Joint Credit Mechanism in Indonesia because all monetary-related policies must go through the Ministry of Finance. Hence, other ministries, such as MoEMR, cannot make any monetary-related policies. Thus, fewer participants said that this mechanism is extremely important.

4.3.4.2 Non-market Based Mechanism

Approximately 29% of participants agreed that strengthening intergovernmental cooperation is significantly important, particularly from the expert and developer point of view. It can be seen in Figure 29 that 42% of experts and developers thought that this factor is extremely important. Firstly, from the previous section, the current regulation may have a conflict with the other regulation from different ministries. Strong cooperation can reduce the possibility of conflicting regulation making the development of solar PV microgrid easier. Secondly, strong collaboration also can help increase the development of solar PV microgrid by maximizing the utilisation of solar PV to increase the economic growth of the local communities. According to a participant,

//… It should be better if coordination between ministries has been conducted since the planning phase. For example, coordinating with the Ministry of Marine Affairs and Fisheries to help mapping economic potential, such as fisheries, in the regions. Coordination with the Ministry of Home Affairs and the Ministry of Village, Development of Disadvantaged Regions, and Transmigration can help in community empowerment. Then, the Ministry of Cooperatives Small and

Medium Enterprise can also participate to encourage electricity use from solar PV. If this can happen, the solar PV project will be more sustainable…//

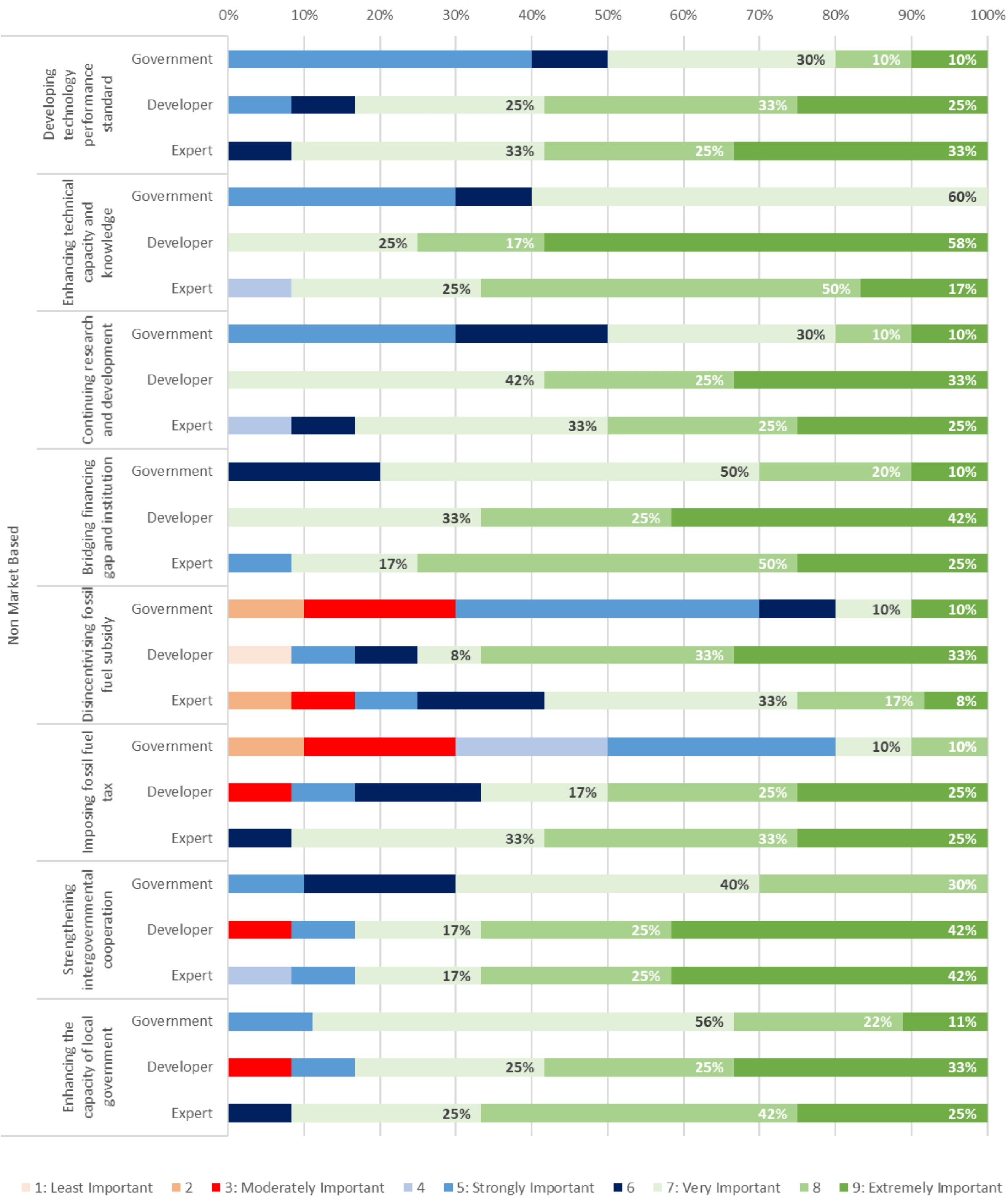


Figure 29 Survey result for non-market based mechanisms

Around 26% of respondents also believed that enhancing technical capacity and knowledge is also extremely an important mechanism. Approximately 58% of participants from the developers group claimed that it is extremely significant (Figure 29). The educational institutions should offer more renewable energy courses to develop human resources capable to handle technical problems in renewable energy generation systems, either in installation or maintenance. Collaboration with different institutions or donor agencies is also important to provide training as well as to increase awareness of the local community so that their willingness-to-pay also increases. From the investor's perspective, the investment will not happen if the buyer does not have the willingness to pay although their ability to pay is high.

Bridging the financing gap and interested financial institutions is also extremely important mentioned by 26% of the total respondent, particularly the developers. Corporate Social Responsibly program can be alternative funding for the development of solar PV microgrid. Furthermore, both experts and governments also concerned that developing technology performance standards as well as continuing research and development are extremely important. Grid code is necessary to manage the reliability of the grid. Additionally, the presence of R&D can be critical in the long run to increase the competitiveness of local products so that technology can be cheaper. Consequently, it may also help the developers to fulfil the local content requirement in Indonesia.

4.3.5 Ranking of Importance for Increasing Solar PV Microgrid

The participants were also asked to rank 10 factors from the most important factor (Rank 1) for increasing solar PV microgrid to the least important one (Rank 10). Interestingly, each group has almost different perspectives (Figure 30). The majority of the government participants (60%) believed that investment cost is in the top tier of the factors while the remaining claimed that affordable price and presence of regulation are the most important thing for increasing the penetration of solar PV microgrid in Indonesia.

The developer has an almost similar answer to the government. However, the majority of developers (50%) responded that the presence of regulation is at the top rank of the important factors. A quarter of the developers stated that investment cost is the most important thing relative to the other factors. Interestingly, the rest of developer participants not only claimed that affordability is supposed to be the most important one but also the commercial maturity must be considered as the most important factor as well.

Figure 30 Ranking of importance.

While the governments and developers have relatively narrow answers, the experts have mixed opinions about the most important factor. The most important factor for the majority of experts is the affordable price for the consumer. 20% of experts believed that access to capital must be at the top tier. The remaining percentage was divided equally for reliability, investment cost, incentive, regulation, and bureaucracy. Although each group has different perspectives, they agree that greenhouse gas and employment potential never be the driver or the top tier of the important factor for increasing solar PV microgrid in Indonesia.

To see the relative importance between the different groups in a diagram, a spider diagram was used (Figure 31). The average ranking formula was calculated for each factor. The employment potential and the greenhouse gases were not included in the spider diagram because from the previous analysis, both factors appear not to be the top rank. Additionally, it can simplify the visualisation. It can be seen that both government and developers are more concerned with the investment cost and presence of regulation. Affordable price seems to be the concern for both government and expert. Besides, experts also concern about access to capital.

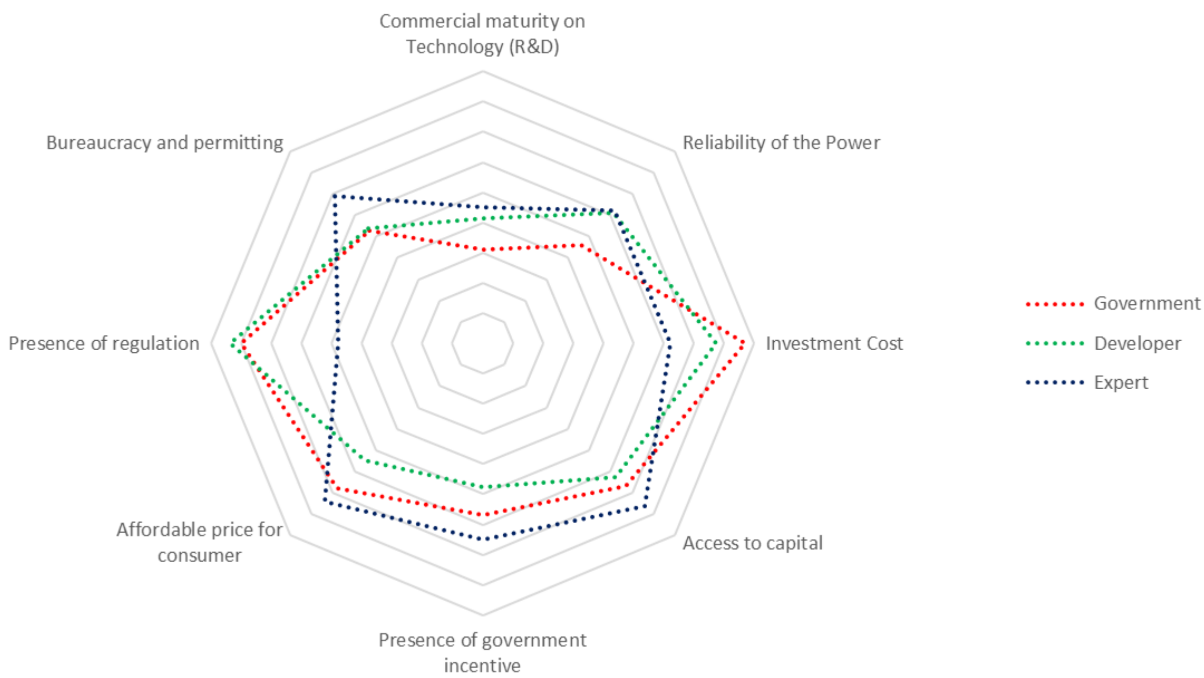


Figure 31 Average ranking of each factor.

Table 10 summarizes the outcomes of extremely important factors from different groups of stakeholders. There are some different opinions between stakeholders regarding barriers, mechanisms, and top rankings. Interestingly, all three groups have the same opinion on the opportunities for developing solar PV microgrid in Indonesia. The declining investment cost and the presence of PPA regulation seem to be extremely important in developing the solar PV microgrid in Indonesia, particularly for the developers. Both developers and experts concern with insufficient technical knowledge and capacity. In contrast, the government is aware of the unstable grid connection.

Table 10 Outcome summary of extremely important factors for the development of solar PV microgrid in Indonesia.

	Government	Developer	Expert
Opportunities	• Declining investment cost • Presence of PPA	• Declining investment cost • Presence of PPA	• Declining investment cost • Presence of PPA
Barriers	• Unstable grid connection • The lack of access to finance • The conflicting regulatory measures	• Insufficient technical knowledge and capacity • The lack of access to finance • The lack of renewable market • The conflicting regulatory measures • Unclear tender process	• Insufficient technical knowledge and capacity • The lack of renewable market • The lack of access to finance • The conflicting regulatory measures
Mechanisms	• Developing technology performance standard • Continuing research and development • Bridging financing gap and institution	• Renewable energy quota • Enhancing technical capacity and knowledge • Strengthening intergovernmental cooperation • Bridging financing gap and institution	• Public-private partnership • Strengthening intergovernmental cooperation • Developing technology performance standard • Continuing research and development
Top Ranking	• Investment Cost • Affordable Price • Presence of Regulation	• Presence of Regulation • Investment Cost	• Affordable Price • Access to Capital

Chapter 5: Interpretation and Discussion

This chapter will discuss the development of a framework based on the information obtained in the previous result. The first part discusses the relationships between parameters in three categories, namely technical, financial, as well as social and regulatory aspects. The second part will determine the priority while the last part will discuss the framework design for increasing solar PV penetration in Indonesia.

5.1 Relationship between Parameters

To increase the penetration of solar PV microgrid in Indonesia, a successful implementation must be executed. However, the implementation of the system itself is affected by different parameters. A conceptual framework may illustrate the key relationships between the elements within the system. Therefore, before developing the main framework for increasing solar PV microgrid in Indonesia, the relationship between parameters mentioned during this research will be discussed in this section.

Using NVivo software, there are three categories presented in this section which are technical aspects, financial aspects, as well as social and regulatory aspects. Categorizing the sub-children can be a challenging process. Some parameters can be categorized in multiple aspects, such as BPP that can be included within the financial aspect as well as the regulatory aspect. However, because the relationship is closer to the financial aspect then BPP is included in the financial one instead of in the social and regulatory one.

The diagram in Figure 32 shows technical issues and factors related to the implementation of solar PV microgrid in Indonesia. The figure was created from the transcript of the review using NVivo Software. There are five key factors raised by the interviewees, namely resources, grid, O&M, electrical component, and R&D. Each parameter also has its sub-children. The number represents the number of interviewees mentioned the issue.

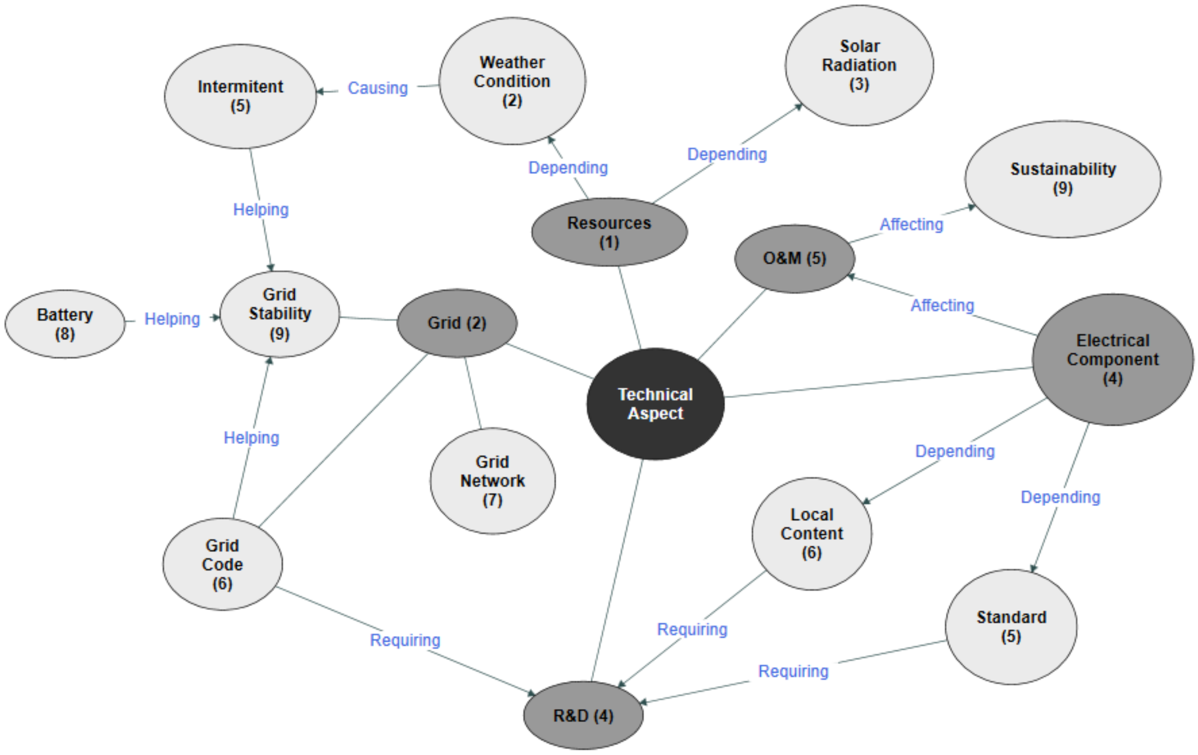


Figure 32 Parameter relationships under the technical aspects' category.

Grid stability was critically discussed by most interviewees. They said that grid stability is affected by the intermittence behaviour of solar resources. Thus, grid code and batteries/back-up generators have been seen as the solution that can help to overcome the problem. There is no problem concerning solar radiation potential yet based on techno-economic evaluation high solar radiation is associated with low performance ratio. The interviewee also mentioned that the system's sustainability is quite critical and hampered by poor execution of operation and maintenance (O&M). Because the number of O&M is affected by the quality of the electrical component itself, they stated that if the electrical components have good quality and meet the requirement/standard, then the number of maintenances can be reduced. Local content also becomes an issue to develop this standard. Thus, R&D must be carried out to fulfil this standard.

The financial issues and factors related to the implementation of solar PV microgrid in Indonesia are shown in Figure 33. Similar to the technical aspect one, this diagram was created from the transcript of the review using NVivo Software. Compared to the technical one, there are more factors raised by the interviewees. There are six key factors raised by the participants, namely, cost, tariff, incentive, market, fossil fuel impact, and access to capital. Each parameter has its sub-children shown in Figure 33. The number represents the number of interviewees mentioned the issue.

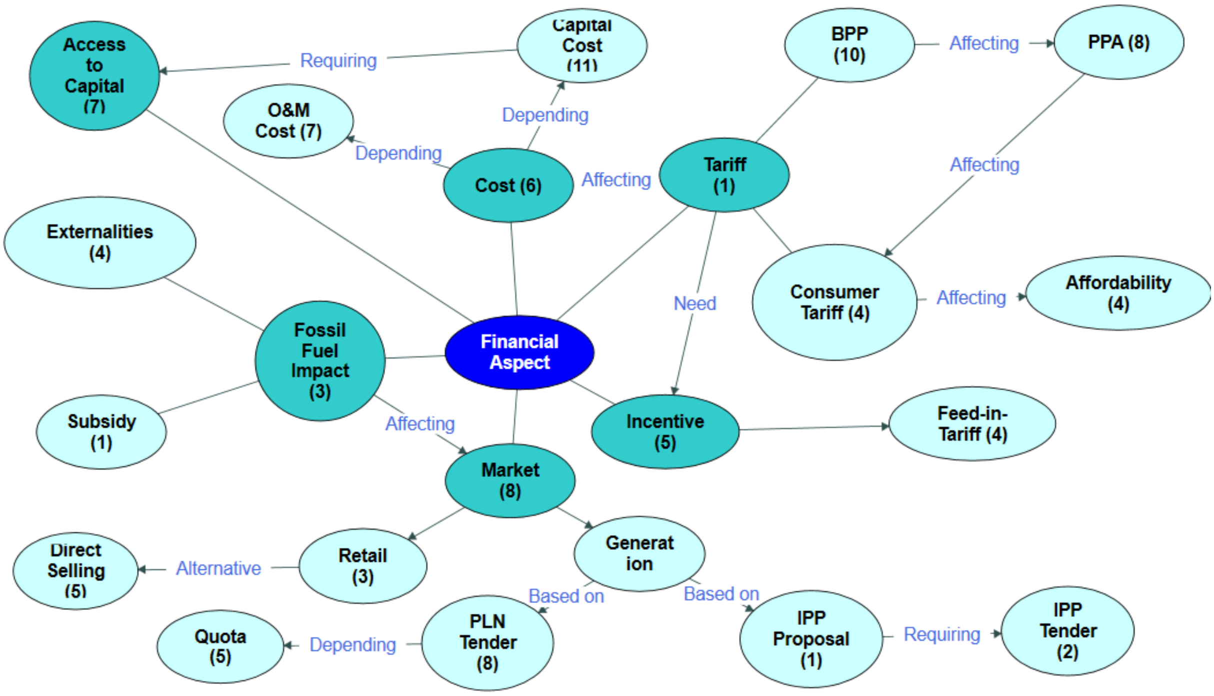


Figure 33 Parameter relationships under the financial aspect category.

Regarding the cost, all interviewees concerned about capital cost. They also mentioned that access to capital is required. Although based on the techno-economic evaluation the variation in initial cost and O&M cost seems not changing the payback period much, the participants concerned that this cost might impact the tariff. The electricity tariff sold from the developer to PLN is decided during the PPA process. The ceiling price for this PPA tariff is regulated by BPP where this BPP becomes a concern for the majority of stakeholders. On the other hand, there is also a conflict with consumer tariffs. The higher the rate under PPA, the higher the consumer tariff. Consequently, it impacts affordability. Although the presence of incentives might help reduce the tariff, feed-in-tariff is not a solution.

The presence of the solar PV microgrid market is also endorsed by most participants. Regarding power generation, the PLN tender has been mentioned as a preferred mechanism compared to the direct proposal from IPP. Yet, PLN tender still has limited quota capacity. Thus, an increase in quota is required. Regarding the distribution or retail side, most participants were aware that PLN is still dominating the market. Direct selling from IPP to the consumer has been mentioned as an alternative although the process can be more complicated. The participants also raised the issue that the current electricity market is still dominated by fossil fuel. As a result, this situation hampered the development of solar PV microgrid. Externalities are mentioned to be included in the cost calculation to make solar PV microgrid more competitive and attractive.

//... If these externalities are included, BPP prices will be higher and solar PV will be more competitive...//

Figure 34 also illustrates the social and regulatory issues related to the implementation of solar PV microgrid in Indonesia. Similar to the previous ones, this diagram was created from the transcript of the review using NVivo Software. Similar to the financial one, there are six key factors raised by the participants, namely, policy, bureaucracy, human resources, education and training, stakeholders, and policy interaction. Each parameter has its sub-children shown in Figure 34. The number represents the number of interviewees mentioned the issue

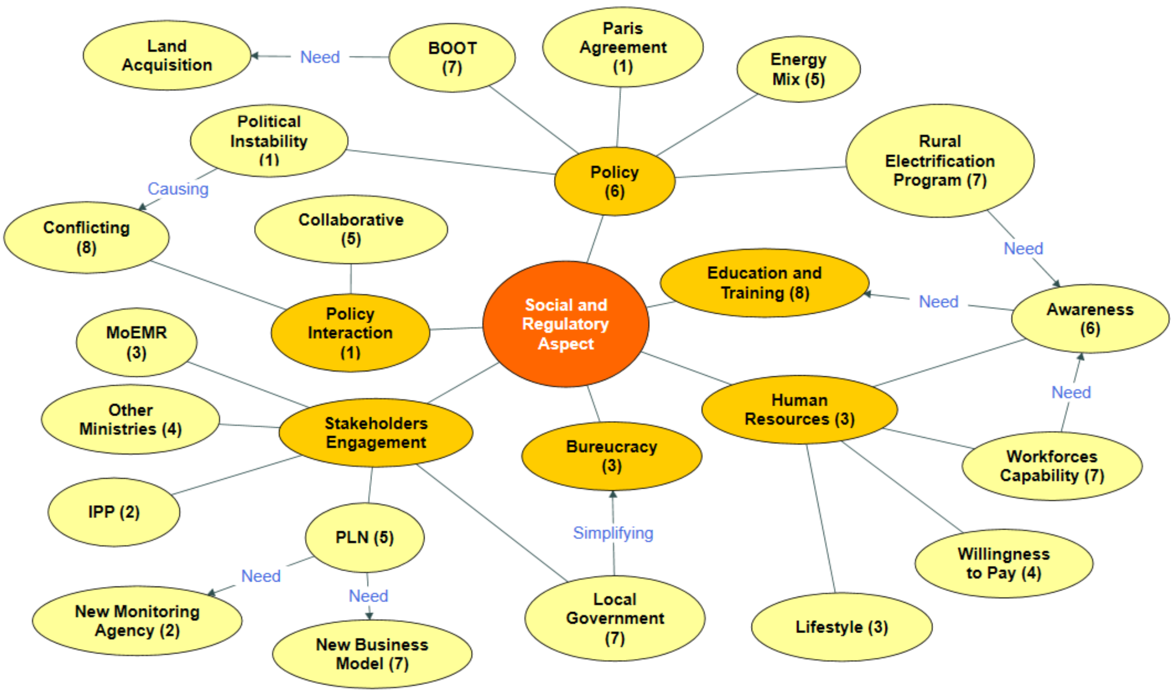


Figure 34 Parameter relationships under the social and regulatory aspects category.

Concerning policy, some participants mentioned about BOOT and Rural Electrification program. The transfer process in a BOOT scheme increases awareness about land acquisition. Based on the techno-economic evaluation, land purchasing can increase profit, but land leasing can reduce the payback period. Thus, the decision to purchase or to rent is based on the aims of the developers. Regarding the rural electrification, some interviewees concern that awareness is needed for a successful implementation. Yet, awareness can be developed by implementing education and training. Additionally, lifestyle, willingness-to-pay, and workforce capabilities are also some concerns related to human resources.

An interviewee also stated about political instability.

//…many political interests make it difficult to create a competitive national electricity market. Each powerholder has its own opinion…//

This political instability causes a conflicting regulatory measure. As a result, it creates an unfavourable atmosphere for solar PV microgrid development. Thus, good stakeholder collaboration is needed. Some people were also recommending that PLN must create a new business model to make solar PV microgrid more attractive and sustainable.

//… PLN is also encouraged to open a new business model. a business model is required to attract the private sector to develop solar PV. This business model must accommodate the limited territory and also the poor community. The development of solar PV microgrid is not only to provide electricity or lighting to the community but also to improve the local economy. If the local economy has improved, then the ability to pay will increase. Hence, the project will be more sustainable… //

In addition to a new business model, an independent new monitoring agency is also important to control and monitor the grid issues. Some people also mentioned the role of local government. The local governments have a significant role in permitting and bureaucracy.

In general, the implementation of solar PV microgrid in Indonesia is a complicated issue that has complex relationships between different parameters.

5.2 Determining Priority

Understanding the relationship between parameters can help in making a good framework. However, the presence of some barriers can hamper a successful framework implementation. Additionally, some barriers must be urgently solved over the other aspect. Thus, it is important to determine the priority based on the results gathered in surveys and interviews.

In addition to the spider diagram presented in chapter 4, a spider diagram was also used to determine the priority based on the survey result. Figure 35 shows the priority based on the outcome from the survey questionnaire showing three different aspects, technical, financial, as well as social and regulatory ones. The larger the area of the aspect, the higher the priority. It can be seen that the technical aspect has the smallest area. The participants considered that technical aspects can be simply overcome by using technology. In contrast, the financial aspect has the largest area. This financial aspect must be considered as a top priority followed by the social and regulatory aspects. This social and regulatory aspect is a concern mostly for the developers.

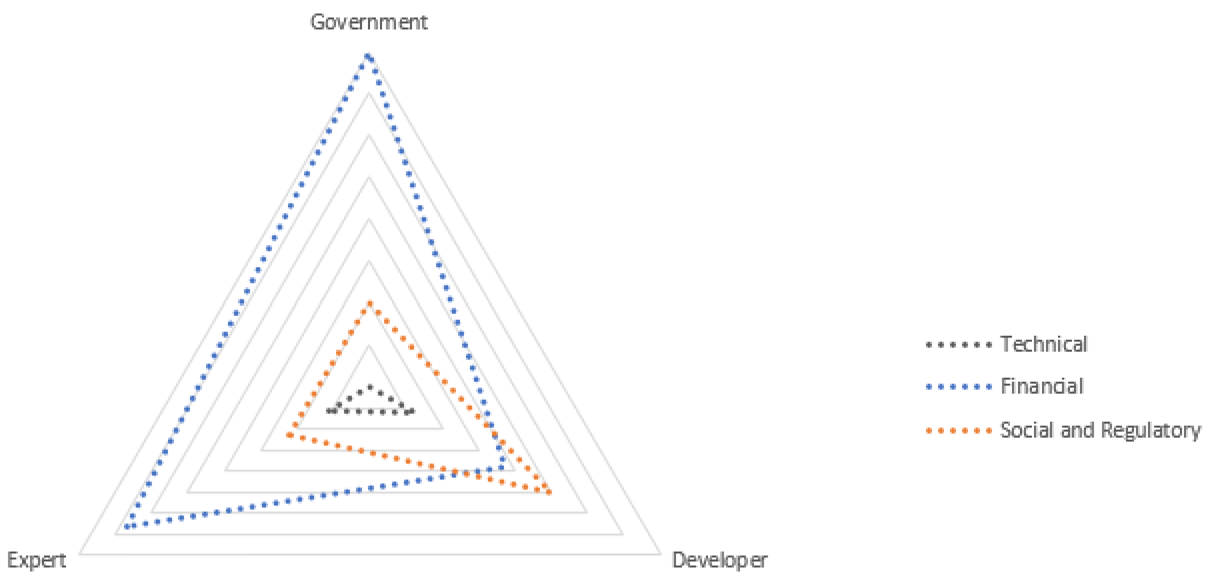


Figure 35 Priority based on survey results.

Figure 36 illustrates the hierarchy chart related to the implementation of solar PV microgrid in Indonesia. This diagram was created from the transcript of the review using NVivo Software to determine the priority. The larger the area of the aspect, the higher the priority.

Interestingly, the priority from this interview results is in accordance with that from the survey one. The financial aspect (blue area) has the largest area followed by the social and regulatory aspect (orange area). Lastly, the technical aspect (grey) has the smallest one. Figure 36 also shows the relative priorities of some key parameters within each category. Under the financial aspect, market, cost, and tariff are top three priorities followed by access to capital and incentive. Policy and stakeholders are two main priorities within the social and regulatory aspect followed by human resources and education. In the technical aspect, the grid issue becomes the top priority over the component and O&M.

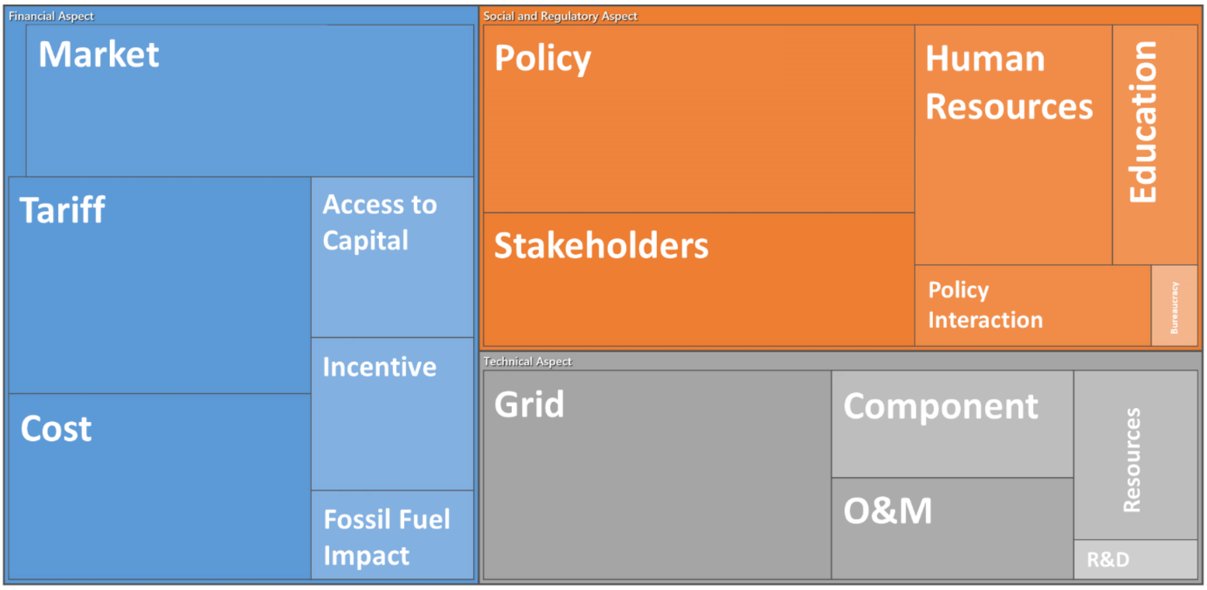


Figure 36 Priority based on interview results. Blue: Financial Aspect, Orange: Social and Regulatory Aspects, and Grey: Technical aspect.

This outcome then can be used to prioritize some actions to overcome the issues in the development of solar PV microgrid implementation in Indonesia. Figure 37 illustrates the issues, proposed solutions, as well as stakeholder roles in order from the lowest priority to the highest priority. This diagram is formed based on the results and discussion stated in chapter 4 and chapter 5. It seems that the lower the priority, the simpler the solution although it is not always the case. It will be discussed here the eight (8) key factors that must be overcome to increase the solar PV microgrid implementation in Indonesia from the lower priority to the higher one.

INCREASING PRIORITY

Category	Issue	Proposed Solution	Stakeholders Role
Technical	Component (Local content and O&M)	• Continuing research and development • Revisiting the TKDN regulation with a strong cooperation • Increasing the number of renewable energy courses and training	Expert Government Government, Expert
	Unstable grid connection because of intermittency	• Providing battery or backup generation • Providing grid code • Providing monitoring agency	Developers Government, Expert Government
Social and Regulatory	Insufficient knowledge and capacity (maintenance and awareness)	• Increasing the number of renewable energy courses and training • Collaborating with private institution to provide CSR funding	Government, Expert Developer
	Conflicting policies and regulatory measures, such as BOOT	• Strengthen intergovernmental relation • Revisiting transfer process on BOOT scheme • Providing support for land acquisition through leasing • New business model for PLN	Government Government, Developer, Expert Government, Developer Government, Developer
Financial	Unclear tender process	• Simplifying the process • Increase the quota of solar PV	Government, Developer Government, Developer
	Lack of access to capital	• Collaborating with private institution to provide CSR funding • Partnership between public and private institution • Bridging the financial gap	Developer, Expert Government, Developer Government
	Cost and tariff	• Revisiting the BPP regulation • Continuing research and development to reduce the cost • Improving PPA regulation • New business model for PLN • Reallocating subsidies and incentives • Incorporating the externalities	Government Expert Government Government, Developer Government Government
	Lack of Solar PV Market	• Increasing demand through awareness • Strengthening the supply by increasing quota • New business model for PLN	Government, Expert Developer Government, Developer

Figure 37 Priority for overcoming the barriers in the implementation of solar PV microgrid in Indonesia.

5.2.1 Component (Local Content and O&M)

According to the relationship analysis, local content and O&M are related to each other. The number of maintenances can be reduced if the electrical components meet the standard. Yet, the local content regulation becomes a dilemma in Indonesia (Burke et al. 2019). According to the participants, the government must revisit the local content or TKDN regulation. This regulation must be adapted to the current stage of technological development in Indonesia. Because at this moment Indonesia is only capable to do the assembling only, hence the proportion of local content requirement must be reduced. Indonesia can have a higher proportion of local content if the country is capable to produce the electrical component by itself. Continuous R&D must be performed to produce high-quality and high-performance electrical components. However, this solution must be supported by the presence of research and educational institutions. Both governments and experts must collaborate to execute this solution.

5.2.2 Grid Connection (Stability and Network)

The intermittency behaviour of solar radiation is causing a problem for grid stability. This issue is extremely important for the government as mentioned in Chapter 4. Although the developers can provide energy storage or backup generator, this solution is not enough. The execution of grid code can help to regulate the grid stability issue. This grid code is expected to be implemented for the off-grid systems as well so that when the network is connected to the area, the system can be connected to the grid easily. Additionally, the presence of a monitoring body to control and manage grid stability and network issue is important. This importance also mentioned by Burke et al. (2019). They stated that grid management is required to achieve a large scale transition to solar energy.

5.2.3 Knowledge and Capacity

Capacity building is an important aspect to help the local community aware and capable to maintain a solar PV microgrid system. This issue has been seen as extremely important for the research participant as discussed in Chapter 4. However, it is not only the role of governments and experts to offer some renewable energy courses and/or training. The developers also can encourage the other institutions to participate in delivering the training through a corporate social responsibility (CSR) program.

5.2.4 Policy and Regulatory Measures

It has been acknowledged that some key solar PV policies are conflicting with other regulations based on the participants' perspective. They argue that strong intergovernmental cooperation is required to overcome this problem. The transfer obligation under a BOOT scheme also becomes a disincentive for the development of solar PV microgrid in Indonesia (Burke et al. 2019). Hence, the government must revisit this transfer regulation. Furthermore, the government must assist the developer in acquiring the land. The developer itself, particularly PLN, must develop an innovative business model to incorporate solar PV.

5.2.5 Tender Process and Capacity Quota

The tender process has been seen as a problem from the developers' point of view particularly about location and capacity quota. The government must increase the capacity quota of solar PV to increase its penetration. Additionally, an interviewee stated that the government must prioritize the quota for solar PV than that for fossil fuel generation. Furthermore, Burke et al. (2019) suggest the implementation of renewable purchase obligations in Indonesia so that solar PV microgrid can produce the green certificate to meet the renewable energy targets.

5.2.6 Capital Access

Capital access might not be an issue for a multinational developer but can be an issue for small entities as discussed in Chapter 4. Thus, it is important to provide alternative funding in addition to bridging the gap between the developers and financial institutions. The government must be able to engage private institutions to provide funding for small companies through a CSR program. The public-private partnership is also one solution that can be endorsed to help provide funding for small companies. According, to a participant

//…Many oil and gas companies also want to become renewable energy investors in Indonesia. These companies can provide cheaper funding…//

However, to achieve this the government must create an attractive investment environment. Transparency over the tender requirement is also required (Burke et al. 2019).

5.2.7 Cost and Tariff

Cost and tariff issues are considered to be almost at the top priority based on the interview. Based on the relationship analysis, those two parameters interact with each other. It is important to find the optimum tariff rate for the developers which can accommodate the developer's incurred cost but also can be affordable for the community. Firstly, it is recommended by participants that the government must revisit the BPP regulation. The externalities must also be considered in calculating the ceiling price under BPP to make solar PV more competitive to fossil fuel generation. Secondly, to reduce the capital and O&M cost, the R&D must be continued so that the price of the local components can be more competitive compared to the imported ones. The participants also mentioned that the government must reallocate the subsidies and incentives for renewable energy government although it seems difficult particularly for the government due to the lack of budget. Yet, the government can introduce more transparency over the terms of a PPA contract (Burke et al. 2019).

5.2.8 Market Presence

The top priority for the implementation of solar PV microgrid in Indonesia is the presence of the market. According to a respondent,

//…All problems that arise in solar PV industries are caused by supply and demand mechanisms…//

Therefore, it is important to solve this demand and supply problems. It is suggested that education must be offered to increase the awareness of Indonesian people for utilizing clean energy. The community can have the power to dictate the government to prioritize the utilization of renewable energy if they have the knowledge. The increasing demand may drive an increase in supply. However, it must be supported by a strong political commitment and ambitious target such as by increasing the capacity quota. Additionally, the state enterprise, PLN, must create a new business model that can make the market more competitive. This solution needs a strong collaboration between governments, developers, and experts.

5.3 Framework to Increase Solar PV Development in Indonesia

To increase solar PV penetration in Indonesia, the successful implementation of solar PV microgrid must be executed. IEA (2003) developed a guide for improving a PV program as presented in chapter 3. Urmee, Harries, and Holtorf (2016) developed a framework for a successful implementation of the Solar Home System (SHS) for rural electrification in developing countries using this IEA roadmap. In this research, this roadmap was adapted to develop a framework for a successful implementation of PV microgrid program in Indonesia (Figure 38).

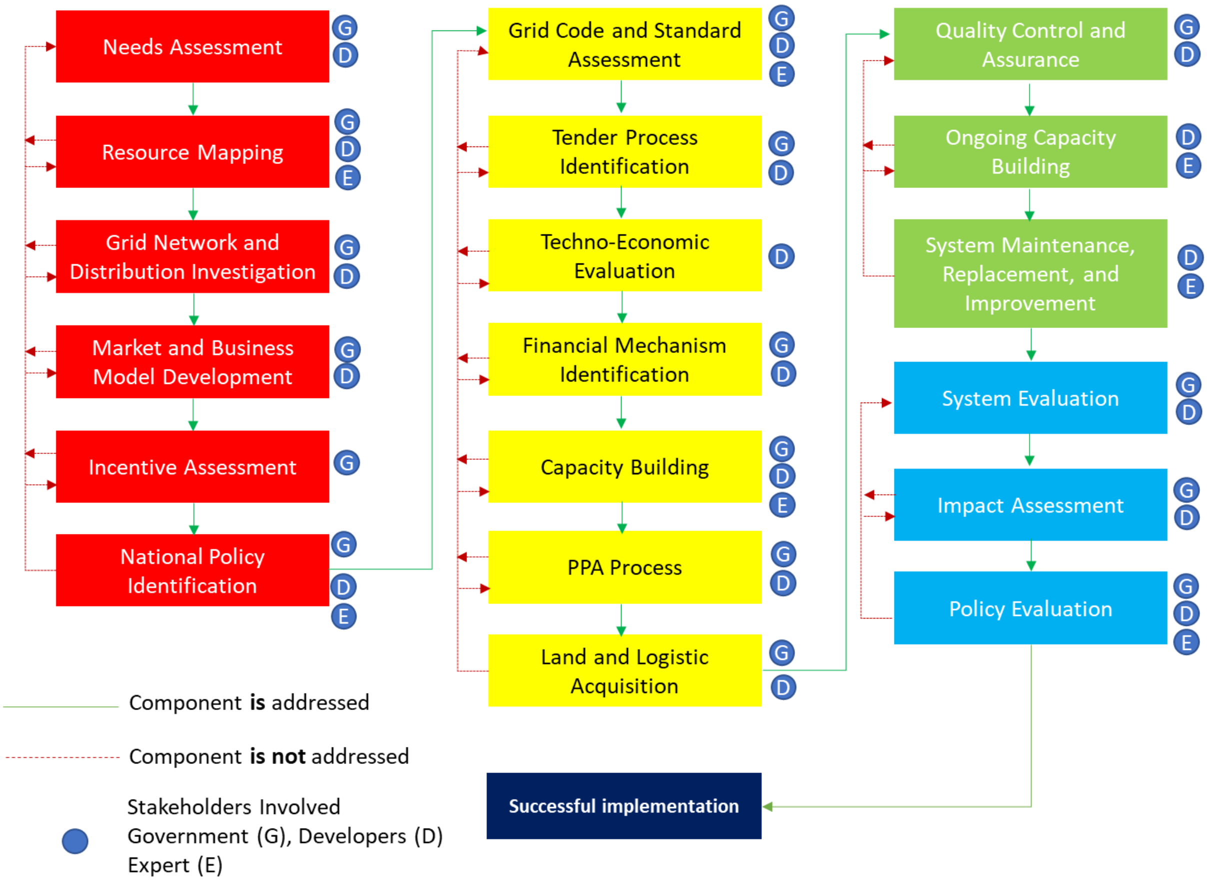


Figure 38 A framework for the successful development of PV microgrid in Indonesia.

There are four stages described in this framework, namely planning, design, implementation, and post-implementation stages. Planning and design stages are the most critical aspect of developing a solar PV microgrid project in Indonesia. The planning stage starts with demand and resource assessment, grid investigation, market and incentive assessment, as well as national policy identification. Grid code assessment, tender and PPA process, as well as land acquisition are the part of the design phase. During the implementation phase, the developer has a more significant role than the other stakeholders. Lastly, the evaluation is conducted at the end of the project. A detailed framework incorporating each key stakeholder role based on the techno-economic evaluation as well as the survey and interview outcome are presented in Figure 39.

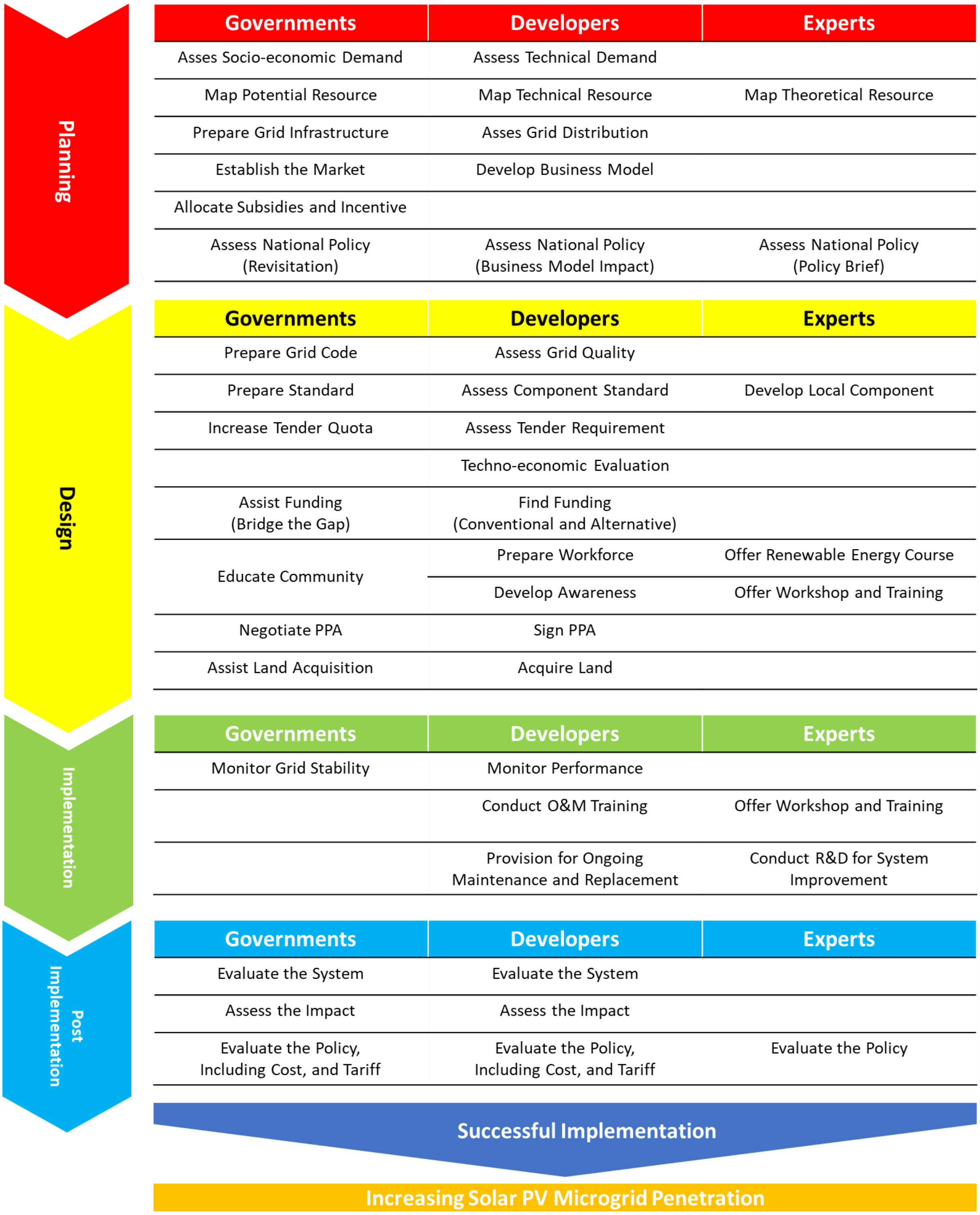


Figure 39 Framework to increase solar PV microgrid in Indonesia.

During the planning stages, the demand must be assessed. The government must assess the socio-economic demand, like the economic potential, while the developer asses the technical demand, such as the load curve. This demand assessment might help identify the potential use of solar PV microgrid in the region. To make sure that the demand can be fulfilled then a resource mapping must be conducted. The experts can help to provide a general theoretical resource while the developers can identify the technical resources incorporating more detailed information. The grid condition in the area must be investigated to ensure proper integration between the main grid with the solar PV microgrid system. The government can start to establish the market in the area while the developers prepare a suitable business model for the region. To increase the attractiveness of the market, the government can reallocate their subsidies and incentives. Furthermore, before designing the system the applicable regulation must be assessed whether the regulation can support the development of solar PV microgrid. It is also important for the developer, to assess the national policy to see how the policy impacts their business model.

In designing the system, the grid code must be executed by the government so that the developer can prepare to assess the assurance of grid quality. In addition to this, the standard must be developed and implemented for proper grid integration. Additionally, the developers must choose a suitable technology that can cope with the local weather condition. For instance, in the Kayubihi case, the performance is affected by solar radiation as well as temperature. Thus, the developers must choose a technology that can adapt to that situation. The expert can help provide the testing and development for the local component so that it can fulfil the local content or TKDN requirements. When the tender process happens, the government must increase the capacity quota based on the previous demand and resource mapping conducted in the planning stages. At the same time, the developers check the tender requirement. A techno-economic evaluation must be conducted by the developer to incorporate the policy and tender requirements. For instance, in this research, a 1-MW Kayubihi solar power plant cannot have a payback period within the project lifetime if the electricity export rate less than 8 cents/kWh. Currently, the BPP in Bali is around 6.91 cents/kWh, so that this project will be not feasible.

After the techno-economic evaluation is conducted, the developer can find the funding either through conventional loans or through alternative funding. The government must assist the developer to find the funding. It is also important for the developer to increase awareness as well as increase the capacity building of the local community. This activity must be supported by the government and expert efforts. After that, the government can negotiate the PPA and then the developer can sign the PPA if the tariff is feasible for the project. Therefore, techno-economic evaluation in the previous stage is important. Furthermore, the government must assist the developer in acquiring the land. The techno-economic evaluation can also help the developers to decide whether it is better to purchase land or to rent it.

After the project is being set up, the developers have the main responsibility to monitor their performance to provide quality control and assurance. Yet, the government also must monitor the grid. Hence, an independent monitoring agency is required. The developer assisted by the experts can continue to provide an ongoing capacity building as well as ongoing maintenance, replacement, and improvement.

At the end of the project, both government and developer must conduct system evaluation as well as impact assessment. All stakeholders also can perform policy evaluation to provide a suggestion to the policymaker to improve the system. If all the stages can be performed well, then the implementation will be successful. This successful implementation can encourage more developers to develop solar PV projects. consequently, the penetration of solar PV in Indonesia can be increased.

The framework given here is representing the situation in Indonesia. However, this framework also can be implemented in a country with a similar condition to Indonesia particularly in regard to its policy. Otherwise, this framework also can be modified to suits the local condition in a country or a region because the procedures and approaches given in this research are reproducible.

Chapter 6: Conclusion and Recommendation

The purpose of this final chapter is to review the original research question, to provide lesson learnt and recommendations for the development of solar PV microgrid particularly in Indonesia, as well as to discuss the significance and the limitations of the research. Additionally, the recommendation for future research will be given here.

6.1 Answering the Research Question

Before addressing the main research question, the sub-questions will be answered first. The first sub-question that was asked in this research was, "*How do environmental conditions affect the performance of solar PV in a tropical region?*"

According to the literature review, the performance of solar PV may vary because of several factors. Firstly, to compare the performance of solar PV systems for different locations and technologies, multiple parameters can be used including the I-V curve, filling factor, efficiency, as well as energy yield. Three factors have been used widely, namely Performance ratio, capacity factor, and the degradation ratio. Interestingly, these performances might be affected by the irradiance, temperature, shading, as well as cell technologies.

Based on the quantitative research performed at Kayubihi power plant discussed in chapter 4, there are three (3) environmental factors that significantly impact the performance ratio of the solar panel. These parameters are solar radiation, ambient temperature, and panel temperature shown by the high correlation ratio. Additionally, the presence of shading, wind speed, and rainfall might increase the performance by providing a cooling effect. However, these factors can be neglected in the Kayubihi case. Thus, multiple environmental parameters can affect the performance due to the interaction between each parameter. This situation can be more complicated in tropical regions where the weather conditions vary.

The second sub-question that was asked in this research was, "*What are the main opportunities and barriers to implement solar PV microgrids and how to overcome those constraints?*"

Based on the literature review, high solar radiation potential, the reduction of PV cost, the presence of rural electrification programs, as well as the presence of feed-in-tariff and power purchase regulation appear to be the opportunities for solar PV implementation in many countries. On the other hand, grid stability, lack of standard, insufficient technical knowledge and capacity, political instability, the presence of fuel subsidy, the lack of renewable energy market, as well as conflicting regulatory measures are the barriers to the diffusion of solar PV. Improving FiTs rate, imposing renewable energy quota, continuing research and development, and strengthening intergovernmental cooperation have been seen as some mechanisms that can help increase solar PV penetration in tropical regions. Some of these opportunities and challenges might happen generally in many countries or might happen specifically only in limited countries.

Quantitative research was conducted in Indonesia and presented in Chapter 4. Interestingly, different stakeholders have different opinions, particularly on the barriers and mechanisms. The government saw that the unstable grid connection, the lack of access to finance, as well as the conflicting regulatory measures are extremely impactful barriers. Meanwhile, both developers and experts though that insufficient technical knowledge and capacity, the lack of renewable market, the lack of access to finance, and the conflicting regulatory measures are the major barriers in addition to the unclear tender process for the developers. The governments mentioned that developing technology performance standards, continuing research and development, and bridging financing gaps and interested financial institutions are extremely important mechanisms to overcome these constrain. Yet, the developers and experts have different points of view. However, all stakeholders stated that declining investment costs and the presence of PPA are extremely important for the implementation.

The third sub-question that was asked in this research was, "*How should these technical and non-technical factors be combined to determine a framework for solar PV microgrids implementation?"*

Economic evaluation is performed to bridge the quantitative result with the qualitative outcome. In this research, economic evaluation was discussed in chapter 4. The result shows that the Kayubihi solar power plant cannot have a payback period within the project lifetime if the electricity export rate less than 8 cents/kWh. Hence, the current BPP cannot accommodate this project to be feasible. Additionally, the economic evaluation shows that the company can get a quick return when the company leases the land. In contrast, the company can get a higher profit when the company purchases the land. Hence, economic evaluation can help in decision making. Additionally, the parameter relationship as wells as the priority determination must be performed. Using the NVivo software, qualitative research can be quantified to determine the priority where the financial aspect is the top priority based on both surveys and interviews.

Lastly, the main research question underpinned in this study is "*What is the 'best practice' integrating both technical and non-technical aspects in order to increase solar PV microgrid penetration in a tropical region, particularly in Indonesia?"*

The best practice is to modify the framework developed by IEA in 2003. The result from the techno-economic evaluation as well as the outcome from the survey and interview are combined to provide a better framework. There are four stages proposed in the framework in this research. Each stage has the information on activities for each key stakeholder. This framework was discussed in Chapter 5. In general, there are four stages that must be addressed namely, planning, design, implementation, and post-implementation stages. Within the planning stages, the needs must be assessed, the resources must be mapped, the grid network and distribution must be investigated, the market and business model must be developed, the incentive and subsidy must be reallocated, and the national policy must be identified. Subsequently, it is important to assess the grid code and standard, to identify the tender process, to perform a techno-economic evaluation, to identify the financial mechanisms, to build the capacity, to execute the PPA process, as well as to acquire land and logistics during the design phase. In the implementation stage, it is necessary to do quality control, to continue capacity building, and to manage the system's maintenance, replacement, and improvement. Lastly, project evaluation, impact assessment, and policy evaluation must be conducted after the implementation. If these activities can be addressed then the project can be successfully implemented and increase the penetration of solar PV microgrid, particularly in Indonesia. This framework also can be modified to suit the local condition in another country in the tropical region.

6.2 Lesson Learnt and Recommendations

There are several lessons learnt and recommendations that can be extracted from both quantitative and qualitative research.

- The government of Indonesia is suggested to develop more stable regulation. The regulation stability may provide an encouraging environment for solar PV microgrid implementation in the country.
- The government is also recommended to revisit the current regulation, particularly on the local content and BOOT mechanism. Strong intergovernmental cooperation is necessary to create a solid regulation.
- The price cap regulation (BPP) can also be revisited because based on a techno-economic evaluation, a certain value might be not economically feasible for the developer to develop the projects.
- It is suggested to the developer that leasing land is a better option to have a quick payback period while purchasing land is better to obtain higher profit. The government may assist the developer for land acquisition.

- Solar radiation and temperature are the critical factors that affect performance. The developer can select proper modules that are capable to handle this issue.
- Additionally, the government can create the market for solar PV microgrid by increasing the awareness to create the demand as well as increasing the quota capacity to raise the supply.
- Lastly, PLN is suggested to develop a new business model based on the proposed framework

6.3 Significances and Limitations of the Results

Several outcomes and the significance of the result for this research are:

- The research was successfully incorporating both quantitative and qualitative analyses to identify the environmental factors affecting the solar PV microgrid performance, to understand the opportunities and barriers in implementing solar PV microgrid, and to develop a framework to increase solar PV microgrid in Indonesia.
- The research was also able to map different stakeholders' perspectives and roles in the implementation of solar PV microgrid in Indonesia as well as to determine the top priority or top issue that must be overcome in Indonesia.

However, because of the lack of time and resources, this research has its own limitations.

- Only one case study for technical evaluation with a limited period of data was conducted in this study. Hence, the data cannot be compared to the other solar PV microgrid in the other regions and the degradation rate cannot be calculated.
- Financial institutions and solar PV microgrid users were not included in this research.
- To get a clear picture of a whole tropical region condition, different countries must be assessed through interviews and surveys as well.

6.4 Recommendations for Future Research

Based on the findings of this research, the following recommendation may be useful for future research:

- Assess the specific business model for PLN to create an attractive solar PV microgrid market in Indonesia.
- Evaluate the appropriate financing mechanisms/scheme for the country by incorporating the stakeholders from financial institutions.
- Conduct a similar qualitative and quantitative research for solar PV rooftop systems in Indonesia.
- Conduct a more detailed study in a different tropical region with more stakeholders involved and develop a generic solar PV microgrid framework for the region.

6.5 Concluding Remarks

Solar PV microgrid is a measure to increase the utilization of clean energy in tropical regions, particularly in remote areas. Meticulous planning is necessary because both techno-economic feasibilities and policy landscapes can impact on its implementation. The performance of solar PV microgrid is affected by environmental parameters, particularly solar radiation, ambient temperature, and module temperature. Additionally, its development can be influenced by some drivers and barriers, such as the presence of regulation.

A framework to increase solar PV microgrid penetration in Indonesia was developed based on the techno-economic evaluation and policy landscape analysis through surveys and interviews. This framework can be used as the checklists for policymakers, developers, and researchers for a successful implementation of solar PV microgrid so that its penetration can be increased. This framework can be adapted to other tropical countries by exercising the techno-economic situation and policy landscape of the countries.

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Appendix I Survey Questionnaire

Developing a Framework to Increase Solar Photovoltaic Microgrid Penetration in Tropical Regions: A Case Study in Indonesia

A. Potential

Please **rate** the importance of each factor that may influence the development of solar PV microgrid in Indonesia using the following scale

(Mohon berikan penilaian berdasarkan seberapa pentingnya setiap faktor dalam mempengaruhi pengembangan solar PV di Indonesia menggunakan skala berikut ini)

1	2	3	4	5	6	7	8	9
Less Importance *(Kurang penting)*		Moderate Importance *(Agak Penting)*		Strong Importance *(Penting)*		Very Importance *(Sangat Penting)*		Extreme Importance *(Sangat Penting Sekali)*

High solar radiation *(Besarnya intensitas radiasi matahari)*	1	2	3	4	5	6	7	8	9
Declining investment cost *(Berkurangnya biaya investasi)*	1	2	3	4	5	6	7	8	9
Presence of rural electrification programs *(Keberadaan program elektrifikasi di daerah-daerah)*	1	2	3	4	5	6	7	8	9
Presence of power purchase regulation for solar power plant *(Keberadaan kebijakan pembelian energi dari pembangkit tenaga surya)*	1	2	3	4	5	6	7	8	9
Presence of feed-in-tariff regulation for solar energy *(Keberadaan kebijakan feed-in-tariff untuk energi surya)*	1	2	3	4	5	6	7	8	9
Other Potentials (please specify and give rating) *Potensi lainnya (Berikan contoh dan penilaian)*									
	1	2	3	4	5	6	7	8	9
	1	2	3	4	5	6	7	8	9

B. Barriers

Please **rate** the impact of each factor that may influence the development of solar PV microgrid in Indonesia using the following scale

(Mohon berikan penilaian berdasarkan seberapa besar dampaknya setiap faktor dalam mempengaruhi pengembangan solar PV di Indonesia menggunakan skala berikut ini)

1	2	3	4	5	6	7	8	9
Less Impactful *(Kurang berdampak)*		Moderate Impactful *(Agak berdampak)*		Strong Impactful *(berdampak)*		Very Impactful *(Sangat berdampak)*		Extreme Impactful *(Sangat berdampak sekali)*

Unstable grid connection *(Koneksi jaringan yang tidak stabil)*	1	2	3	4	5	6	7	8	9
Lack of quality control, standards, and code *(Kurangnya kontrol kualitas, standar, dan kode)*	1	2	3	4	5	6	7	8	9
Insufficient technical knowledge and capacity *(Kurang memadainya kemampuan dan keilmuan teknis)*	1	2	3	4	5	6	7	8	9
Low research and development investment *(Rendahnya investasi dalam riset dan pengembangan)*	1	2	3	4	5	6	7	8	9
The lack of access to finance *(Terbatasnya akses finansial)*	1	2	3	4	5	6	7	8	9

The inappropriate tariff incentive *(Incentive yang tidak memadai)*	1 2 3 4 5 6 7 8 9
The presence of fuel subsidy *(Keberadaan subsidi bahan bakar minyak)*	1 2 3 4 5 6 7 8 9
The lack of renewable energy market *(Kurangnya pasar untuk energi terbarukan)*	1 2 3 4 5 6 7 8 9
High cost of regulatory compliance *(Tingginya biaya untuk mematuhi peraturan)*	1 2 3 4 5 6 7 8 9
Unclear tender process *(Proses lelang yang kurang jelas)*	1 2 3 4 5 6 7 8 9
The presence of political instability *(Adanya ketidakstabilan politik)*	1 2 3 4 5 6 7 8 9
The complex bureaucracy *(Birokrasi yang kompleks)*	1 2 3 4 5 6 7 8 9
The conflicting regulatory measures *(Adanya konflik antar kebijakan)*	1 2 3 4 5 6 7 8 9
Centralization in electricity distribution *(Distribusi listrik yang terpusat)*	1 2 3 4 5 6 7 8 9
Other Barriers (please specify and give rating) *Tantangan lainnya (Berikan contoh dan penilaian)*	
	1 2 3 4 5 6 7 8 9
	1 2 3 4 5 6 7 8 9

C. Enabling Mechanism

Please **rate** the importance of each factor that may influence the development of solar PV microgrid in Indonesia using the following scale

(Mohon berikan penilaian berdasarkan seberapa pentingnya setiap faktor dalam mempengaruhi pengembangan solar PV di Indonesia menggunakan skala berikut ini)

1	2	3	4	5	6	7	8	9
Less Importance *(Kurang penting)*		Moderate Importance *(Agak Penting)*		Strong Importance *(Penting)*		Very Importance *(Sangat Penting)*		Extreme Importance *(Sangat Penting Sekali)*

Market Based

Public-Private Partnership *(Kerjasama BUMN BUMS)*	1 2 3 4 5 6 7 8 9
Joint Credit Mechanism *(Mekanisme kredit kerjasama)*	1 2 3 4 5 6 7 8 9
Improvement in Feed-in-Tariff *(Peningkatan feed in tariff)*	1 2 3 4 5 6 7 8 9
Renewable Energy Quota *(Kuota energi terbarukan)*	1 2 3 4 5 6 7 8 9
Other Market Based Mechanism (please specify and give rating) *Mekanisme pasar lainnya (Berikan contoh dan penilaian)*	
	1 2 3 4 5 6 7 8 9
	1 2 3 4 5 6 7 8 9

Non-Market Based

Developing technology performance standard *(pengembangan standar performa teknologi)*	1 2 3 4 5 6 7 8 9
Enhancing technical capacity and knowledge (training) *(Pengembangan dan pelatihan keilmuan dan kapabilitas teknik)*	1 2 3 4 5 6 7 8 9

Continuing Research and Development *(Riset dan pengembangan berkelanjutan)*	1	2	3	4	5	6	7	8	9
Bridging financing gap and institution *(Memberikan kemudahan akses financial)*	1	2	3	4	5	6	7	8	9
Disincentivising fossil fuel subsidy *(Pengurangan subsidi bahan bakar fosil)*	1	2	3	4	5	6	7	8	9
Imposing Fossil Fuel Tax *(Menerapkan pajak bahan bakar fosil)*	1	2	3	4	5	6	7	8	9
Strengthening intergovernmental cooperation *(Penguatan kerjasama antar organisasi pemerintah)*	1	2	3	4	5	6	7	8	9
Enhancing the capacity of local government *(Pengembangan kapasitas pemerintah daerah)*	1	2	3	4	5	6	7	8	9
Other Non-Market Based Mechanism (please specify and give rating) *Mekanisme non pasar lainnya (Berikan contoh dan penilaian)*									
	1	2	3	4	5	6	7	8	9
	1	2	3	4	5	6	7	8	9

D. Summary

Please **rank** in order the following aspect based on its significants that may influence the development of solar PV microgrid in Indonesia. There are 10 factors in the following table, rank 1 for the most significant thing and rank 10 for the least significant one.

(Mohon berikan peringkat sesuai urutan pada aspek-aspek berikut ini berdasarkan seberapa pentingnya setiap faktor dalam mempengaruhi pengembangan solar PV di Indonesia. Terdapat 10 faktor pada table berikut. Beri peringkat 1 untuk yang paling signifikan dan peringkat 10 terhadap yang paling kurang signifikan

Investment Cost *(Biaya Investasi)*	
Commercial Maturity on Technology (R&D) *(Komersialitas dari teknologi termasuk riset)*	
Affordable Price for Consumer *(Harga yang terjangkau bagi pelanggan)*	
Reliability of the Power *(Reliabilitas dari tenaga listrik)*	
Greenhouse Gas Mitigation Potential *(Potensi dalam mengurangi gas rumah kaca)*	
Employment Potential *(Potensi untuk menambah jumlah pekerjaan)*	
Presence of Regulation *(Keberadaan regulasi yang mendukung energi terbarukan)*	
Presence of Government Incentive *(Keberadaan insentif dari pemerintah)*	
Access to Capital *(Akses terhadap modal)*	
Bureaucracy and Permitting *(Birokrasi dan perizinan)*	

Please give comment on your answer (beri komentar terhadap jawaban anda)

E. Insight

Please give your insight about the current opportunities and challenges in implementing solar PV microgrid in Indonesia based on your experience? Do you have any feedback or suggestion to improve its penetration?

(Mohon berikan pandangan anda mengenai peluang dan tantangan pengembangan solar PV microgrid di Indonesia berdasarkan pengalaman anda. Apakah anda mempunyai tanggapan dan saran untuk meningkatkan penetrasinya?)

Appendices II Interview Question

Developing a Framework to Increase Solar Photovoltaic Microgrid Penetration in Tropical Regions: A Case Study in Indonesia

Semi-structured Question

This research uses semi-structured interviews. There are four categories that will be explored during the interviews including

- Technical potential and constraint
- Financial potential and constraint
- Regulatory potential and constraint
- Enabling mechanisms

There are 6 key stakeholders that will be examined in this research:

- The IPP's operators
- The IPP's and/or PLN senior level employees
- The academics in university
- The experts in a renewable energy research institution
- The local governments
- The staffs in the Ministry of Energy and Mineral Resource

Each stakeholder will receive different question category.

The following questions are some questions that would be used as the guidance.

Technical Potential and Constraint

Target:

- The IPP's operators
- The IPP's and/or PLN senior level employees
- The academics in university

1. *The utilisation of solar energy has been facing some difficulties, such as its reliance on weather as well as grid stability issue.* Can you describe any difficulties that affect the performance of the system to the grid?
   (Penggunaan energi surya menghadapi beberapa kendala, seperti ketergantungan terhadap cuaca dan juga masalah stabilitas koneksi. Bisa tolong dijelaskan, apa saja kendala yang mempengaruhi performa dari system ke koneksi?)

2. *Currently, Indonesia has a regulation that regulate the electrical components, such as inverter, in a solar photovoltaic grid.* What is your opinion on this technical standard regulated by government? Have you found any difficulties in the implementation of this regulation? Any suggestion?
   (Saat ini, Indonesia mempunyai regulasi untuk mengatur komponen elektronik seperti inverter pada pembangkit listrik tenaga surya? Apakah opini anda mengenai standar keteknisan yang diterapkan oleh pemerintah? Apakah and menenmukan kesulitan dalam mengimplementasikan aturan ini? Ada saran?)

3. *The utilisation of solar PV microgrid also need some institutional capacity as well as technical capability*. Can you describe any presence of training or workshop to maintain the knowledge? What is your opinion on the presence of this training? Any suggestion?
   (Penggunaan energi surya membutuhkan pengetahuan dan keterampilan. Apakah anda dapat menjelaskan keberadaan pelatihan untuk mengembangkan pengetahuan? Apa pendapat anda mengenai pelatihan ini? Ada saran?)

4. *Solar PV is a technology that is still being researched progressively in order to increase its performance as well as to reduce its cost.* What is your opinion on current research and development of solar PV in Indonesia?
   (Solar panel merupakan teknologi yang sedang dikembangkan secara progresif melalui riset dalam rangka meningkatkan kualitas performanya dan juga mengurangi harganya. Apa pendapat anda terhadap kondisit riset solar PV di Indonesia?)

Financial Potential and Constraint

Target:

- The IPP's operators
- The IPP's and/or PLN senior level employees
- The academics in university

1. *The utilisation of solar energy as power plant has shaping the technology cost becomes more affordable.* What is your opinion on the current cost on solar PV microgrid? Can you describe any difficulties in finding the capital?
   (Penggunaan energi surya sebagai pembangkit listrik telah membuat biaya dari teknologi ini lebih terjangkau. Bagaimana pendapat anda mengenai kondisi biaya solar PV saat ini? Dapatkah anda menjelaskan kesulitan dalam memperoleh modal?)

2. *The government of Indonesia has been creating some regulation to attracts the investment in Indonesia such as power purchase agreement and feed-in-tariff.* What do you feel about the implementation of this power purchase agreement and FIT? Any suggestion?
   (Pemerintah Indonesia telah membuat peraturan untuk menarik investasi solar panel di Indonesia seperti perjanjian pembelian daya dan juga feed-in-tariff. Bagaimana pendapat saudara dalam penerapan aturan-aturan ini? Ada saran?)

3. *Solar PV microgrid needs market to sell its product.* What do you think about current renewable energy market condition in Indonesia? Can you describe how the tender being executed?
   (Solar panel membutuhkan pasar untuk menjual produknya. Bagaimana pendapat saudara mengenai kondisi pasar energi terbarukan di Indonesia? Dapatkan anda menjelaskan bagaimana proses tender berlangsung?)

4. *There are different arguments on the presence of current fossil fuel subsidy.* What do you think about the presence of this subsidy on renewable energy investment? Any suggestion?
   (Terdapat beragam pendapat mengenai keberadaan subsidi bahan bakar minyak saat ini. Bagaimana pendapat anda mengenai keberadaan subsidi BBM terhadap investasi energi terbarukan? Ada saran?)

Regulation Potential and Constraint

Target:

- The experts in a renewable energy research institution
- The local governments
- The staffs in the Ministry of Energy and Mineral Resource

1. *The government of Indonesia create some programs such as rural electrification program to increase renewable energy penetration, like solar PV.* What is your opinion on the presence of this program as well as its implementation? Any suggestion?
   (Pemerintah Indonesia telah membuat program seperti program elektrifikasi daerah untuk meningkatkan proporsi energy terbarukan. Apa pandangan anda mengenai keberadan program ini dan juga implementasinya. Ada masukan?)

2. *The implementation of some regulations might face some difficulties in regard to its bureaucracy as well as its compliance.* Can you describe the process in developing solar PV microgrid in Indonesia from the national level to the local level? Any suggestion to simplify the process?
(Penerapan beberapa kebijakan dapat menghadapi kendala terutama terkait masalah birokrasi dan juga kepatuhannya. Dapatkah anda menjelaskan proses dalam mengembangkan solar PV di Indonesia dari skala nasional ke skala lokal? Ada saran untuk menyederhanakan proses?)

3. *Decentralization has been seen as an alternative to increase the competitiveness of electricity market.* What is your opinion on decentralization for increase the solar PV penetration? Any suggestion?
(Desentralisasi telah dilihat sebagai alternative untuk meningkatkan kompetisi pasar dalam industri listrik. Bagaimana pendapat anda mengenai desentralisasi untuk meningkatkan proporsi solar PV? Ada saran?)

4. *The interaction between one regulation to the other regulation can be either a supportive one or a conflicting one.* What kind of difficulties in implementing renewable energy regulation, particularly solar PV in Indonesia?
(Interaksi antar satu regulasi dengan regulasi yang lainnya dapat saling mendukung atau justru bertentangan. Apakah kendala dalam menerapkan kebijakan energi terbarukan, terutama solar PV di Indonesia?)

Enabling Mechanism

Target:

- The experts in a renewable energy research institution
- The local governments
- The staffs in the Ministry of Energy and Mineral Resource

1. *Market based mechanisms, such as feed-in-tariff and renewable energy quota, have been considered as the solution to increase solar PV penetration.* How effective is the implementation of this regulation? What is your opinion on the presence fossil fuel subsidy and/or tax in current market? Any suggestion?
(Mekanisme pasar seperti feed-in-tariff dan kuota energi terbarukan telah dipandang sebagai solusi untuk meningkatkan proporsi solar PV. Seberapa efektifkah implementasi dari kebijakan ini? Bagaimana pendapat saudara mengenai keberadaan subsidi hana bakar atau pajak dalam kondisi pasar sekarang? Ada saran?)

2. *Institutional capacity has been considered as the solution to increase solar PV penetration.* How effective is the presence of training and awareness on the increase in solar PV microgrid penetration? How does it affect research and development as well?
(Kapasitas institusional telah dipertimbangkan sebagai salah satu solusi untuk meningkatkan proporsi solar PV. Sebereapa efektifkah keberadaan pelatihan dalam meningkatkan persentase solar PV? Seberapa besarkah dampak riset dalam hal ini?)

3. *Regulation and its implementation are the responsibility of all stakeholders from top to bottom level.* How effective is the collaboration between local and national government in increasing solar PV in Indonesia?
(Kebijakan dan implementasinya merupakan tanggung jawab semua pihak dari tingkat atas hingga bawah. Seberapa efektifkah kolaborasi antara pemerintah daerah dan pusat dalam meningkatkan solar PV di Indonesia?)

4. *In developing a mechanism, both technical and non-technical aspects must be considered. Sometimes, it is difficult to implement all regulation at the same time.* In your opinion, what is the solution that must be prioritized to increase renewable energy penetration in Indonesia? Is that the best solution? why? Any advantages or disadvantages from this solution?
(Dalam mengembangkan sebuah mekanisme, baik aspek teknis maupun non-teknis harus dipertimbangkan. Terkadang, terdapat kesulitan untuk mengimplementasikan beberapa kebijakan dalam waktu bersamaan. Menurut anda, apakah solusi yang harus diprioritaskan untuk meningkatkan penetrasi energi terbarukan di Indonesia? Apakah solusi tersebut merupakan yang terbaik? Kenapa? Apakah ada kelebihan maupun kekurangan dari solusi ini?)

Appendices III Comments from Interviewee

Weather Pattern and Solar Potential

//…Regarding resources, Indonesia has good potential in general. However, several considerations must be taken to choose the best location…//

//… It seems that this solar radiation is not evenly distributed throughout Indonesia. Some areas in Eastern Indonesia has significant solar radiation potential. Despite its abundance potentials, if there are no supportive regulations or incentives, then the execution will be difficult...//

//… Indonesia has great potential. Based on the study by Balitbang and some donor agencies, it shows that the average radiation in Indonesia is around 4-5 kWh / day. Hence, there is no problem with the potential side. ESDM creates a roadmap to overlook these investment opportunities. This roadmap also considers the local economic opportunities that can be developed from the presence of solar PV…//

Grid Connection

//... If the grid conditions are good, there are no significant issues. In contrast, in an area with weak grid condition, a technical calculation must be performed so that the grid connection is still stable without any intermittent effects…//

//… So far there are no technical problems on the grid because most solar PV capacity is still small. Most government project is off-grid projects, or hybrid projects connected to a diesel power plant so that there is no grid connection issue…//

//… At present, only half of the installed capacity can be delivered to the PLN grid. It happens because this solar PV microgrid does not use batteries. So, the off-taker receives less electricity in order to avoid risk in providing too much buffer when shading occurs. Therefore, a smart grid management system is needed…//

//… Sometimes, solar PV systems were also damaged because there were many systems in the past that technically did not meet the standards. Many solar PVs built by the government are currently off-grid. When PLN enters the area, hopefully, PLN can adopt the system. However, it might depend on whether the system meets the PLN's standards or not. However, most current systems should have at least followed SNI because it is a pre-requisite in the tender document. Yet, sometimes, this pre-requisite is not mandatory because there is only one testing institution in Indonesia…//

//… In developing solar PV, on-grid PV will have more consideration to be deployed commercially. The network capabilities will be seen for this PV interconnection. Solar PV might cause an unstable network connection so that it will be a barrier for the grid. Hence, the investor must know whether the grid is ready or not. The stable grid connection is an absolute requirement for solar PV investment itself…//

Electrical Component

//… Yes, because the panel is more expensive so that the installation cost becomes higher. In general, the local panel is not bankable yet…//

//… When talking about specifications, the project owner will provide the specifications. For example, the project funded by the State Budget is owned by MoEMR. There is some equipment that is technically performing better but does not meet the prerequisites. Hence, further review for this specification is required.…//

//… At present, LEN is the only solar PV manufacturer in Indonesia. However, LEN itself only assembles solar cells imported from other countries. Additionally, because the scale is still small, the local-assembled solar panels are much more expensive than the imported ones…//

//… The standard is relatively similar between village-to-village because the standard refers to the technical specifications provided by the Ministry of Energy and Mineral Resources. The difference might be the capacity of the system as well as its AC/DC output depending on the demand at the location…//

//… Even, the component that can be fulfilled domestically is only the solar panel. However, the inverter is still imported because the country has an incapability to make one…//

//… the solar modules can be assembled locally. Yet, other components such as inverter are imported. In terms of price, imported modules from China are much cheaper. Indonesian module is more expensive because the solar PV market in Indonesia is limited. Regarding the standards, solar PV adopted IEC standards. Under the tender requirements, the products must comply with SNI standards or IEC standards, especially in regard to safety. Capacity building is also needed to improve the quality and specifications…//

//… Local modules are currently expensive because Indonesia is only capable of assembly. Furthermore, its market is not on an economic scale. To enter the economic scale, solar PV capacity must be around 200 MW_p. However, it is constrained by its off-taker, either financially or technically…//

Grid Intermittency and Grid Code

//… The battery is one solution to overcome the intermittent issue. The cost will be paid by the developers and will be calculated as part of the tariff…//

//… Intermittent issues can be solved by utilizing a battery. However, the project will be less economical if battery components are included…//

//… For the case in Indonesia, this intermittent condition changes rapidly causing the output variation in a period of minutes. Consequently, the system requires a battery. Fortunately, a grid impact study has been carried out during feasibility so that the impact should have been identified from the beginning. Usually, PLN provides the buffer, especially for the case of the national grid. Because the impacted system is quite large, then PLN will regulate its power flow. In addition to the utilization of batteries, sometimes diesel power plant is deployed for balancing the system…//

//… Solar PV is intermittent or varies in nature. It becomes a big issue for the system, especially if the penetration is large. If intermittent generation enters the system, then the system uncertainty becomes high. Consequently, it will be more challenging to balance the load and supply. Actually, it can be overcome but it requires high costs. However, currently, there is no incentive for system operators to overcome this intermittent problem…//

//… Although solar PV is intermittent, it can be overcome by using batteries. The better the battery, the more intermittent problem can be handled better…//

//… Regarding solar PV, PLN must pay for the high intermittent fee. PLN will look at demand, supply, grid condition, as well as intermittent cost before approving a solar PV project. The only buffer utilized by PLN to overcome this intermittence is diesel PP, which costs more than 15 cents / kWh. Therefore, PLN is a bit reluctant to approve a solar PV project. It can be worsened If this solar PV is built in a region where the demand is low. It will cause a great loss for PLN to provide buffer…//

//… Currently, solar PV is still regulated by a limited quota mechanism. PLN determines the location by considering its grid condition. The larger the capacity, the cheaper the cost. The barriers are the grid condition and the supply-demand balance. The usage of battery is currently being reviewed to help to reduce the intermittence impact. It will be a prerequisite for IPP from PLN. The batteries can be used to prepare another generator during intermittent conditions. The grid code itself will be issued by ESDM but has been agreed by some stakeholders, including regulators, PLN, and business representatives. It is likely that grid code will be published in 2019…//

//… Regarding grid code, the latest regulation in the Java-Bali system is MoEMR 3/2007 which is currently being revised. Although intermittency can be overcome by storage, there is a question who will pay for it whether the utility or developer. If the developer installs a battery, the investment cost will increase. When investment costs rise, the project will become less feasible under current regulation, MoEMR 50/2017. Consequently, the developer can lose in the bidding because the price is too high. It is also an obstacle for PLN, even though PLN is quite ready to face renewable energy penetration. Nevertheless, support is needed to strengthen the system due to the penetration of this renewable energy…//

//… A grid code is currently being developed for renewable energy. RE has not been prepared for on-grid because, in the past, RE is mainly used off-grid to help people in remote areas. Because there is a new policy to connect the renewables to the network, including rooftop PV, then grid code is required. Thus, intermittent generators such as solar PV can enter. Unstable grid is a barrier…//

//… Grid code is also important, yet its influence on microgrids is relatively small because the systems only used for lightings and small equipment. However, when PLN is expanding its network, the network must be prepared to connect to this solar system. Demand mapping is also quite important…//

Maintenance Issue

//… In general, local residents are still not familiar with the technology, as a result, ongoing training and workshops are needed. The aim is that local people can be more independent not only in terms of O&M but also in terms of financial management. Additionally, training is carried out before the project began and IPP provides mentoring and monitoring for the first few years…//

//… Many projects under ESDM are designed by EPC. The EPC must deliver the project, must obtain a certificate of operation (SLO), and must maintain the project in a certain period. Within the contract, the budget is only for development while O&M cost is not included. The projects financed by the State Budget must be completed in the same financial year. So, if the project has not completed, the IPP must provide a bank guarantee to the government as a guarantee that the IPP will complete the project. Because the project must be completed in the same financial year, the recurring O&M costs cannot be covered…//

//… Technically, there are several obstacles including the ability of the community to maintain the solar PV itself. Therefore, it is important to improve the capacity of local residents in regard to solar PV components, including their functions and maintenance. Furthermore, even though the training has been given during the initial phase, this training must be held several times…//

//… If the local government has provided institutions to manage the solar PV project, then it will be sustainable. Unsustainability can be caused by the length of the handover, especially for assets valued at 10 billion. The delivery of these assets must be based on presidential approval which takes a long time. However, at the same time, the local government cannot allocate the maintenance budget because they have not been handed over…//

//… Regulation is also quite influential. For example, ESDM builds an off-grid solar PV that will be handed over to the local government. This hand-over takes a long time. In the state budget, only the construction is allocated under the supply budget while maintenance costs have no budget allocation. Local governments also cannot budget for the maintenance before the handover process. Consequently, the system is damaged because for a long time no one cared for the maintenance. Currently, there are about 85 projects that are in the process of being handed over. This thing is hampered because of the handover and the maintenance budgeting regulation…//

Workforce Issue

//… In general, IPP is trying to get as many workers from the local area as possible, especially during construction, licensing, and operation phase…//

//… After EPC built solar PV, training was conducted for local residents. Unfortunately, each location is unique. There are some areas that have highly motivated and skilled citizens, but there are some areas that do not have them. It makes the sustainability of the system vulnerable. A few years ago, many projects still used lead-acid batteries. Many communities did have the financial capability to cover the replacement cost.

As a result, many projects are stalled in just a few years, even though the original lifespan is expected to be 20 years…//

//… However, when the solar panel system is implemented, the community is not really involved in the process, particularly in maintenance. Consequently, many solar PV projects did not sustain after being installed. This is worsened by the condition of the community that does not have awareness on this issue…//

//…This training depends on project implementers. However, only construction costs are calculated for APBN projects. Local governments do not have the authority to propose financing for either training or community empowerment. Therefore, the training must be organized by NGOs or by local educational institutions…//

//… When the central government enters an area to build a solar power plant, then the solar power plant will be handed over to the local government/community to be managed. Unfortunately, they do not yet have the capability to manage solar PV, institutionally, as well as to operate the system. As a result, many government's assets have been damaged because the systems are not being operated and maintained properly…//

//… Because PLN will receive electricity from solar PV, PLN must prepare human resources who have knowledge in the system and the interconnection of solar PV. So, if the human resources are not prepared for this situation, it will hamper the development of solar PV…//

Awareness and Willingness to Pay

//… Community awareness is very important because it will help extend the lifespan of the project. Currently, the lifetime of solar PV is quite short because of no participation from the community. Having knowledge of clean energy technology will help the community to switch to solar PV. Theoretically, awareness is very important. Yet, there is no truly effective method to make people aware of this issue even though training/workshop has been done. It is worsened by a situation where many Indonesians have not been educated. However, awareness can be done as early as possible as a subject in schools. This awareness implementation will also have impacts on energy efficiency, such as building management…//

//… In addition, solar PV technology suits best in remote areas that do not have access to the PLN network. However, the people in remote areas have limited income so they cannot afford solar PV without any support. The consumer does not need to have a high education level because maintaining solar PV is quite easy as long as some training and workshops are provided. However, from the supplier side, there are not many experts in the solar PV industry due to the lack of demand. The government also needs to train technicians in rural areas to be more reliable. In addition, because Indonesia is still a developing country, energy and environmental issues are not yet the priority of the community…//

//… It is a transition period for people who have never used electricity and then have to use it. It happens because of the improvement in well-being. However, many people assume that this new energy should be free particularly many solar PV projects are still being initiated by the government. Hence, this willingness-to-pay must be becoming an obligation. The mindset of local residents must be changed that they have also a responsibility to maintain solar PV not only the government…//

//… the ability and willingness to pay of the community must be considered. In the case of projects funded by the state budget, the government cannot provide electricity free of charge to the public. However, there are still some people who think that electricity from solar energy or electricity generated from government programs should be free. In some communal solar PV projects, many people want to pay the monthly bill as cheap as possible although economically they are able to pay more. From the investor's perspective, the investment will not happen if the buyer does not have the willingness to pay. Thus, developers prefer to sell their electricity to PLN. On the other hand, PLN also has its own assessment. PLN does not want to extend their network too far to remote areas…//

Lifestyle

//… The changes in electricity consumption also happen due to lifestyle improvement. Initially, solar PV was designed only for lighting, but then people began to buy electronic equipment. Consequently, the loads were becoming more difficult to predict. It becomes a dilemma in the planning phase as well. The capacity must not be inadequate but also must not be excessive. This situation will impact and burden the construction costs. However, the increasing demand for productive activities, such as corn milling, is not a problem…//

//… Another problem is the lack of public awareness. For example, the solar PV capacity has been allocated to fulfil a certain amount of demand. Yet, over time, the demand increases because the residents use more electronic equipment. Then. many people transmigrate to the area. Consequently, the initial capacity is no longer sufficient, and the capacity must be expanded. Yet, during area expansion, the land is often becoming the source of commotion…//

//…Initially, the government allocates 200-600 Wh/day for lighting purposes. However, electricity usage in Eastern Indonesia itself can reach 4 kWh per day because people began to buy electronic devices. This situation becomes a hidden load for the system causing over-discharge. Because the DoD is too high, the batteries break down quickly within 2 years out of a 10-year lifetime…//

Research and Education

//…R&D in the near future does not have much effect. Additionally, Indonesia does not yet have manufacturing capabilities at this moment…//

//…Regarding training, ESDM has KEBTKE training centres that offer training in Jakarta for operators from the provincial/municipal/village level. The partnership with the donors depends on the donor objective as well as the location of the project. Donors are now focusing on Eastern Indonesia…//

//…The government does not have a budget for training or workshop. Thus, there is no sustainability after a solar PV is being built. Sometimes, donor agencies aid with training, either technical training or economic empowerment. There is a lack of awareness of green energy. The community does not even care about the source of electricity as long as it has an affordable price. Their environmental awareness is still limited. Thus, education is important…//

//…Additionally, the current vocational education offers renewable energy subject to prepare human resources which are capable to handle technical problems in renewable energy generation. Training also already exists. BPSDM within ESDM provides training for both government agencies and the general public because the organisation has been a Public Service Agency. In remote areas, training is still limited…//

Electricity Supply Cost

//…The main considerations are access to the location and the presence of regulation. IPP must provide electricity lower than the BPP…//

//…Currently, the economic value of solar PV in Eastern Indonesia is around 17 cents / kWh (the ceiling price based on the calculation of 85% of the BPP value). At some places, like NTT, it can reach around 20 cents / kWh because the generation cost (BPP) from fossils is high. Unfortunately, the system in Eastern Indonesia is technically not ready to accept renewable energy penetration although the price is attractive…//

//…Financially, at present, the determination of the tariff is based on the electricity supply cost (BPP). In Java, BPP is less attractive because its value is low due to the presence of the steam power plants. Outside of Java, the BPP price is attractive but the network is not ready to get solar penetration. Battery and bidirectional inverters can be a solution, but this solution may affect the calculation of initial capital cost and tariff. BPP has an impact on small developers because the regulation makes some projects are economically not feasible. For example, Java is not an attractive place for investment although the island has a large market, around 70% of electricity demand in Indonesia…//

Access to Capital

//…At present, local banks are still less competitive because they have high-interest rates. Approaching foreign banks or development banks is a better solution for IPP because these banks provide loans for renewable energy projects with lower interest…//

//…Unfortunately, Indonesian banks are not interested yet in solar projects. Many banks are not aware of the existence of this industry and they have doubts about the sustainability of this industry. Globally, banks are the last option for financing renewable energy projects. Usually, private equity or other developers are the first options. In addition, the interest rate from national banks is quite high around double digits…//

//… the Indonesian government itself has provided funds for the installation of solar PV. Solar PV is mainly targeted at remote areas which are not reached by PLN's transmission. Thus, the possibility of investment can be obtained from government funds…//

//…At present, the main problem for IPP is the purchasing price from PLN. The multinational IPP does not have much problem in accessing capital…//

//…At present, there are no other funding sources. Hence, the community must pay for maintenance costs. Currently, there is a scheme for local governments to collaborate with the private entities. Yet, the amount of loans is limited. Additionally, not many loans are provided for the energy sector. Furthermore, guidance for solar PV investment in the rural area is needed…//

//…Nowadays, funding is difficult because financial institutions have their own standards. In addition, they see that PPA is a bit problematic. For example, the time interval after the PPA signature until the financial closing is too short. Meanwhile, financial institutions need time for analysis. In the past, many companies within DPT did not have access to finance. The partnership is mostly in the form of technical assistance or grants. Soft loans or credit are usually directed to be appointed. One obstacle related to soft loans is that funding institutions require government guarantees. Unfortunately, government guarantees cannot be issued for the private sector…//

//…Currently, there are not many JCM implementation in Indonesia because all monetary-related policies must go through the Ministry of Finance. Hence, other ministries, such as ESDM, cannot make any monetary-related policies, such as tax. However, the ESDM can provide recommendations to the Ministry of Finance but the approval is not guaranteed. Electricity subsidies also come from the Ministry of Finance decision, where ESDM helps calculate the amount…//

Cost and Tariff

//…There are no technical problems that cannot be solved. Yet, awareness and financial capacity must be improved. PLN has an IRR of 10%. There are unfeasible projects because they are carried out in the locations where land is premium…//

//… PLN is targeted by the government to reduce subsidies. However, because electricity tariffs have been determined, then one way to achieve this target is to provide power generation as cheaply as possible. Unfortunately, in operating system theory, inexpensive generation will be less reliable than that with higher costs…//

//…If the investment cost is still expensive, it will be difficult to execute the project properly. The higher the investment cost, the higher the electricity tariff. Whereas, PLN already regulates the electricity tariff. Additionally, in most places that have an abundance of solar potential, the people in these areas have low income. Hence, if the investment costs are too high, the implementation will be difficult…//

//…In addition, PLN has a target to reduce production costs. Even though the operational cost of solar PV is cheap, its production costs are high. As a result, the government's target cannot be achieved. PLN has created an EBT division to help accelerate solar PV penetration, but a solution is still required to overcome intermittent costs…//

Feed-in-Tariff

//…compared to FiT, an auction cannot provide capping price easily although the renewable energy market will be more developed. The auction will make the process easy as well because the government does not need to check international market prices every time in order to provide a cap price for FiT. However, it is feared that investors will give the lowest price in the auction but then the project will stall…//

//…Once, there was a Ministry Regulation 38/2016 for the development of off-grid solar PV in remote areas. However, limited entities interested in this regulation. This regulation is constrained by the operating area scheme as well as the subsidy clause for the price difference. Regarding this subsidy, its application is not easy because parliament approval is needed. The parliament sees that subsidies should be given to the needs, not to the private sector…//

//…FiT is beneficial for developers but not for PLN. Solar PV is site-specific, as a result, its price is varied depending on the regional BPP. If the price is set at one price, it becomes unfair for another region. If the variation is only 1-2 cents, then FiT is not a problem. FiT can be applied in a condition where PLN still have negotiating room to bid lower prices which are harming for small developers…//

Power Purchase Agreement

//…Even though the communal solar PV is not connected to the grid and not a part of PPA contract, the tariff determination must still be lower than the local BPP…//

//…Currently, it is more profitable if IPP sells the electricity to PLN. Although IPP can sell electricity directly to the community, the mechanism is quite long. On the other hand, for most investors, the selling price to PLN is less attractive. Energy purchase policy is very important to provide certainty for investors. By knowing the price, the investors can calculate their payback and IRR. Consequently, its supporting policies must be clear, such as the PPA regulation. According to the current regulation, the PPA price is valid for the entire period of operation…//

//…PLN is also assigned to electrify the country as a single off-taker. However, due to capital constraints, some power plants are handed over to be built by the private sector using the PPA scheme as the cost recovery. Yet, this PPA tariff is also regulated by the government. PLN currently has two tasks, as a company and also as a regulator. No conflict interests arise from performing these two tasks, yet problems arise in PLN's cash flow…//

Market Presence and Direct Selling

//…In terms of generating electricity, PLN is already competitive. In terms of distribution, PLN is also already competitive with the presence of business areas. However, grid transmission still cannot be competitive due to PLN's ownership…//

//…there are not many renewable energy markets. Hence, many companies are not yet interested in opening solar PV's manufacturing industry in Indonesia…//

//…The main problem is related to economic principle, demand and supply. Regarding demand, the price of solar PV is more expensive than the traditional power plant, although the global price has been cheaper in the last five years because of China's mass production. The reason for the small scale of the PLTS project is that demand in Indonesia is still small, especially in eastern Indonesia. Since the Ministry Regulation 50/2017 was approved, all investments have declined…//

//…At present, the only off-taker is PLN. In terms of BPP, outside of Java, PV competes with diesel power plants. Larger investors prefer to build large capacities. However, PLN also wants the solar PV projects to comply with grid code. Initial costs for PV projects usually include 50% component costs and 20% construction costs. Ancillary services have been borne by PLN. PLN prepares expensive load followers to anticipate intermittence. Consequently, the total BPP becomes more expensive even though the cost of solar PV is relatively cheap. With the planned grid code regulation, it is expected that ancillary costs can be shared between PLN and IPP. However, it can impact on IPP's return…//

//… The electricity retailer is in a monopoly. In the regulation, PLN must purchase electricity from renewable energy at a maximum price of 85% from the BPP. It makes the investment in Java unattractive because the BPP in Java competes with PLTU. However, at present PLN is encouraged not to build a steam power plant, especially in areas such as Kalimantan…//

//…It would be better if IPP could sell directly their electricity from solar PV. It could make the market become more competitive. However, the investment will be quite expensive for IPP particularly in the area where the demand is not enough commensurate with the investment cost. Therefore, PLN intervention is required, especially as the pioneer to build the grid connection…//

//…Now it is necessary to change the mindset that PLN is no longer monopolizing electricity business in Indonesia. IUPTL has been held by 50 business areas outside PLN. It means that PLN is not the only holder of the electricity business. IPP can sell the electricity directly to the community with a mechanism that has been regulated by the Ministry of Energy and Mineral Resources. However, at present, the IPP relies on a very reliable PLN's grid…//

//…Microgrid penetration requires both land and technology. Therefore, a strong business model is needed. According to regulation, developers actually can sell their electricity directly to the community. However, they must create their own IUPTL. It is more difficult because IPP must determine the tariff structure. This tariff structure must be approved by the DPR / DPRD in which the time cannot be ascertained. Hence, IPPs prefers to sell their electricity to PLN using the PPA mechanism…//

//…It is possible for companies other than PLN to provide and sell electricity directly to the public at a regulated price. However, all business areas in Indonesia were owned by PLN initially. If some areas want to be electrified by the private sector, then the business area must be released based on Ministry Regulation 38. However, this mechanism is still being evaluated due to a lack of implementation. In terms of electricity tariff, the government maintains the public tariff. If the private sector enters, then the prices will be high.…//

//…For the IPPs, price and technical are the issues, especially for on-grid PV. Even off-grid PV has its difficulties. To sell electricity directly to the community, the IPP must have a business area unless they sell the electricity to the PLN…//

Procurement Process

//…It depends on the IPP itself. It can be open tenders or closed tenders. Some companies already have a list/ catalogue of providers with the best reputation for the IPP itself. However, there is still no exclusivity to appoint a company as the goods/services provider…//

//…In the context of the developer itself, the developer will invite several companies internally to participate in the procurement tender. The developer also has its own criteria…//

PLN Tender

//…In contrast, under the current mechanism, the location and capacity have been determined. This condition increased the risk of the IPP because there is a possibility that the IPP is not selected while the cost already incurred. To be selected in DPT is not difficult. Yet, sometimes there are inconsistencies in the tender requirements during announcements and during the bid so that the IPP has to work twice. Whereas, the initial purpose of the DPT was to simplify and to speed up the process…//

//…PLN opens the tender for renewable energy projects. Companies registered in the PLN's DPT will be invited to purchase the documents. After that, if interested, the company must submit the proposal. The second mechanism, the developers determine a location and can carry out projects at that location. Then, they can submit a proposal especially for the projects with a capacity of less than 10 MW. Subsequently, regional PLN will conduct a closed tender by inviting other companies under the DPT. If there is a company that is able to offer lower BPP and capable to match the criteria, then that company will be selected. However, if the original developer is willing to match PLN's criteria, then this company will be a priority…//

//…The current method, direct selection, is better because of its competitiveness and objectiveness. Under this method, all DPTs are screened for their feasibility studies, including the financial analysis as well as the interconnection studies. Then, the most well-prepared developer which also has the best track record, financially and technically, is chosen. This process will reduce the risk for both developers and off-takers so that it is equally beneficial…//

//…There is no perfect method. However, the current method is the best method to be applied at this time. Everything has its merits and demerits depending on whose point of view. PLN has its own reasons for choosing the current method, match to match…//

//…Using the potential Solar PV map, the government will open existing projects, to PLN and to the private sector. Then, the tender is conducted. The problem happens after the tender is closed and investors finished a feasibility study. The process is deadlocked during PPA negotiation with PLN. Furthermore, The BPP's 85% rule is ambiguous, whether this 85% based on the power plant location or based on the transmission zone. Currently, the LCOE for small-scale solar PV is around 12 cents / kWh. The largest solar PV in Indonesia is valued at around 25 cents / kWh…//

//…For projects financed by the State Budget, tendering is an important process especially in terms of administration. For the IPP projects, PLN holds direct selection. PLN has a yearly plan, namely RUPTL, which determines the capacity quota for each region. The IPP must be registered in the DPT (list of selected participants) before PLN choose the best IPP…//

Quota Mechanism

//…Quota mechanism is fairer than the current mechanism because, in the previous scheme, IPP has more flexibility…//

//…As long as there is no policy that really mandates replacing steam or diesel power plant, then renewable energy quota has no effect. Some people argue that the current renewable energy targets in RUEN are too optimistic…//

//…The quota for solar PV is based on the network/grid study. Additionally, there are also distributed quota in each region even though it depends on the network conditions too…//

//…Quotas are indeed important because each region has different network potentials and demands…//

//…Because of the quota mechanism from PLN, IPP encounters obstacles to develop solar PV. The demand increase will be distributed partially for baseload and for other generations. Intermittent generators usually get a small quota. Additionally, PLN will choose the most reliable and the cheapest baseload. The government should have prioritized renewable energy quotas whose prices are below the BPP before taking thermal generation into account…//

Impact of Fossil Fuel Subsidies

//…At present, many generations utilize coal. Coal is still dominating the market in Indonesia because its domestic production is large. Renewable is not a priority in Indonesia because it has not been seen as a factor to increase energy security. From a macroeconomics view, coal does not reduce foreign exchange. Coal is also cheaper for power generation. However, coal has a significant emission impact. It is important to study when renewable energy can enter the Indonesian power market effectively because this energy source can increase the future's energy security if a commodity embargo occurs…//

Rural Electrification

//… Solar PV itself has the potential to help to increase the electrification ratio in rural areas, like NTT. Additionally, there is a serious commitment to utilize solar PV although some financial problems still occur. It becomes a dilemma for increasing the electrification ratio while the system is financially uneconomic. If the LCOE is higher than the BPP, then no one will purchase the electricity. Hence, supports from the government, such as research grants and incentives, are needed. PLN and also ESDM has a big homework to present solar PV's location and capacity meticulously under the RUPTL…//

//…Under the rural electrification program, the government still prioritizes diesel even though diesel operating costs are 6 times more expensive than coal and 3 times more expensive than gas. However, diesel can be distributed easily compared to gas and coal. Hence, many diesel powers have been built in areas not covered by the PLN transmission. The solar market can potentially be placed at the location of these diesel powers…//

//…At present, the program only affects the electrification ratio rather than the renewable energy share…//

//…It currently shows that there is a progress in solar PV development from year to year. A few years ago, in 2010-2012 solar PV was still non-commercially available and dedicated to remote areas while ESDM was also learning how to make this solar PV commercial. Then, using the state budget, some larger solar PV power plants were built with a capacity of 1 MW. Over time, several commercial projects were developed by the private sector as the implementation of Ministry Regulation 17/2013…//

Energy Mix

//…Lastly, the government is not yet committed to meet the renewable energy target. The existing policy only provides guidelines without any mandatory actions. The Paris agreement itself has not been able to make the government increase the capacity of solar PV. Although there are emissions reduction targets, they are not legally binding yet…//

//…It does not have any impact because the government has no direction in its energy or climate policy. There are still many investments in fossil fuel…//

//…The energy mix in Indonesia is only a target without any mandatory or sanction. The renewable target of 45.2 GW installed capacity cannot be achieved. The scenario is created using the economic growth of 7% whereas the current growth is around 5%. Therefore, the target should be lowered. Additionally, this energy mix is very difficult to breakdown by province because it is created not based on a bottom-up analysis. It is better to analyse each system to get a national target…//

BOOT

//…The regulation forces the IPP to acquire land for solar PV. However, at someplace, the BPP prices cannot cover the land premium. One suggested solution is to lease a government land, so at the end of the project, the usage rights can be transferred…//

//…The BOOT scheme became a public debate in which there was a lot of resistance from the IPP. IPP feels that the regulation is not beneficial for IPP particularly after building a solar PV with high installation costs. Some IPP complained about land acquisition. Actually, land acquisition has been considered in cost estimation, included in the non-EPC cost component. Land acquisition becomes a problem mainly for new players, whereas for more experienced players this BOOT scheme becomes a problem in calculating the company's IRR. Another burdensome issue in the BOOT scheme is that the IPP must guarantee that the plant is in an operable condition during transfer. This pre-requisite is costly, particularly at the end of the contract…//

//…At present, the existence of BOOT regulations makes it difficult for IPP to get loans because they do not have collateral. IPP cannot use its assets as collateral because these assets must be transferred to the government at the end of the contract. The government does not aid with land purchasing process…//

//… Secondly, BPP and BOOT under ESDM Regulation 50/2017 become a problem. If the transfer in the BOOT mechanism is removed, then it will have a significant impact. Actually, investors are not concerned about any scheme as long as the developer can get a good investment return. However, the developers cannot get funding from banks because there is no collateral in this BOOT scheme. It will impact local companies whose financial capabilities are limited…//

//…In some villages, public land is used to install solar PV because the residents expect electricity services in the region while connections to the PLN network are impossible. In other villages, residents relinquish their barren land for solar PV development. However, if the installed capacity is quite large, the land purchase must be done by developers…//

//… Land certificates in remote areas are still difficult to obtain. Additionally, there is still a lot of uncharted lands. Sometimes, land ownership is based on hereditary so when the land is used for a business, it will become a problem…//

//… The transfer under BOOT is not a complicated process for the IPP. Private assets are handed over to PLN at the end of the projects, even though small developers concern about its bankability. This BOOT scheme creates problems if the project owner is a government or state company, BUMN / BUMD. This regulation needs to be reviewed…//

Local Content

//…Local content also sometimes becomes a problem. Although it has a good purpose to advance the local industry, the synergy between the Ministry of Industry and Energy and Mineral Resources is required. They must coordinate on how much local content in a component must be, as well as to make it clear whether this local content is product specific or project specific. This local content issue will be a problem when the installed capacity is large because currently there are not many certified local-assembled products. In the absence of this certification, bankability is impossible...//

//…The current local content requirements are high, 60%. If the IPP wants to meet this requirement, then the price will definitely be higher because domestic modules are more expensive than the import ones. Additionally, Indonesia only assembles imported solar cells. This situation can be worsened because Some financial institutions, especially the international ones, have their own standards related to equipment specifications. Domestic capabilities are not yet capable to meet local content requirements, 60%...//

Complex Bureaucracy

//…Nowadays the licensing and permitting process has been better. In addition, the government provides clear estimation, so that project implementation can be certainly estimated…//

//…This bureaucratic problem depends on the type of project. However, in general, the bureaucratic process is simpler now except if there are individuals in the region that slow down the process…//

Local Government

//…At the moment, local governments have not helped much on land acquisition, because many areas in Indonesia still privately owned…//

//…Sometimes it is still difficult to collaborate because the local governments also have their own interests. Sometimes, the implementation can be hampered if the local government still does not have a commitment to solar PV. In addition, many regions in Indonesia do not yet have a regional energy plan, RUED…//

//…DEN is encouraging local governments to compile and to study their own energy policy, RUED. However, because there are limited human resources who understand energy issues as well as energy issue has not been a priority, it takes a long time to draft RUED. Currently, only two provinces, West Java and Central Java, have RUED…//

//…Some regions already have their RUED. Most models and targets within RUED are derived from National Energy Plan Policy, RUEN. So hopefully, the cumulative target in RUED is in accordance with national targets. From the process that has already taken place, RUEN is a reference for RUED. Yet, the regional potential has been considered as well. Hence, it is not difficult to draft a RUED. The difficulty is in implementing the target due to the lack of investment…//

Conflicting Regulation

//…It becomes a problem for PLN because there are many conflict interests between ministries. PLN should be supervised under one ministry or even under the president directly like PERTAMINA because PLN has many strategic projects that concern the well-being of many people…//

//…The government has not yet forced solar PV because PLN must produce the least-cost electricity. Additionally, the purchasing power of the Indonesian people is still low…//

//…Solar PV regulation has changed over the years. The regulation includes Ministry Regulation 17/2013, Ministry Regulation 19/2016, Ministry Regulation 12/2017 and Ministry Regulation 50/2017. Before the implementation of Ministry Regulation 50/2017, the PPA tariff is more attractive for investors…//

//… There is coordination between ministries. However, sometimes many policies are overlapping like renewable energy policies overlapped with environmental policy. Regarding land issues, ESDM proposes the use of ex-mining land for solar PV installation. However, the KLH regulations forbid this because the ex-mining land must be reforested. Additionally, there is also a problem with land acquisition…//

//…Political enforcement is required to accelerate solar PV penetration. Supporting regulation is also needed to increase electricity demand. Currently, renewable energy targets already exist. However, it requires regulations to encourage its implementation, such as the provision of renewable energy law. At this moment, renewable is governed by Ministerial Regulations which sometimes overlap with other ministries. The presence of law will make renewable energy position stronger…//

Intergovernmental Stakeholders

//…There is a need to have a body that monitors technical aspects of the system or the grid. The perspectives from organizations outside of PLN are required as an input for the company. As a result, PLN does not need to conduct its own audits and the process can be more integrated…//

//…The big homework for the Indonesia government is to supervise its electricity system. At present, there is no agency dedicated to enforcing grid code rules. Currently, PLN must report to KMAJ (Network Regulation Management Committee) where its member is the stakeholder within the system itself. Hence, a body dedicated to supervising and enforcing the grid code is necessary. A good grid code will be valueless if there is no enforcement…//

//…PLN is currently under the Ministry of BUMN, ESDM, and also finance. Each ministry applies its own policies and own performance targets for PLN so that it becomes a challenge for PLN…//

//.. Each powerholder has their own opinion. For example, when a change of power happens, the BOOT regulation might change. However, when there is another power change, the regulation might return to BOOT again. Many stakeholders did not evaluate the feedback from the previous policy. This situation will certainly affect the investment climate in Indonesia…//

//…At present, ESDM only focuses on building power plants without considering post-implementation. It should be better if coordination between ministries has been conducted since the planning phase. For example, coordinating with the CTF to help mapping economic potential in the regions. Coordination with the Ministry of Home Affairs and the Ministry of Rural Area can help in community empowerment. Then KUKM can also participate to encourage electricity use from solar PV. If this can happen, the solar PV project will be more sustainable. Currently, collaboration with a German agency is being conducted to implement this intergovernmental partnership, namely SOLID…//

Emission Tax

//…Implementing renewable energy at a macro level is quite expensive, so there should be extraordinary support from the government. The source of funds can be obtained by applying a carbon credit/tax. It becomes an irony when there is diversification into renewable energy, but the source of emission is still there. Additionally, economic or monetary driven is usually more effective…//

//…By including a carbon tax, the price of electricity / BPP supply in Indonesia will rise. Because the price of solar PV is getting down, then solar investment will be more attractive. Besides, the received taxes can also be used as subsidies…//

//…Of course, it is possible to make solar PV more competitive. At present solar, gas, and diesel power plants have not yet considered the environmental impact on their cost component. If these externalities are included, BPP prices will be higher and solar PV will be more competitive. However, this situation will increase the electricity tariff. This tariff is a socio-political issue although direct subsidy can be a solution to overcome this…//

Ceiling Price

//…Its availability, affordability, and acceptability must be considered. In terms of power generation, the government still prioritizes affordability. FIT can be implemented with a ceiling price lower than BPP so that small developers get a decent price. Large scale developers get the funding easier from international funding…//

Business Model

//… Currently, BAPPENAS and PLN are evaluating how the electricity business should be implemented in Indonesia. However, its side effects must also be assessed. We cannot only talk about a sophisticated model, but its effects on society must be examined as well…//

//…At present, PLN has no competitors so that the electricity prices are still monopolized. This condition also did not force PLN to improve its performance. On the other hand, this kind of monopoly helps the government to regulate electricity prices easily. Electricity price is the most sensitive issue in society…//

//…It is theoretically possible. At the moment, PLN does monopoly and monopsony, which is economically not good because there is no competition. However, many political interests make it difficult to create a competitive national electricity market…//

//…Currently, ESDM is working with UNDP to study appropriate business models for the development of off-grid, microgrid or mini-grid solar PV. PLN is also encouraged to open a new business model. For example, PLN should see solar rooftop as a new business opportunity. Nevertheless, many PLN subsidiaries in the power generation sector are more actively developing solar PV. PLN itself has also started building lots of solar PV microgrid…//

//… the government has to change the law. In 2002, this idea was proposed but then it is rejected by the Supreme Court. In 2004, the original law returned, so that the power of PLN becomes very powerful. In addition, the nature of commodities in the electricity industry is different from that in the oil and gas industry, making it difficult for PLN to be like PERTAMINA. At this moment, PLN is the only off-taker in charge of market prices…//