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Technical Note

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Residential Rooftop Solar

Technical and Market Potential in 34 Provinces in Indonesia

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Background

To meet its growing energy needs and reduce dependency on fossil fuels, the Government of Indonesia has planned to increase renewable energy utilization. The National Energy Policy set to increase renewable energy use to 23% of national energy mix by 2025; a target considered ambitious for many. Unfortunately, the ambitious target is not followed by ambitious implementation; driving sluggish development of renewable energy in the last few years since the target announced in 2014.

In the last 3 years, renewables growth reached only 3.6% each year[1]. The share of renewables in Indonesia's electricity generation has been locked at 11 – 13% since then. They are mostly large-scale renewables, dominated by large hydropower and geothermal. Variable renewable energy (VRE), such as wind and solar, only contributed less than 1% of total renewable installed capacity in 2018. In contrast, to follow exactly the target of National Energy Plan, renewable power plant has to grow at the level of 5 to 6 GW per year or about 6 to 8 times higher than current

1 IESR, 2018, *Laporan Status Energi Bersih Indonesia 2018*

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level until 2025. Meeting the NEP's target requires rapid deployment of renewable energy technologies at significant scale.

Indonesia, situated at the equator, is of great potential to harness solar energy. With average global horizontal irradiation[2] of 4.8 kWh/m^2, Indonesia can generate a significant amount of electricity per year, as high as 1,534 kWh/year for each installed kWp of solar panels[2]. MEMR calculates that technical potential of photovoltaic electricity generation in Indonesia reaches 559 GWp, calculated with panel efficiency of 15%[3]. However, as apparent in total share of solar energy in electricity generation, the development of solar energy in Indonesia has yet to reach cumulative capacity of 100 MW. This capacity is far behind Indonesia's neighboring countries: Thailand leads with over 2.7 GW of solar power (and it is more than the rest of Southeast Asia combined), The Philippines is second in the region with 886 MW, Malaysia has 438 MW, and Singapore has achieved 150 MW[4].

In 2017, Ministry of Energy and Mineral Resources of Republic of Indonesia in collaboration with Ministry of Industry, Indonesia Solar Energy Association, Institute for Essential Services Reform, and several other government agencies, associations, and university launched the One Million Rooftop Solar Initiative or *Gerakan Nasional Sejuta Surya Atap* (GNSSA); aiming to boost solar energy development and utilization in Indonesia, particularly the application of rooftop solar photovoltaic. The Initiative targets one million homes/buildings, each with minimal installed capacity of 1 kWp rooftop solar or equals to a cumulative installed capacity of 1 GWp. Since the launching of The Initiative, the number of homeowners registering their house for grid-tie rooftop solar has increased by more than 2-folds and commercial and industrial building also started to realise the potential and benefit of having rooftop solar.

Responding to the increasing demand, the Ministry of Energy and Mineral Resources issued, MEMR Regulation No. 49/2018 on rooftop solar PV. The regulation targeted PLN's customer and it covers a number of issues: procedures to install rooftop solar, EPC qualifications and installation standards, and net-metering credit scheme. One of significant issue in the regulation is the transaction scheme or credit scheme using net-metering that is substantially different compare to previous PLN's Directors' regulation issued in 2013. Past net-metering credit scheme employs the ratio of 1:1 (1 unit of solar-generated electricity equals to 1 unit of PLN's electricity used by consumers), while current ministerial regulation only allows 1:0.65 ratio (1 unit of solar-generated electricity equals to 0.65 unit of PLN's electricity used by consumers).

We have yet to see the effect of this regulation to consumers' interest, however, as a market study by GIZ-INFIS and IESR conducted in Greater Jakarta area in 2018 shows that electricity saving is one of respondent's main reasons to use rooftop solar; changes in net-metering credit scheme could make solar PV becomes less attractive. The survey also indicates the need of supporting regulations with fiscal and financial incentives to encourage homeowner to install solar PV.

In order to understand potential of solar power and to provide policy makers and public with sound, technical information on rooftop solar potential in Indonesia and with further aim to drive the acceleration of rooftop solar use; Institute for Essential Services Reform (IESR) calculated residential rooftop solar photovoltaic technical potential in all 34 provinces in Indonesia. With this data of technical potential, it is expected that the government, both national and local, can set up ambitious target to increase renewable energy share and start transitioning to low-carbon energy system.

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2 Solargis, https://solargis.com/maps-and-gis-data/download/indonesia

3 Ministry of Energy and Mineral Resources, 2014, P3TKEBT

4 IRENA, 2019, *Renewable Energy Statistics 2019*

Introduction

Solar photovoltaic (PV) cells are mature technologies. Increasing demand in the past decade has made solar PV cells price declining rapidly. This trigger more interests and demand from public for various use application, e.g. households, public facilities, commercial and industrial buildings. Given the current trend, it is likely that solar PV would play a vital role in global energy transition as predicted by International Energy Agency (IEA)[5]. The application of solar cell in the form of rooftop solar is growing and getting popular in many countries, although it is still infant in Indonesia. However, as the cost of solar cell getting cheaper over time, with support of right policies and/or incentives, rooftop solar installation will be increasing in the near future.

Estimating the technical potential of rooftop solar application could provide information on solar market potential in Indonesia. This information alone could inform policy maker to design suitable policy and regulatory instrument to harness this potential to meet renewable energy capacity target and climate mitigation strategies. In order to find rooftop solar potential in the form of installed capacity, it is important to understand the suitability of rooftop area for PV installations, not only the amount of rooftops area itself, but also the characteristics of rooftop space. Subsequently, when rooftop area suitable for solar PV is available, solar PV power density and other technical details on solar PV technology are applied to estimate potential installed capacity.

To date, there are three major rooftop-area estimation methods, i.e. constant-value methods, manual selection methods, and GIS-based methods. Each of them has their own advantages and disadvantages, as depicted in Table 1.

While having several disadvantages, constant-value methods can provide a useful starting point in estimating rooftop solar energy generation for a certain area. It is also relatively easy to commence. Rule of thumb assumptions, such as proportion of sloped roofs and flat roofs, shading, slope, and orientation effects, as well as climate condition are incorporated into the estimation. Variation of assumptions certainly occurs, as different research use different datasets and approximations. For example,

Table 1. Advantages and disadvantages of three major rooftop-area estimation methods

Methods	Advantages	Disadvantages
Constant-value methods	Quick to execute and rooftop area is easy to be estimated	The results are generalized and do not consider localized rooftop characteristic. Validating the results will be a challenge.
Manual selection methods	Very detail-specific and can accommodate assumptions based on specific understandings on regions and buildings.	Time-intensive, not easily replicable across multiple regions.
GIS-based methods	Very detail-specific, replicable across multiple regions, and can be automated for more efficient computing	Time-intensive, computer-resource intensive.

Source: (adapted from Melius, et.al.[6])

5 OECD/IEA, 2018, *World Energy Outlook 2018*, https://www.iea.org/weo2018/

6 Melius, et.al., NREL, 2013, *Estimating Rooftop Suitability for PV: A Review of Methods, Patents, and Validation Techniques*

Ladner-Garcia and O'Neill-Carrillo[7] used a constant value to total building area to estimate PV energy potential for Puerto-Rico, of which shadows and uncertainty in rooftop layout were considered, but not slope or orientation. On the other hand, reports by NREL[8] and IEA[9] evaluate buildings based on multiple characteristics, such as building components, shade, and orientation. They also assigned a constant rooftop-availability value based on population density. These variations result in diverse number of percentages of total rooftop area suitable for PV applications. Melius et.al. listed their reviews of several research employing constant-value methods as follows:

Table 2. Rooftop area estimation from several research employing constant-value methods

Study	Study Area	Percent of Total Rooftop Area Suitable for PV	PV-suitable rooftop area per capita	Potential percent of energy demand/ consumption met by rooftop solar
Chaudhari et al. 2004[10], Denholm and Margolis 2008[11], Frantzis et al. 2007[12], Paidipati et al. 2004[13]	United States	60%–65% (commercial) 22%–27% (residential)	—	—
Frantzis et al. 1998[14]	Minneapolis/ St. Paul metro area	35%–65% (flat) 16% (pitched)	—	Up to 23% (total demand); up to 50% (daytime peak)
Ladner-Garcia and O'Neill-Carrillo 2009[7]	Puerto Rico	50%	—	All residential energy from 25% of residential rooftop space available; all commercial and industrial energy from all available rooftop space
Vardimon 2011[15]	Israel	30% (all buildings) 50% (large buildings only)	—	32% of electricity consumption (all buildings); 10%–15% (large buildings only)
Eiffert 2003[16], IEA 2001[17]	23 IEA countries	15% (Japan)–57.8% (United States)	—	—
Lehmann and Peter undated[18]	Northrhine-Westfalia, Germany	—	13.4 m^2 (rooftop) 7.1 m^2 (façade)	—
Wiginton et al. 2010[19]	Southeastern Ontario	30%	70 m^2	30% of electricity demand

Source: Melius et.al.

7 Ladner-Garcia, et. al., Calgary, Alberta Canada, 2009, *Determining Realistic Photovoltaic Generation Targets in an Isolated Power System*
8 Eiffert, P., NREL, 2003, *Non-Technical Barriers to the Commercialization of PV Power Systems in the Built Environment*
9 IEA, 2001, *Potential for Building Integrated Photovoltaics*
10 Chaudari, et al, Navigant Consulting, 2004, PV Grid Connected Market Potential Under a Cost Breakthrough Scenario
11 Denholm, P. and Margolis, R., NREL, 2008, Supply Curves for Rooftop Solar PV-Generated Electricity for the United States.
12 Frantzis, et. al., 2007, Navigant Consulting, California Rooftop Photovoltaic (PV) Resource Assessment and Growth Potential by County
13 Paidipati et.al., Navigant Consulting, NREL, 2008, Rooftop Photovoltaics Market Penetration Scenarios, https://www.nrel.gov/docs/fy08osti/42306.pdf
14 Frantzis, et al, 1998, The Potential for Building-Integrated Photovoltaics within the Minneapolis/St. Paul Metro Area: Critical Solar Access/Installation Issues, 2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion in Vienna, Austria
15 Vardimon, 2011, Assessment of the Potential for Distributed Photovoltaic Electricity Production in Israel
16 Eiffert, NREL, 2003, Non-Technical Barriers to the Commercialization of PV Power Systems in the Built Environment and IEA, 2001, Potential for Building Integrated Photovoltaics
17 IEA, 2001, Potential for Building Integrated Photovoltaics
18 Lehmann, et al, Institute for Sustainable Solutions and Innovations, undated, Assessment of Roof and Façade Potentials for Solar Use in Europe
19 Wiginton, et al, 2010, Quantifying Rooftop Solar Photovoltaic Potential for Regional Renewable Energy Policy

Due to limitation on datasets available in Indonesia and seeing how we intend to use this estimation to ignite discussion in promoting acceleration of rooftop solar in Indonesia, we use constant-value method to estimate technical potential of rooftop solar in 34 provinces in Indonesia and its subsequent market potential.

Methodology

Technical potential of residential rooftop solar in 34 provinces in Indonesia

To calculate technical potential of rooftop solar, we need information of total residential building roof spaces available in 34 provinces in Indonesia. There are no datasets available for this information, thus we used datasets on the amount of floor space in residential buildings in Indonesia provided by Central Bureau of Statistics and converted them to the size of roof space. Indonesia's Central Bureau of Statistics classifies residential buildings into 5 categories based on their floor space: < 19 m^2, 20 – 48 m^2, 50 – 99 m^2, 100 – 148 m^2, and > 150 m^2. We used average floor space for each category for the year 2015[20] (latest complete datasets available) and multiplied them with the number of households[21] for each corresponding category. From the first step, we obtained total floor space for any given province.

To estimate how floor space translates to roof space, we assumed all households in Indonesia to have pitched roofs of 18 degree (4/12)[13] or flat roofs of 5 degree (1/12), for the ease of consequent PV access factor incorporation. The pitch degree is a typical number; however, the number can vary from 0 to 45 degree in any given region. There are no available datasets on residential buildings pitch degree for Indonesia. Roof space in this estimation was obtained by multiplying floor space with correction factor corresponding to pitch degree, in this case 1.054 for pitched roofs of 18 degree and 1.003 for flat roofs. After obtaining roof space area, we calculated the amount of roof space suitable for PV by multiplying the amount of roof space with PV access factor. The factor refers to percentage of roof suitable for PV installation. We use 4 different access factors:

1. Constant-value method:
   - Scenario 1: 24% access factor, assuming pitched roof in warmer climate (tree shading, other shading, and orientation are considered)[13]
   - Scenario 2: 60% access factor, assuming flat roof in warmer climate[13]
   - Scenario 3: 81% access factor, assuming pitched roof in warmer climate (tree shading and other shading are considered, orientation is not considered)[13]
2. Manual-selection method:
   - Scenario 4: 33% access factor, assuming pitched roof, the percentage was averaged from Helioscope simulation[22]. We took 1 location (house) for each floor space category based on Indonesia's CBS classification, in 5 cities across 5 provinces in Indonesia (Medan, Jakarta, Surabaya, Denpasar, and Kupang); then performed rooftop solar simulation on their roofs. Helioscope calculated suitable roof spaces for PV range from 20% to 42% and we found the average percentage to be 33%. This method can be regarded as manual-selection method, as we used aerial photography embedded in Helioscope to automatically determine roof space suitable for PV.

From above calculation, we obtained total size of suitable roof area for PV in any given

20 Central Bureau of Statistics, https://www.bps.go.id/dynamictable/2015/09/07/841/persentase-rumah-tangga-menurut-provinsi-dan-luas-lantai-meter-persegi-2014-2015.html

21 Central Bureau of Statistics, https://www.bps.go.id/dynamictable/2015/09/07/851/banyaknya-rumah-tangga-menurut-provinsi-2000-2015.html

22 IESR own simulation using Helioscope, https://www.helioscope.com/

province in Indonesia. We then proceeded to calculate technical potential by multiplying the number with power density of a solar PV system. We listed 10 brands of monocrystalline PV module with current highest efficiency[23] and we calculated their power density on a square-meter basis, then applied a packing factor of 1.25[13] for residential system. The packing factor affects (as a decrease) the PV power density by considering space need for the system, such as space for access between modules, wiring, and inverters. Power density of those 10 brands was then averaged and multiplied to available suitable roof area obtained previously to estimate technical potential of PV for each province in Indonesia (in GWp unit). We also calculated yearly produced energy for each province, the average photovoltaic power potential data (in kWh/kWp) for each province in Indonesia was generated from NREL Renewable Energy Data Explorer for Southeast Asia[24].

Market Potential of Rooftop Solar in 34 Provinces in Indonesia

Technical potential calculation shows rooftop solar potential based on the availability of residential roof space in Indonesia or in another term, technically feasible to install. However, with current market price and availability, limited public information, and lack of supportive policies; realistic market potential will be substantially less. Thus, we stipulate that realistic market potential of rooftop solar in Indonesia depends on financial sate of homeowners.

To calculate market potential, we only consider households connected to PLN grid (PLN consumers). We used datasets on PLN's household consumers[25] classified based on their installed electricity capacity per province and region[26] and assumed that only households with installed electricity of ≥ 1300 VA having the financial capacity to install rooftop solar. The assumption is made partially due to limitation in publicly available data on PLN consumers. We made the conversion of technical potential to market potential by accounting the number of PLN's consumers for each province and by disregarding PLN's consumers receiving electricity subsidies (households belonging to 450 and 900 VA groups)[27] using the formula:

$$\frac{\textit{Number of total PLN's household consumers}}{\textit{Number of total households (CBS data) in each province}} \times \textit{technical potential for each province} \; \frac{\textit{Number of total PLN's household consumers} \geq 1300\ \textit{VA}}{\textit{Number of total PLN's household consumers}}$$

We enclose all data used for this estimation in the annex.

Result

We run 4 scenarios based on different access factor while keeping the same value for other variables: Scenario 1 (24% access factor), Scenario 2 (60% access factor), Scenario 3 (81% access factor), Scenario 4 (33% access factor). With these scenarios, we found that technical potential of residential building rooftop solar in Indonesia ranges from 194.1 GWp to 655 GWp (see Figure 1). The numbers reflect very high potential of solar photovoltaic generation in Indonesia, even without considering public, commercial, industrial buildings and solar parks. The highest potential (with 81% access factor) is higher than the estimation made by Ministry of Energy and Mineral Resources (559 GWp[3]).

Detailed numbers are tabulated in Table 3. Top 10 provinces with highest technical potential are: East Java, West Java, Central Java, North Sumatera, Banten, Jakarta, Lampung, South Sulawesi, South Sumatera, and Riau. Three provinces in Java Island are of the highest potential, corresponds to their high

23 https://ecotality.com/most-efficient-solar-panels/

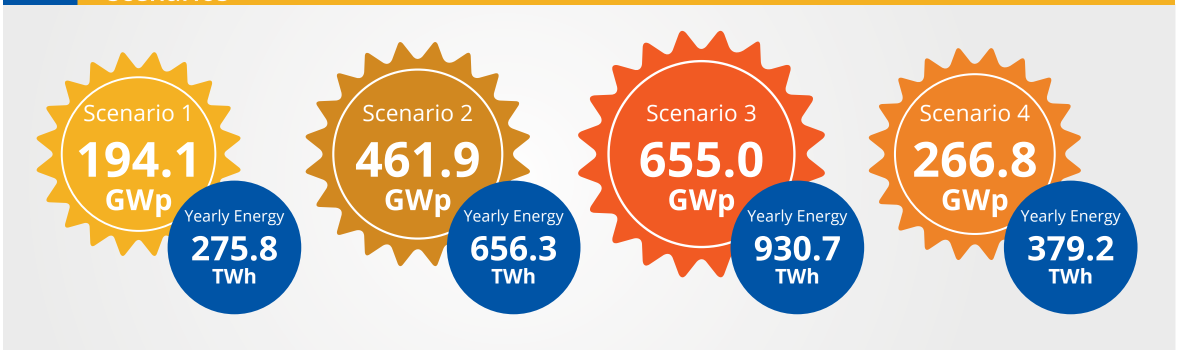
24 NREL, accessed during April 2019, https://maps.nrel.gov/rede-southeast-asia

25 PLN, 2016, Penerapan Subsidi Listrik Tepat Sasaran Bagi Konsumen R-1/900 VA. Power Point Presentation.

26 PLN's data are clustered ununiformly into provinces and regions (2 – 3 provinces)

27 Statistik PLN 2016, https://www.pln.co.id/statics/uploads/2017/05/Statistik2016.pdf

Figure 1. Technical potential of rooftop solar in Indonesia based on 4 different scenarios



number of households. Homeowners in Java Island are also potential power prosumers (producer-consumer), as our market surveys[28] in Greater Jakarta and Surabaya shows the presence of 13% and 19% market potential[29], respectively. These findings can be useful in projecting power demand in Java, to include the potential of consumers generating their own power and thus affecting power demand scenario for PLN. It is also important to note that the technical potential will grow as house number increases.

With Indonesia's moderate to high photovoltaic power potential, Indonesia's technical potential of rooftop solar calculated in this study translates to yearly energy range of 275 to 930 TWh. The number, even for the lowest access factor (24%), is already more than combined electricity demand for all sectors in Indonesia in 2018 (232 TWh[30]) and projected demand for 2019 (245 TWh[30]).

While technical potential calculation aims to show cumulative potential installed capacity of rooftop solar based on roof area availability, in the actuality, not all homeowners have the willingness and/or financial means to install rooftop solar on their roofs. Therefore, we define a term "market potential" in this study, referring to the cumulative installed rooftop solar capacity by taking only households with assumed sound financial capability to install rooftop solar into account. With this assumption, only 17.8% of Indonesia's technical potential of rooftop solar can be regarded as feasible to achieve, marketwise. The market potential calculated by different scenarios ranges from 34.5 to 116.3 GWp and are tabulated in Table 4.

We found that three provinces with highest market potential are (1) Jakarta, (2) West Java, and (3) East Java, corresponds to their high number of ≥1300 VA PLN consumers. In addition to our market surveys results, showing that homeowners in Greater Jakarta and Surabaya have the willingness to use rooftop solar on their houses, provincial and city governments can use this market potential estimation as a supporting data and analysis to drive clean and renewable energy development, particularly solar energy, in their own respective area of authority. In IESR's view, the role of local governments is important to further accelerate solar energy development in provinces and cities, as they have certain authority to make supporting policies, such as issuing local regulations and giving fiscal and non-fiscal incentives. Bali, its market potential of rooftop solar ranked 10 in this study, is on its way to issue Indonesia's very first local regulation for clean energy (governor regulation). The regulation also covers solar energy use for households, with Bali government plans to give attractive incentives, such as land value tax and property tax exemptions for those installing rooftop

28 GIZ-INFIS & IESR for survey in Greater Jakarta (2018), IESR for survey in Surabaya (2019)

29 The market potential of the surveys refers to percentage of population having the tendency to be "early adopters" and "early followers". For further information, please visit: http://iesr.or.id/pustaka/key-findings-studi-potensi-pasar-rooftop-solar-di-jabodetabek/

30 PLN, 2019, RUPTL 2019 - 2028

Table 3. Technical potential of rooftop solar in Indonesia based on 4 different scenarios

Province	Technical potential of rooftop solar in Indonesia, GWp			
	Scenario 1 – 24%	Scenario 2 – 60%	Scenario 3 – 81%	Scenario 4 – 33%
Aceh	3.1	7.4	10.5	4.3
North Sumatera	10.2	24.4	34.6	14.1
West Sumatera	3.6	8.5	12.1	4.9
Riau	4.4	10.4	14.8	6.0
Riau Islands	1.4	3.3	4.7	1.9
Jambi	2.4	5.8	8.3	3.4
South Sumatera	5.1	12.1	17.1	7.0
Bengkulu	1.3	3.0	4.2	1.7
Lampung	6.5	15.4	21.9	8.9
Bangka Belitung Islands	1.1	2.6	3.6	1.5
Jakarta	6.8	16.1	22.9	9.3
West Java	33.1	78.9	111.9	45.6
Central Java	32.5	77.3	109.6	44.6
Yogyakarta	3.7	8.9	12.6	5.1
East Java	34.7	82.6	117.2	47.7
Banten	8.6	20.5	29.1	11.9
Bali	3.2	7.7	10.9	4.4
West Nusa Tenggara	2.9	6.9	9.8	4.0
East Nusa Tenggara	2.6	6.1	8.7	3.5
West Kalimantan	3.0	7.2	10.3	4.2
Central Kalimantan	1.7	4.0	5.7	2.3
South Kalimantan	2.9	6.9	9.8	4.0
East Kalimantan	2.5	6.0	8.6	3.5
North Kalimantan	0.4	1.0	1.5	0.6
North Sulawesi	1.6	3.8	5.4	2.2
Central Sulawesi	1.9	4.5	6.3	2.6
Gorontalo	0.7	1.7	2.4	1.0
South Sulawesi	6.3	15.0	21.3	8.7
Southeast Sulawesi	1.7	3.9	5.6	2.3
West Sulawesi	0.8	1.9	2.6	1.1
Maluku	0.9	2.2	3.1	1.3
North Maluku	0.7	1.7	2.4	1.0
West Papua	0.5	1.1	1.6	0.6
Papua	1.2	2.8	4.0	1.6
INDONESIA	**194.1**	**461.9**	**655.0**	**266.8**
YEARLY ENERGY (TWh)	**275.8**	**656.3**	**930.7**	**379.2**

solar. This example of supporting incentives is in line with IESR's recommendation[31], in order to increase the attractiveness of rooftop solar use and to create enabling environment for its accelerated development. We also expect other local governments to follow Bali government's initiative and to explore their own unique, untapped renewable energy potential not only to meet local energy demand but also to drive local economic and productive growth.

31 IESR, 2019, http://iesr.or.id/ranpergub-bali-energi-bersih/

Table 4. Market potential of rooftop solar in Indonesia based on 4 different scenarios

Province	Market potential of rooftop solar, GWp			
	Scenario 1 – 24%	Scenario 2 – 60%	Scenario 3 – 81%	Scenario 4 – 33%
Aceh	0.3	0.8	1.1	0.5
North Sumatera	1.4	3.4	4.9	2.0
West Sumatera	0.4	0.9	1.3	0.5
Riau	1.6	3.8	5.4	2.2
Riau Islands				
Jambi	2.1	4.9	6.9	2.8
South Sumatera				
Bengkulu				
Lampung	0.7	1.6	2.3	0.9
Bangka Belitung Islands	0.4	0.8	1.2	0.5
Jakarta	6.2	14.7	20.8	8.5
West Java	5.8	13.8	19.5	8.0
Central Java	3.3	7.8	11.0	4.5
Yogyakarta				
East Java	3.7	8.8	12.5	5.1
Banten	2.2	5.2	7.4	3.0
Bali	1.3	3.0	4.3	1.7
West Nusa Tenggara	0.3	0.7	1.0	0.4
East Nusa Tenggara	0.4	1.0	1.4	0.6
West Kalimantan	0.5	1.1	1.6	0.6
Central Kalimantan	0.5	1.2	1.7	0.7
South Kalimantan				
East Kalimantan	0.9	2.2	3.1	1.3
North Kalimantan				
North Sulawesi	0.5	1.2	1.7	0.7
Central Sulawesi				
Gorontalo				
South Sulawesi	1.4	3.4	4.8	2.0
Southeast Sulawesi				
West Sulawesi				
Maluku	0.2	0.5	0.7	0.3
North Maluku				
West Papua	0.5	1.1	1.6	0.6
Papua				
INDONESIA	**34.5**	**82.0**	**116.3**	**47.4**
YEARLY ENERGY (TWh)	**48.6**	**115.5**	**163.6**	**66.8**

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Annex

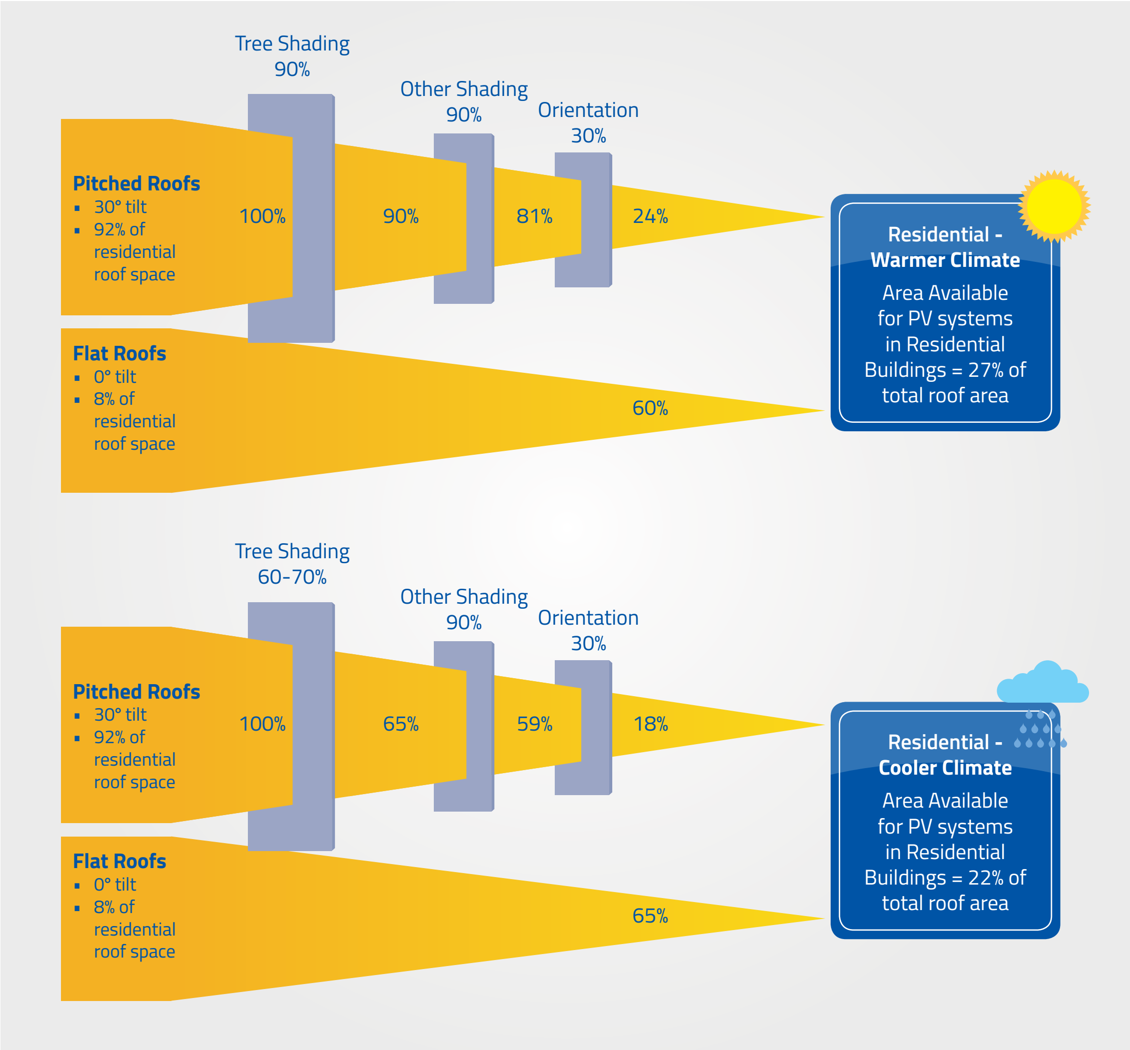
Annex A. 1. Percentage of households in Indonesia classified based on floor space area, per province, 2015

Province	2015					
	Percentage of households in Indonesia classified based on floor space area (m^2), per province					
	<=19	20–49	50–99	100–149	150+	Total
Aceh	1.83	46.23	38.82	9.07	5.05	100
Sumatera Utara	2.53	35.66	56.61	10.7	5.5	100
Sumatera Barat	4.52	31.49	44.35	13.48	6.16	100
Riau	2.34	35.91	42.76	12.5	6.49	100
Kepulauan Riau	5.22	34.42	48.23	7.48	4.65	100
Jambi	1.68	32.63	48.73	12.19	4.77	100
Sumatera Selatan	4.09	41.55	41.24	8.75	4.37	100
Bengkulu	2.85	40.63	43.4	7.83	5.29	100
Lampung	1.22	22.03	56.97	13.87	5.91	100
Kep. Bangka Belitung	1.44	26.31	50.96	16.05	5.24	100
DKI Jakarta	22.08	31.18	22.2	11.74	11.8	100
Jawa Barat	4.63	37.67	43.37	9.68	4.65	100
Jawa Tengah	1.5	14.07	52.79	19.11	12.53	100
DI Yogyakarta	10.55	13.66	43.33	17.97	14.49	100
Jawa Timur	3.07	20.87	52.12	14.87	9.07	100
Banten	4.95	29.64	45.07	12.97	7.37	100
Bali	11.69	29.94	38.42	13.26	9.69	100
Nusa Tenggara Barat	6.12	56.4	29.79	4.92	2.77	100
Nusa Tenggara Timur	5.08	49.46	37.13	5.95	2.38	100
Kalimantan Barat	2.18	38.61	44.88	9.02	5.31	100
Kalimantan Tengah	2.79	41.68	43.26	8.4	3.87	100
Kalimantan Selatan	4.93	36.9	42.41	10.94	4.82	100
Kalimantan Timur	3.07	33.39	41.82	13.05	8.67	100
Kalimantan Utara	3.61	32.59	40.78	14.69	8.33	100
Sulawesi Utara	4.06	44.81	35.47	9.47	6.19	100
Sulawesi Tengah	3.05	38.4	41.8	10.85	5.9	100
Gorontalo	4.24	43.91	34.22	11.7	5.93	100
Sulawesi Selatan	3.19	22.87	48.68	16.33	8.93	100
Sulawesi Tenggara	4.61	29.38	45.96	13.88	6.17	100
Sulawesi Barat	3.63	37.32	43.33	11.39	4.33	100
Maluku	4.26	38.09	43.95	9.68	4.02	100
Maluku Utara	3.42	27.01	50.32	14.93	4.32	100
Papua Barat	4.94	47.59	36.19	7.42	3.86	100
Papua	23.32	55.97	16.34	3.11	1.26	100
INDONESIA	4.58	30.3	45.09	12.65	7.38	100

Annex A. 2. Number of households in Indonesia, per province, 2015

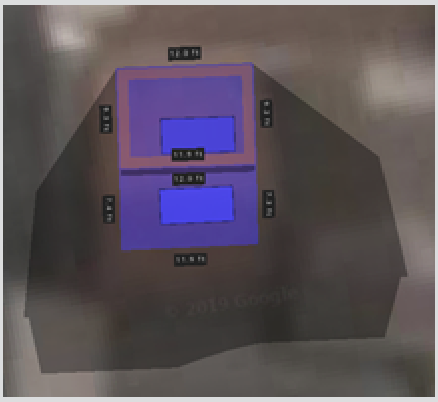
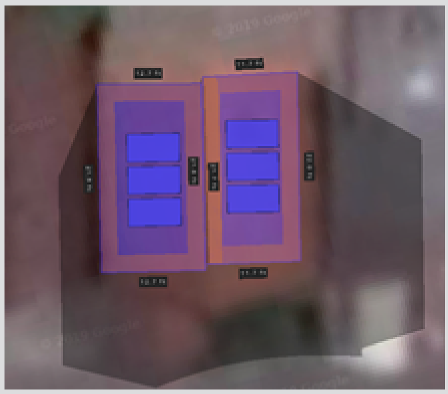
Province	2015					
	Number of households in Indonesia, per province					
	<=19 m^2	20–49 m^2	50–99 m^2	100–149 m^2	150+ m^2	Total
Aceh	21714	548565	460638	107624	59923	1186600
Sumatera Utara	82407	1161517	1843900	348520	179146	3257200
Sumatera Barat	55794	388712	547456	166397	76039	1234400
Riau	35631	546801	651106	190337	98823	1522700
Kepulauan Riau	27201	179362	251326	38978	24231	521100
Jambi	14231	276408	412791	103261	40406	847100
Sumatera Selatan	80127	814006	807932	171421	85612	1959100
Bengkulu	13474	192098	205195	37020	25011	472800
Lampung	25138	453928	1173866	285791	121775	2060500
Kep. Bangka Belitung	5032	91953	178105	56094	18313	349500
DKI Jakarta	587151	829138	590342	312190	313785	2659200
Jawa Barat	574833	4676881	5384558	1201810	577316	12415400
Jawa Tengah	135994	1275628	4786099	1732569	1136007	9066300
DI Yogyakarta	116651	151038	479099	198694	160215	1105700
Jawa Timur	329684	2241208	5597114	1596874	974018	10738900
Banten	145044	868511	1320641	380046	215955	2930200
Bali	128554	329250	422504	145820	106560	1099700
Nusa Tenggara Barat	82252	758016	400377	66124	37228	1344000
Nusa Tenggara Timur	56306	548214	411548	65949	26379	1108400
Kalimantan Barat	24289	430192	500052	100500	59164	1114200
Kalimantan Tengah	18045	269586	279805	54331	25031	646800
Kalimantan Selatan	52869	395715	454804	117320	51689	1072400
Kalimantan Timur	26159	284516	356348	111199	73877	852100
Kalimantan Utara	5216	47092	58927	21227	12036	144500
Sulawesi Utara	25062	276612	218956	58458	38210	617300
Sulawesi Tengah	20660	260121	283153	73497	39966	677400
Gorontalo	11278	116800	91025	31122	15773	266000
Sulawesi Selatan	62415	447474	952472	319512	174724	1956600
Sulawesi Tenggara	25931	165262	258525	78075	34706	562500
Sulawesi Barat	10392	106847	124053	32609	12396	286300
Maluku	14880	133048	153517	33812	14041	349300
Maluku Utara	8211	64851	120818	35846	10372	240100
Papua Barat	9509	91610	69665	14283	7430	192500
Papua	170679	409644	119592	22762	9221	731900
INDONESIA	3003962	19873376	29573944	8296970	4840446	65588700

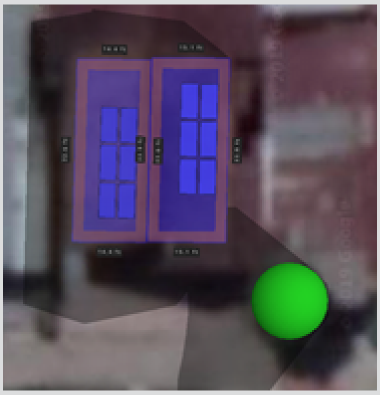
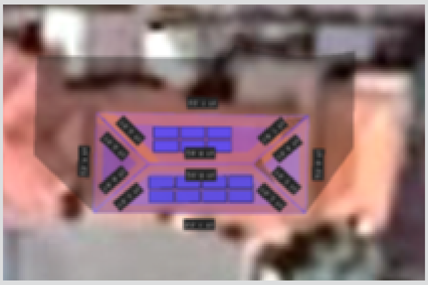
Annex A. 3. PV access factor for residential, warmer and cooler climate (based on Paidipati, et.al., 200813)



Annex A. 4. Helioscope simulation

Design condition	Remarks
Modul	330 Wp Trina
Module spacing	15 cm
Row spacing	30 cm
Set back	1 m
Shading	under 3%
House height	5 – 10 m

Province	Helioscope simulation classified based on floor space area (m²), six samples of province							
	<=19 m²				20–49 m²			
	Rooftop space (m²)	Suitable Space for PV (m²)	Percent-age of Suitable Space for PV (m²)	Potential Capacity (kWp)	Rooftop space (m²)	Suitable Space for PV (m²)	Percent-age of Suitable Space for PV (m²)	Potential Capacity (kWp)
Sumatra (Medan)	18	5	28%	0.66	41	14	34%	2
Kalimantan (Pontianak)	18	5	28%	0.66	44	14	32%	2
Jawa Timur (Surabaya)	18	5	28%	0.66	46	14	30%	1.9
DKI Jakarta	18	5	28%	0.66	49	10	20%	1.3
NTB (Bali)	17	5	29%	0.66	26	9	35%	1.2
NTT (Kupang)	17	5	29%	0.66	48	18	38%	2.6
Average			28%				31%	
Documentation	Example of 18m² Rooftop Space in Jakarta 				Example of 46 m² Rooftop Space in Surabaya 			

Province	Helioscope simulation classified based on floor space area (m2), six samples of province							
	50–99 m^2				100–149 m2			
	Rooftop space (m^2)	Suitable Space for PV (m^2)	Percent-age of Suitable Space for PV (m^2)	Potential Capacity (kWp)	Rooftop space (m^2)	Suitable Space for PV (m^2)	Percent-age of Suitable Space for PV (m^2)	Potential Capacity (kWp)
Sumatra (Medan)	90	30	33%	4	120	46	38%	5.9
Kalimantan (Pontianak)	85	30	35%	4	143	64	45%	7.9
Jawa Timur (Surabaya)	75	25	33%	2.6	125	48	38%	5.9
DKI Jakarta	68	20	29%	2.6	130	52	40%	6.9
NTB (Bali)	86	25	29%	3.3	136	34	25%	4.6
NTT (Kupang)	75	25	33%	3.3	148	41	28%	5.6
Average			32%				36%	
Documentation	Example of 90 m^2 Rooftop Space in Medan 				Example of 136 m^2 Rooftop Space in Bali 			

Province	Rooftop space (m^2)	Suitable Space for PV (m^2)	Percentage of Suitable Space for PV (m^2)	Potential Capacity (kWp)
Sumatra (Medan)	156	55	35%	7.6
Kalimantan (Pontianak)	161	56	35%	7.9
Jawa Timur (Surabaya)	186	70	38%	8.6
DKI Jakarta	214	68	32%	8.2
NTB (Bali)	185	56	30%	7.9
NTT (Kupang)	240	100	42%	14.5
Average			35%	
Documentation	Example of 240 m^2 Rooftop Space in Kupang 			

The total average percentage of suitable space for PV is 33%.

Annex A. 5. List of monocrystalline PV system brands used to estimate power density

Brand	Monocrystalline		
	Capacity (Wp)	Area (m^2)	Power density (W/m^2)
SunPower	370	1.629668	227.0401088
LG	365	1.7272	211.3246874
Panasonic	340	1.67427	203.0735783
Trina Solar	395	1.984	199.0927419
Solaria	360	1.809036	199.0010149
Canadian Solar	420	2.061376	203.7473998
JinkoSolar	400	2.012016	198.8055761
REC	330	1.669975	197.6077486
Yingli Solar	390	1.977038	197.2647971
Seraphim	405	2.034168	199.0985995
Average			203.6056252
Module Efficiency (%)			20.4%

Annex A. 6. List of average photovoltaic power potential data (in kWh/kWp) for each province in Indonesia, generated from NREL Renewable Energy Data Explorer for Southeast Asia

Province	Photovoltaic power potential (kWh/kWp)
Aceh	3.873499997
Sumatera Utara	3.621369987
Sumatera Barat	3.179519999
Riau	3.594499993
Kepulauan Riau	3.554520001
Jambi	3.408409996
Sumatera Selatan	3.454199996
Bengkulu	3.686869996
Lampung	3.589249995
Kepulauan Bangka Belitung	3.620869992
DKI Jakarta	3.824429996
Jawa Barat	3.949990001
Jawa Tengah	4.047939987
DI Yogyakarta	3.518920004
Jawa Timur	4.226319995
Banten	3.774420004
Bali	4.31748003
Nusa Tenggara Barat	4.30953999
Nusa Tenggara Timur	4.353390007
Kalimantan Barat	3.354510007
Kalimantan Tengah	3.165439992
Kalimantan Selatan	3.302670004
Kalimantan Timur	3.403629997
Kalimantan Utara	3.68402
Sulawesi Utara	4.119429994
Sulawesi Tengah	3.87727999
Gorontalo	4.054229975
Sulawesi Selatan	3.852949977
Sulawesi Tenggara	3.790249999
Sulawesi Barat	3.721210001
Maluku	3.92427001
Maluku Utara	3.766849997
Papua Barat	3.987159991
Papua	3.690659997
INDONESIA	3.752941173