DIGITALES ARCHIV

ZBW – Leibniz-Informationszentrum Wirtschaft
ZBW – Leibniz Information Centre for Economics

Budi, Rizki Firmansyah Setya; Sarjiya; Hadi, Sasongko Pramoho

Article

The prospect of rooftop photovoltaic development considering global horizontal irradiation uncertainty and government policies : a case of Java Island, Indonesia

International Journal of Energy Economics and Policy

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Budi, Rizki Firmansyah Setya/Sarjiya et. al. (2022). The prospect of rooftop photovoltaic development considering global horizontal irradiation uncertainty and government policies : a case of Java Island, Indonesia. In: International Journal of Energy Economics and Policy 12 (4), S. 104 - 116.
https://econjournals.com/index.php/ijeep/article/download/13066/6825/30747.
doi:10.32479/ijeep.13066.

This Version is available at:
http://hdl.handle.net/11159/12272

Kontakt/Contact
ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: *rights[at]zbw.eu*
https://www.zbw.eu/

Standard-Nutzungsbedingungen:
Dieses Dokument darf zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden. Sie dürfen dieses Dokument nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, aufführen, vertreiben oder anderweitig nutzen. Sofern für das Dokument eine Open-Content-Lizenz verwendet wurde, so gelten abweichend von diesen Nutzungsbedingungen die in der Lizenz gewährten Nutzungsrechte. Alle auf diesem Vorblatt angegebenen Informationen einschließlich der Rechteinformationen (z.B. Nennung einer Creative Commons Lizenz) wurden automatisch generiert und müssen durch Nutzer:innen vor einer Nachnutzung sorgfältig überprüft werden. Die Lizenzangaben stammen aus Publikationsmetadaten und können Fehler oder Ungenauigkeiten enthalten.

Terms of use:
This document may be saved and copied for your personal and scholarly purposes. You are not to copy it for public or commercial purposes, to exhibit the document in public, to perform, distribute or otherwise use the document in public. If the document is made available under a Creative Commons Licence you may exercise further usage rights as specified in the licence. All information provided on this publication cover sheet, including copyright details (e.g. indication of a Creative Commons license), was automatically generated and must be carefully reviewed by users prior to reuse. The license information is derived from publication metadata and may contain errors or inaccuracies.

https://savearchive.zbw.eu/termsofuse

ZBW Leibniz-Informationszentrum Wirtschaft
Leibniz Information Centre for Economics

Mitglied der Leibniz-Gemeinschaft

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2022, 12(4), 104-116.

The Prospect of Rooftop Photovoltaic Development Considering Global Horizontal Irradiation Uncertainty and Government Policies: A Case of Java Island, Indonesia

Rizki Firmansyah Setya Budi, Sarjiya*, Sasongko Pramono Hadi

Department of Electrical and Information Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia. *Email: sarjiya@ugm.ac.id

Received: 28 February 2022 **Accepted:** 20 May 2022 **DOI:** https://doi.org/10.32479/ijeep.13001

ABSTRACT

Global horizontal irradiation (GHI) uncertainty and government policy significantly affect the economics of rooftop photovoltaic (PV) development. Unfortunately, previous studies neglect these aspects. Therefore, it is necessary to undertake the economic analysis of rooftop PV development by considering its GHI uncertainty and government policies. This research creates a model that can be used to perform analysis and assess rooftop PV development prospects by considering irradiation uncertainty and government policies. The attractiveness of rooftop PV development is indicated by the value of the levelized cost of electricity, net present value, and internal rate of return (IRR). Monte Carlo simulation models irradiation uncertainty. Java Island in Indonesia is used as a case study to show the performance of the proposed model. The research results show that the rooftop PV is not economically viable if built by the utility. Rooftop PV systems are only profitable when built by the private sector and is used for internal usage only. These rooftop PV investments provide an IRR above 14%, which shows that investors with green capital funds and local investors are interested in investing. The emission reductions from a 100 m^2 rooftop PV system vary from 214 to 384 tons of Carbon dioxide per year.

Keywords: Government Policies, Economics of Rooftop Photovoltaic, Global Horizontal Irradiation Uncertainty, Carbon Dioxide Emission Reduction, Monte Carlo Simulation
JEL classifications: C15, D21, D22, E39

1. INTRODUCTION

Improving clean energy usage and reducing Carbon dioxide (CO_2) emissions are sustainable development goals (SDGs) related to the electricity generation energy sector. The electricity and heat sector contributes 40.9% of global CO_2 emissions (Ritchie and Roser, 2020). Therefore, reducing CO_2 emissions from the electricity sector is crucial because of this high share contribution. Furthermore, this reduction can be achieved using energy resources with zero CO_2 emissions, such as renewable energy (RE). Therefore, many countries have set an RE target to improve their clean energy usage and reduce their CO_2 emissions, for example, Indonesia. Indonesia has set its RE targets of 23% by 2025 and 31% by 2050 (President of Republik Indonesia, 2014). Unfortunately, each country has faced problems in achieving its RE targets, including Indonesia. The problems vary widely in these countries, but these problems can be grouped globally into an investment cost requirement problem and an RE economic problem. These problems significantly impact the development of RE in developing countries that have limited financial capacity. Like other developing countries, the government of Indonesia experiences financial problems in achieving its RE targets. An additional 14.3 GW of renewable power capacity is required in Indonesia (PT PLN, 2019), which requires an investment cost of 36.95 billion USD to achieve the RE target in 2025 (MoEMR, 2020). Based on the Minister of Energy and Mineral Resources' regulation (MoEMR, 2017) and the electricity supply business plan (PT PLN, 2019), achieving Indonesia's RE targets is an obligation of Perusahaan Listrik Negara (PLN) as a government utility. However, PLN's limited financial capacity is an obstacle to achieving the RE targets. Therefore, the government must devise solutions to this problem. Sharing the burden of meeting RE target obligations with the private sector is a solution to achieving the target. The financial burden of PLN can be reduced by inviting the private sector to build renewable power plants.

The government must also choose the renewable power plant type which is economically developed to solve the RE economic problem in Indonesia. Choosing the renewable power plant type requires consideration of its energy resources and economic aspects (Sarjiya et al., 2020). Based on resource availability, solar photovoltaic (PV) systems are an excellent option for Indonesia. Indonesia has immense potential for solar energy, reaching 207.8 GW because it is located in the equatorial area (Hidayatno et al., 2020). However, although it has abundant resources, solar PV development encounters a land availability problem in densely populated areas (Schallenberg-Rodríguez, 2013). Therefore, solar PV development in densely populated areas requires a solution which overcomes the land availability problem.

A potential solution to overcome the land availability problem is rooftop PV installations. The decreasing rooftop PV investment cost has caused the levelized cost of electricity (LCOE) of rooftop PV systems to be below the electricity tariff in several countries (IEA, 2015). The investment cost of rooftop PV systems has fallen by 50% since 2010 (Ali et al., 2018). This investment cost reduction makes the installation of rooftop PV systems even more attractive. A rooftop PV system is also the easiest type of energy plant to construct and can be built in a short period (Budi et al., 2020) and can solve the land availability problem. Thus, a rooftop PV system is an RE technology that can potentially be developed to achieve RE targets.

Rooftop PV systems have been implemented in various countries, such as the United States of America (Sueyoshi and Wang, 2017), Sweden (Haegermark et al., 2017), China (Chen et al., 2018), Germany (Mainzer et al., 2014), Palestine, Abu Dhabi (Emziane and Al Ali, 2015), and Singapore (Kosorić et al., 2018). The profit obtained from rooftop PV investment in these countries varies greatly as it depends on global horizontal irradiation (GHI) and the electricity tariff. GHI and electricity tariffs are local aspects that determine rooftop PV economics. GHI also fluctuates based on weather conditions (Fan and Huang, 2018) which significantly affects the rooftop PV system's capacity and energy production (Li et al., 2018). Therefore, neglecting GHI uncertainty impacts the mismatch between the rooftop PV system's planned energy production and its reality, which causes the economic analysis to be less precise.

Unlike the GHI value which depends on the geographic location, the electricity tariff depends on each country's policy and affects the income from the sale of the rooftop PV system's electricity. Neglecting government policy results in the profit and attractiveness of rooftop PV investment not being appropriately known and can lead to incorrect investment decisions. Therefore, a techno-economy analysis of rooftop PV investment is required by considering GHI uncertainty and government policy to obtain a more precise economic analysis on the rooftop PV investment.

Unfortunately, based on the literature reviews that were undertaken, previous studies only used one GHI value without considering its uncertainty to analyze the rooftop PV economics. More specifically, there is a research gap in using the GHI value to analyze Indonesia's rooftop PV economics. The current studies still use an average rooftop PV capacity factor to calculate the rooftop PV energy production and do not analyze the government policies to obtain the prospect of rooftop PV development, such as in the electricity supply business plan 2019-2028 (PT PLN, 2019), RE tariffs and incentives in Indonesia (ADB, 2020), and the LCOE in Indonesia (IESR, 2019). Using the average capacity factor creates inaccurate economic analysis, which leads to errors in policy formulation. Therefore, an economic analysis of rooftop PV investment is required by considering GHI uncertainty and government policy, especially for Indonesia.

This research creates a model that can be used to perform analysis and assess the prospect of rooftop PV development by considering GHI uncertainty and government policies. Based on this analysis and assessment, it can be seen that the actual profit on the investment and the mechanism of the investment can be obtained. This research aims to determine the attractiveness of rooftop PV investment, investment feasibility, and the investment mechanism. The calculation of CO_2 emission reduction resulting from rooftop PV investment is also conducted to identify the role of rooftop PV systems in supporting the SDGs.

Indonesia is a developing country with the fourth largest population globally. It is an archipelagic country with a power system that is not evenly distributed and has not been interconnected (Budi et al., 2019). Its most extensive electricity system is the Java-Bali system, which supplies the load on the Java and Bali islands. Of the total generating capacity in Indonesia, 74% comes from the Java-Bali system (Budi et al., 2019). Considering its size, the successful implementation of rooftop PV systems in the Java-Bali system greatly determines RE target achievement in Indonesia. Therefore, Java Island is used as a case study to demonstrate the performance of the proposed model. The problems achieving the RE targets in Indonesia can be solved using this proposed model. It is hoped that rooftop PV systems can be a potential component in achieving these targets and supporting the SDGs.

1.1. Literature Review

Solving the research problems requires the economic analysis of rooftop PV investment by considering GHI uncertainty and government policy, especially for Indonesia. Therefore, a literature review on the economic analysis of rooftop PV systems, government policy related to rooftop PV development, and the GHI uncertainty model is conducted in this research. Based on the literature review, the proposed model can be developed to solve the research problems.

Several studies analyzed the economics of rooftop PV investment based on each country's government policy and conditions. For example, Tomar and Tiwari conducted a techno-economic evaluation of rooftop PV systems for households in New Delhi, India, by considering the time-of-day tariff and feed-in tariff regulation impacts (Tomar and Tiwari, 2017). The regulations significantly impacted the attractiveness of rooftop PV investment. The research used LCOE to show the attractiveness of rooftop PV investment. Omar and Mahmoud analyzed the performance of existing rooftop PV systems by considering the feed-in tariff and net metering regulation (Omar and Mahmoud, 2018). A performance analysis was conducted because the uncertainty of solar irradiation was neglected when the rooftop PV systems were built. The internal rate of return (IRR) and Net present value (NPV) were used to show the economics of rooftop PV systems. This research showed that neglecting solar irradiation uncertainty could lead to planning errors and rooftop PV investment failures.

In addition, other studies examined the requirement for a new policy to support rooftop PV development in some countries. For example, Korsavi et al., analyzed the economic performance of existing rooftop PV installations in Iran (Korsavi et al., 2018). The economics of rooftop PV systems was shown by the payback period, NPV, ROI, and LCOE. Based on the analysis, it was found that rooftop PV systems are not economically feasible in Iran because of subsidized tariff regulations. Therefore, rooftop PV development in Iran requires a new policy that could make the installation of rooftop PV systems more economically viable. Furthermore, similar to Korsavi et al., 2018; Bódis et al., 2019 and Duman and Güler, 2020 raised policy issues on developing a rooftop PV system, i.e., the current policies in Turkey and some European Union countries were not enough to support rooftop PV development. Therefore, these countries require a supporting policy to develop rooftop PV systems.

The previous studies on rooftop PV economics and government policy impacts on rooftop PV development showed that several parameters were used to represent the attractiveness of rooftop PV investment and government policy significantly affected rooftop PV economics. The parameters are IRR, LCOE, NPV, payback period, and ROI. Unfortunately, these previous studies only used one GHI value without considering its uncertainty in conducting economic analysis. Therefore, these previous studies' methods cannot solve the research problems in this research.

A method that can represent GHI uncertainty is needed to analyze its impact on the economic analysis of rooftop PV systems. The two-point method, Taguchi's orthogonal array testing method, and Monte Carlo simulation were used to model uncertainty. The three models depend on the number of iterations to represent GHI uncertainty (Beltrán et al., 2020). The Monte Carlo simulation produced the closest results to the uncertainty process with many iterations (Stepanov and Amosov, 2007). Several studies used it to model GHI uncertainty, such as Alfi et al., 2017; Patelli et al., 2017; and Yin and Chen, 2017. Alfi et al., 2017 used the Monte Carlo simulation to model solar irradiance uncertainty. The Monte Carlo simulation is also used to model other types of uncertainty related to solar PV, such as solar PV operation patterns (Patelli et al., 2017) and weather and meteorological conditions (Yin and Chen, 2017). However, the Monte Carlo is only used to represent uncertainty in these studies. Furthermore, no economic analysis was undertaken in these studies to show the profit and attractiveness of rooftop PV investment. Therefore, the model in these studies cannot solve the research problems in this research.

Solving this research problem requires a model that can be used to conduct economic analysis by considering GHI uncertainty. Therefore, this research uses Monte Carlo simulation to represent GHI uncertainty. The economic analysis and the attractiveness of rooftop PV investment are indicated by the value of LCOE, NPV, and IRR. Finally, government policies are used to determine the electricity tariff for rooftop PV systems.

1.2. Novel Contributions of the Research

Based on the introduction and literature reviews, an overview of this research is shown in Figure 1. The first novel contribution of this research is a model that can be used to analyze and assess the prospect of rooftop PV development by considering GHI uncertainty and government policies. The proposed model is developed to fill the research gap. To the best of the authors' knowledge, this is the first study to analyze investment attractiveness, investment feasibility, and the investment mechanism of the rooftop PV systems by considering Indonesia's GHI uncertainty and government policies. Therefore, this research also contributes to the prospective analysis of rooftop PV investment attractiveness, investment feasibility, and the investment mechanism in Java to support SDGs and the RE target.

It is expected that the model proposed and the case study implementation can be used to analyze and assess rooftop PV development prospects more precisely. The remainder of this paper is organized as follows: Section 2 explains the development of the framework, Section 3 explains the research method, Section 4 explains the case study, data, and assumptions used, Section 5 explains the results and discussion, and the final section presents the conclusions of this research.

2. DEVELOPING THE FRAMEWORK OF THE PROPOSED MODEL

Using rooftop PV systems as an alternative to achieving SDGs and RE targets requires economic and financial analysis to understand the attractiveness of rooftop PV investment. Sharing the financial burden with the private sector is crucial to reducing the government utility's financial burden on developing RE power plants. However, the private sector's involvement is highly dependent on this attractiveness. Furthermore, GHI uncertainty and government policies significantly impact this attractiveness. Therefore, this research proposes a model that can be used to perform the analysis and assess the prospect of rooftop PV investment by considering GHI uncertainty and government policies.

Before creating the proposed model, a global framework of the proposed model is constructed, as shown in Figure 2. The global framework describes the aspects required to create the proposed model, such as Monte Carlo simulation, capacity decisions, energy production calculations, government policies, economic and financial analysis, and the potency of CO_2 emission reduction using

Figure 1: An overview of this research

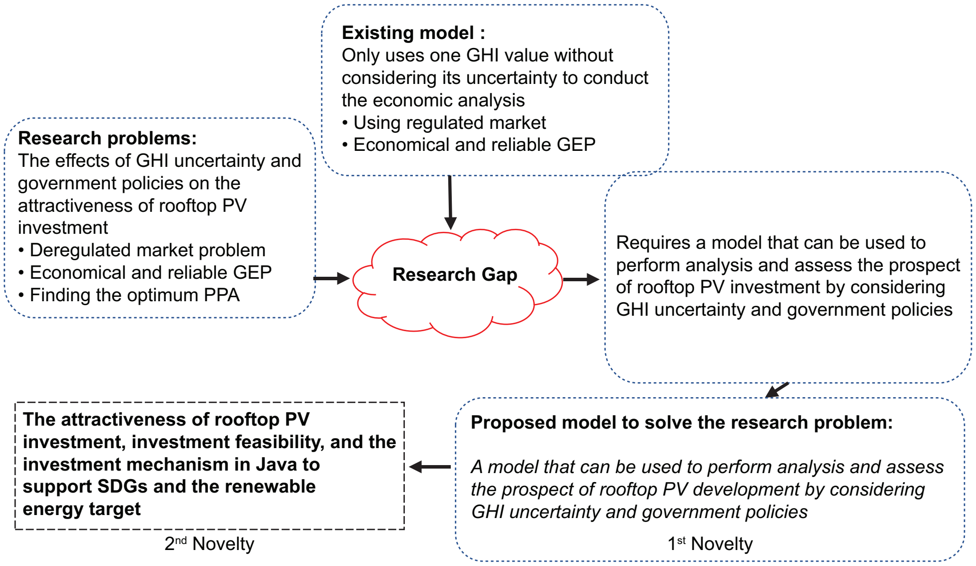
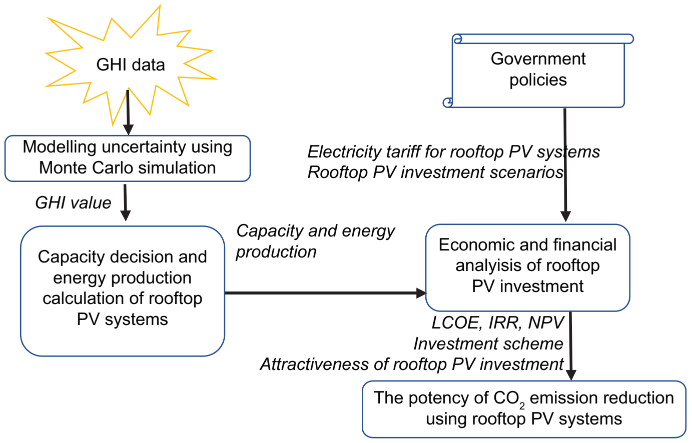


Figure 2: The global framework of the proposed model



rooftop PV systems. Each aspect is described in the following sub-section.

2.1. Modeling GHI Uncertainty

GHI uncertainty modeling is carried out using GHI historical data on Java Island. Based on this data, the GHI uncertainty curve can be viewed each month. Based on the uncertainty curve, a cumulative distribution function (CDF) is calculated. The CDF begins by sorting the data from the smallest to the largest. After this, the CDF is calculated using equation (1). The CDF of G (G € g) is represented by $cdf(G_n)$. i represents the GHI data index. g_i represents the lowest GHI value, and g_n represents the GHI. The CDF is used in the Monte Carlo simulation to generate the random value of GHI and it is calculated for each period. This research uses historical data at 10-min periods so the number of CDF curves formed is 1,728 curves (24 [h in a day] × 6 [1 h consisting of 6 time slices/10]. min) × 12 [months in a year]).

$$cdf(G_n) = \sum_{i=1}^{n} \mathrm{Prob}(g_i) \tag{1}$$

After the CDF is obtained, the Monte Carlo simulation is used to handle GHI uncertainty. The Monte Carlo generates a random value based on statistical parameters from the available historical data (Nuryanti, 2015). The random value generation is performed multiple times to represent the uncertainty more accurately. The Monte Carlo starts the random value generation by generating a random CDF using equation (2). p refers to a random value between 0 and 1. Based on the CDF curve, the random GHI that has the same CDF value as the random CDF is calculated using equation (3). The $\mathrm{GHI}_{(\mathrm{random\ CDF})}$ refers to the GHI value which has a CDF value similar to the random CDF. The random value generation process is carried out for a pre-specified number of iterations so that the GHI generated by the Monte Carlo simulation has a similar distribution function to the historical data.

$$Random\ cdf = random\ (p) \tag{2}$$

$$Random\ GHI = GHI_{(random\ cdf)} \tag{3}$$

2.2. Capacity Decision and Energy Production of Rooftop PV Systems

The GHI value determines the optimal rooftop PV capacity and energy production. The optimal capacity is estimated using equation (4). GHI_{avg} represents the average GHI annually (kWyr/m^2) from the historical data. A represents the roof area on which the rooftop PV system is installed. eff represents the rooftop PV system's efficiency, and CF represents the rooftop PV system's capacity factor. The electrical energy production of the rooftop PV system is calculated using equation (5).

$$RooftopPVsize(kW) = \frac{\mathrm{GHI}_{avg} \times A \times eff}{CF} \tag{4}$$

$$Energy\ Production = GHI \times A \times eff \tag{5}$$

2.3. Government Policies

The Indonesian government has issued several policies related to RE, especially rooftop PV systems. Based on the policies in (PT PLN, 2019) and (MoEMR, 2017), it can be seen that achieving RE targets is an obligation of PLN as a government utility.

However, the financial capacity of PLN, which is limited, becomes an obstacle to achieving RE targets. Therefore, the Indonesian government had introduced a new policy that allows the private sector to build rooftop PV systems. As a result, rooftop PV systems can meet their electricity demand and transfer any energy surplus to PLN's grid (MoEMR, 2019b). This policy aims to reduce PLN's financial burden and accelerate renewable power plant growth to achieve RE targets.

The regulation (MoEMR, 2019b) describes all aspects of rooftop PV systems built by the private sector, such as the operation schemes and rooftop PV pricing. The operation schemes are shown in Figure 3. Rooftop PV systems have two operation schemes, i.e., rooftop PV systems for internal use (Scheme 1) and rooftop PV systems for internal use and excess power is transferred to PLN's grid (Scheme 2). In Scheme 1, the power generated by rooftop PV systems is used to reduce the private sector's demand supplied by PLN. In this scheme, the profit of rooftop investment is calculated from the private sector's savings on their electricity bills, whereas in Scheme 2, the savings are obtained from the internal use and excess power is transferred to PLN's grid. However, the saving calculation differs between the internal use and the power transferred to PLN. For internal use, the power generated by rooftop PV systems is valued at 100% for reducing demand. On the other hand, the power transferred to PLN is only valued at 65% of the transferred power's real value (MoEMR, 2019b).

By considering the policies related to rooftop PV investment, three scenarios of rooftop investment are developed, namely Scenario 1: PLN builds the rooftop PV systems, Scenario 2: the rooftop PV systems are built by the private sector for internal use, and Scenario 3: the rooftop PV systems are built by the private sector for internal use and excess power is transferred to PLN. The difference between the three schemes is in the rooftop PV system's pricing. In Scenario 1, when the rooftop PV system is built by the government utility, the rooftop PV system's pricing is the electricity generation cost (Gencost) from the power system installed by the rooftop PV system. This pricing is because the utility tries to minimize the Gencost of each power system as much as possible. Therefore, if the rooftop PV tariff is higher than the Gencost, it creates a higher Gencost than before. On the other hand, when the rooftop PV system is built by the private sector, its pricing is set as the same as the basic electricity tariff (BET) for internal use and 65% of the BET for the energy transferred to PLN.

2.4. Financial-economic Aspect

The financial-economic parameters are used to determine the rooftop PV investment's attractiveness based on the funding scheme used, which determines the level of equity and debt involved in obtaining the investment costs. In this research, the funding scheme used is 30% equity and 70% debt. Based on this composition, the value of the weighted average cost of capital (WACC) is obtained. The WACC is calculated using equation (6). *Ep* refers to the equity portion (30%), *CoE* refers to the cost of equity (%), *Dp* refers to the debt portion (70%), and *CoD* refers to the cost of debt (%).

$$WACC = (Ep \times CoE) + (Dp \times CoD \times [1\text{-}tax]) \tag{6}$$

The WACC is used as a discount rate when calculating the LCOE of rooftop PV systems. The LCOE calculation is shown in equation (7). $Investment_t$ refers to the investment cost in the t^{th} year. Operation and maintenance (O&M) $O\&M_t$ refers to the summation of fixed and variable O&M costs in the t^{th} year. $Fuel_t$ refers to the fuel cost in the t^{th} year. r refers to the WACC.

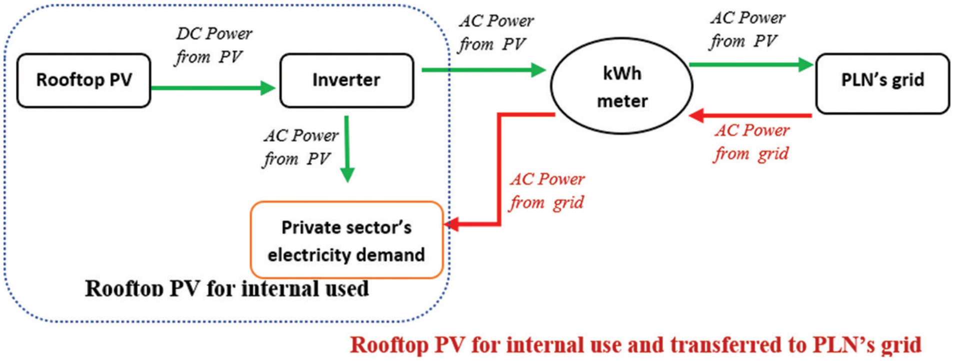
$$LCOE = \frac{\sum_{t=0}^{n} \frac{Investment_t + O\&M_t + Fuel_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{Energyproduction_t}{(1+r)^t}} \tag{7}$$

With the electricity tariff for rooftop PV systems and the LCOE calculation results, the income, NPV, and IRR can be calculated. The rooftop PV system's income is calculated using equation (8), and the NPV is calculated using equation (9). The IRR is the discount rate when generating the NPV value = 0. Therefore, the NPV and IRR show the rooftop PV investment's attractiveness, making a profit if the NPV > 0. However, the IRR is required to determine whether the rate of return can attract investors or not. Therefore, each investor expects a different IRR, as shown in Table 1.

$$Rooftop\ PV\ income = Electricity\ tariff \times Energy\ production \tag{8}$$

$$NPV = (Electricitytariff - LCOE)x\sum_{t=0}^{n} \frac{Energy_t}{(1+r)^t} \tag{9}$$

Figure 3: The operation schemes of rooftop PV systems (MoEMR, 2019b)



2.5. The Potency of CO_2 Emission Reduction Using Rooftop PV Systems

The potency of CO_2 emission reduction using rooftop PV systems is used to calculate the emission reduction in Java. The emission reduction is calculated using equation (10). The energy mix in Java is shown in Figure 4. Combining this energy mix with the emission factor in Table 2 shows that Java's emission factor is 0.935 kTon/GWh.

$$\text{Emission reduction} = \text{Energy produced by rooftop PV systems} \times \text{emission factor in Java} \quad (10)$$

3. RESEARCH METHOD

This research is conducted using the following method, as shown in Figure 5. This research method is based on the global framework. The first step is to collect GHI data from several representative points in cities on Java Island. The period of the GHI data collection depends on the availability of data from each of these regions. Based on historical GHI data, the GHI*avg* can be obtained, which is used to calculate the appropriate capacity of the rooftop PV systems for each city. Rooftop PV capacity is calculated using equation (4). The next step is to calculate the CDF of GHI using equation (1). Finally, the CDF is used in the random value generation in the Monte Carlo simulation.

After the GHI's CDF is obtained, the Monte Carlo simulation is initiated. The first step of the Monte Carlo simulation is to generate a random value of GHI's CDF using equation (2). Next, the random CDF is used to obtain the GHI's random value, using equation (3). After the random GHI is obtained, the rooftop PV system's energy production is calculated using equation (5). By using the energy production, the LCOE of the rooftop PV system is calculated using equation (7). Finally, the WACC obtained from equation (6) is used as the discount rate to calculate the LCOE.

Based on the LCOE, the rooftop PV system owner can be known. If the LCOE is less than the power system Gencost, the rooftop PV system can be built by either the utility or private sectors. The power system Gencost is used as the rooftop PV pricing if the owner is the utility. BET is used as the rooftop PV system's pricing if the rooftop PV system is built by the private sector. On the other hand, if the LCOE is larger than the power system Gencost, the rooftop PV system is only feasible if built by the private sector. When the private sector's rooftop PV system is built, the private sector can choose the rooftop PV operation scheme. The rooftop PV can be used for internal use only or for internal use and the surplus energy can be transferred to the utility's grid. The rooftop PV pricing uses BET if the rooftop PV system is used for internal use and uses 65% of the BET for the energy surplus transferred to the grid.

After setting the rooftop PV pricing, the next step calculates the rooftop PV income, NPV, and IRR using equations (8) and (9). Based on the NPV and IRR, the attractiveness of the rooftop PV investment can be obtained. If the NPV is more than zero, then the investment is profitable. However, the IRR needs to be considered to determine whether the private sector will invest in rooftop PV systems. As shown in Table 1, each investor type has a different standard in relation to what constitutes an attractive IRR. The IRR determines whether it is feasible to build a rooftop PV system or not. If it is feasible to build a rooftop PV system, then the emission reduction is calculated using equation (10).

Table 1: Expected IRR based on investor type (USAID-ICED-LPEM FEB UI, 2016)

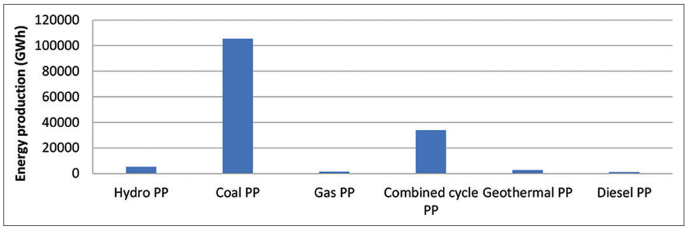
Investor type	Expected IRR
Green capital funds	12-16%
Local investors	14-17%
Strategic investors	15-18%
International finance corporations	17-20%
Equity funds	18-20%
Institutional investors	20-24%

Table 2: CO_2 emission factor (Budi et al., 2011)

PP	CO_2 Emission Factor (kTon/GWh)
Coal PP	1.14
Gas PP	1.002
Combine Cycle PP	0.505
Diesel PP	0.786
Geothermal PP	0.2

PP: Power Plant

Figure 4: The energy mix in the Java-Bali system (PT. PLN, 2020)



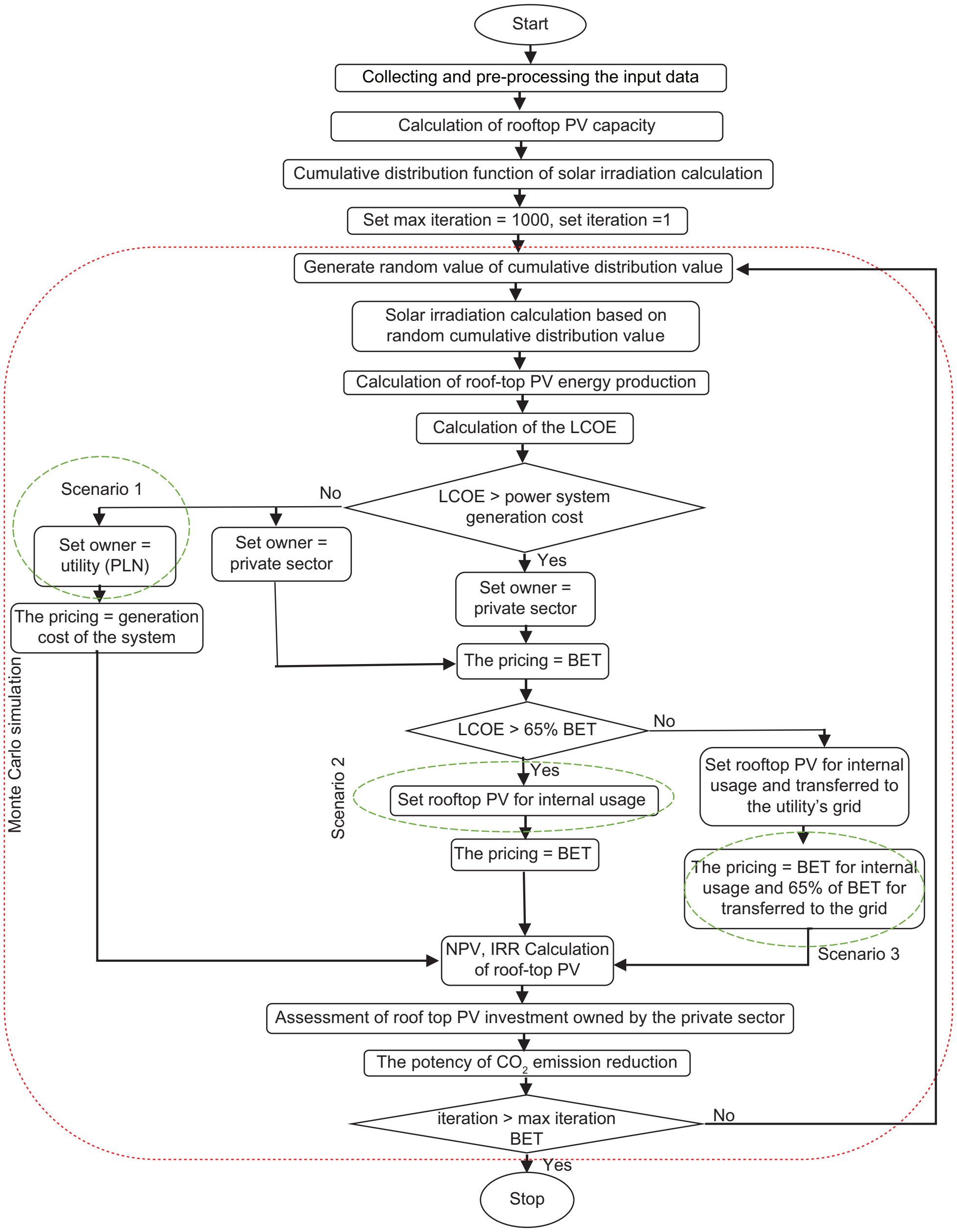
All calculations in the Monte Carlo simulation are repeated until the predetermined iteration limits are reached. Each iteration produces a different GHI, LCOE, NPV, IRR, and emission reduction depending on the GHI's random value. In other words, the result of this Monte Carlo simulation is data that has a distribution function, not a single value. Based on this data profile, it can be seen that GHI uncertainty affects the LCOE, NPV, and IRR values. With these values, an assessment of rooftop PV investment can be carried out for all scenarios.

This proposed method can be used not only to address the problems on Java Island but for problems in other regions as well. This method is flexible as the input GHI and rooftop PV pricing data can be changed based on the characteristics of solar irradiation and government policies in the region. However, despite its flexibility, this proposed model has a limitation, as it uses data from several locations to represent the GHI conditions of a city.

4. CASE STUDY

Java Island is the most populous island in Indonesia. With an area of 128,000 km^2 (about 6.7% of Indonesia's land area), the island has a population of 160 million (60% of Indonesia's population). Comparing the area and total population, the island of Java has a population density of 1.247 inhabitants/km^2. This density means

Figure 5: Research method



there is a shortage of land, so a rooftop PV system which does not require land is the best renewable power plant for the island.

Rooftop PV investment prospect analysis and assessment in Java Island uses GHI data from 12 automatic weather systems (AWSs) scattered in Java's urban and industrial cities. Also, in selecting the AWS locations, the average GHI value of the city can be considered. Table 3 contains annotations of the 12 AWS datasets along with the range of GHI data availability. The 12 AWS locations are shown in Figure 6. Figure 6 is modified from solargis map (World Bank Group, 2021).

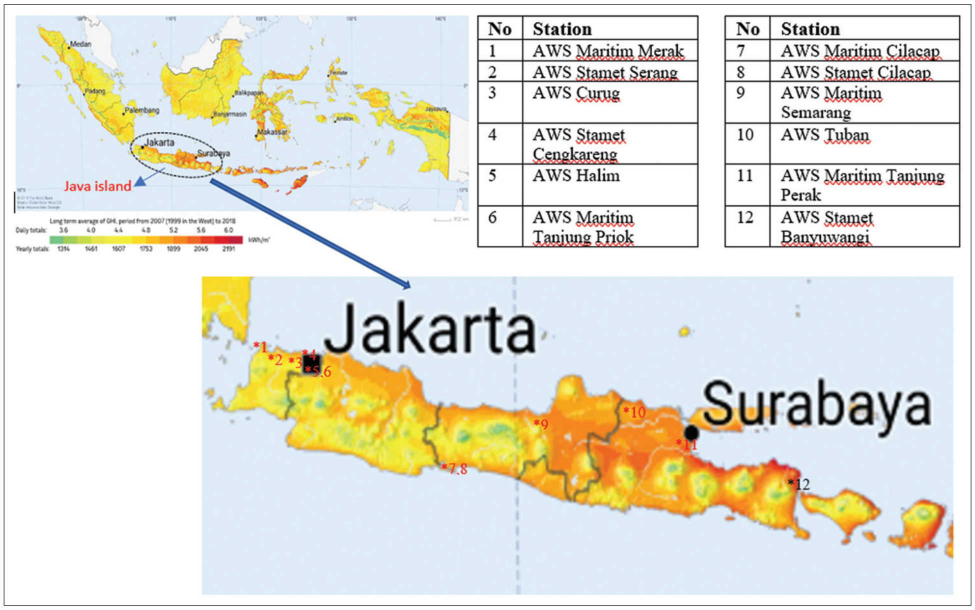
The GHI data from the 12 AWSs have a recording period of every 10 minutes. Then, the GHI data are grouped by month. Figures 7 and 8 show the GHI data from four AWSs on Java. In addition to the GHI data, the calculation of LCOE, NPV, and IRR requires electricity rates for rooftop PV pricing and techno-economic-financial parameter data from the rooftop PV systems. There are two types of electricity rates for rooftop PV pricing: the BET of 9.66 cents USD/kWh and power system Gencost, as shown in Table 4. The techno-economic parameters are shown in Table 5 and the financial parameters are shown in Table 6.

5. RESULTS AND DISCUSSION

The proposed model was built and solved with MATLAB R2014A on a 3.5 GHz laptop with 8 GB RAM. According to the capacity calculations, the capacity for a 100 m^2 area on each AWS is obtained, as shown in Figure 9. The rooftop PV capacity for each AWS represents the rooftop capacity for each city and region, as shown in Table 7.

The capacity varies significantly for each region. For example, it ranges from 17–19 kW in the Banten region. Based on the data from AWS Halim and Tanjung Priok, with an area of 100 m^2,

Figure 6: The twelve AWS locations modified from solargis



No	Station	No	Station
1	AWS Maritim Merak	7	AWS Maritim Cilacap
2	AWS Stamet Serang	8	AWS Stamet Cilacap
3	AWS Curug	9	AWS Maritim Semarang
4	AWS Stamet Cengkareng	10	AWS Tuban
5	AWS Halim	11	AWS Maritim Tanjung Perak
6	AWS Maritim Tanjung Priok	12	AWS Stamet Banyuwangi

Figure 7: GHI data in AWS Maritim Merak from June 1, 2015 to August 31, 2018

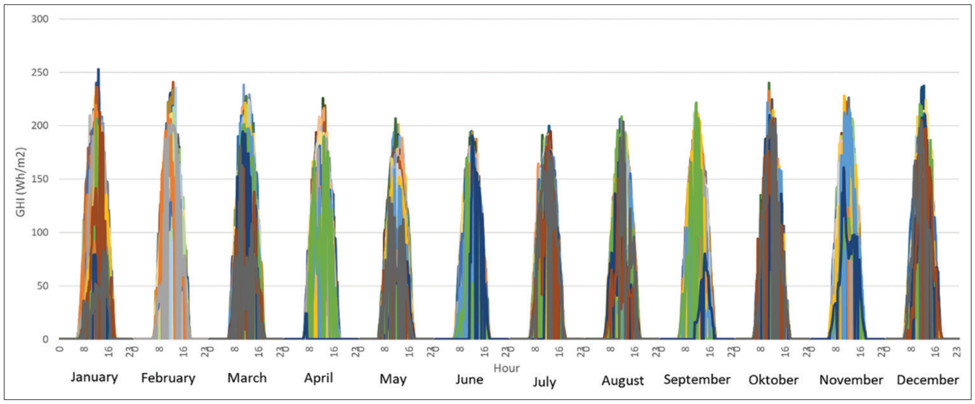


Table 3: Detailed descriptions of the twelve AWS

S. No.	AWS	City		GHI data availability
1.	AWS Maritim Merak	Cilegon	Industrial city	01/06/2015–31/08/2018
2.	AWS Stamet Serang	Serang	Industrial city	01/06/2015–31/08/2018
3.	AWS Curug	Tangerang district	Densely populated city	01/06/2015–31/08/2018
4.	AWS Stamet Cengkareng	Tangerang	Industrial city	01/07/2015–31/08/2018
5.	AWS Halim	Jakarta	The capital city of Indonesia	01/07/2015–31/08/2018
6.	AWS Maritim Tanjung Priok		Densely populated city Industrial city Business center	01/05/2015–31/08/2018
7.	AWS Maritim Cilacap	Cilacap	Industrial city	01/03/2017–31/08/2018
8.	AWS Stamet Cilacap			01/06/2015–31/08/2018
9.	AWS Maritim Semarang	Semarang	Industrial city Densely populated city	01/09/2016–31/08/2018
10.	AWS Tuban	Tuban	Industrial city	01/06/2016–31/08/2018
11.	AWS Maritim Tanjung Perak	Surabaya	Industrial city Densely populated city	01/05/2016–31/08/2018
12.	AWS Stamet Banyuwangi	Banyuwangi	Industrial city Tourist destination	01/05/2016–31/08/2018

AWS: Automatic weather system

the optimal rooftop PV capacity in Jakarta is 15 kW. The wrong choice of a rooftop PV capacity decreases its capacity factor which causes the LCOE to increase, leading to a decline in the rooftop PV system's profitability. Using these results, the government or private sector can determine the optimal PV rooftop capacity and the required roof area for each city.

Figure 8: GHI in AWS Stamet Banyuwangi from May 1, 2016 to August 31, 2018

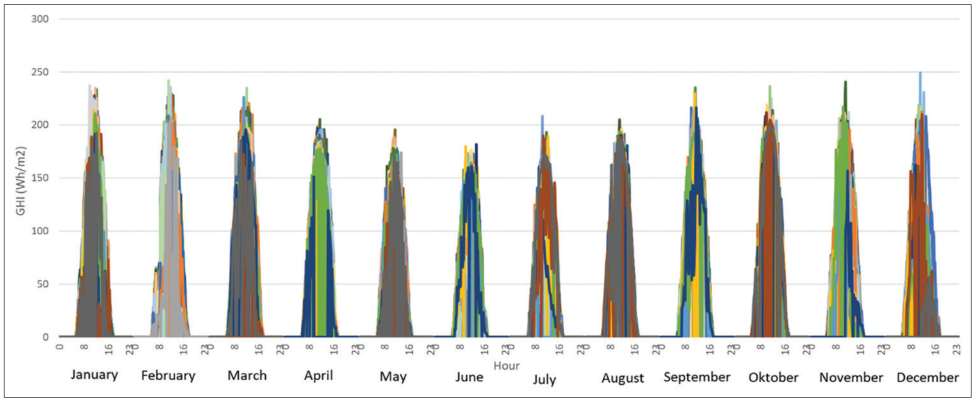


Figure 9: Rooftop PV capacity based on the weather stations' GHI data

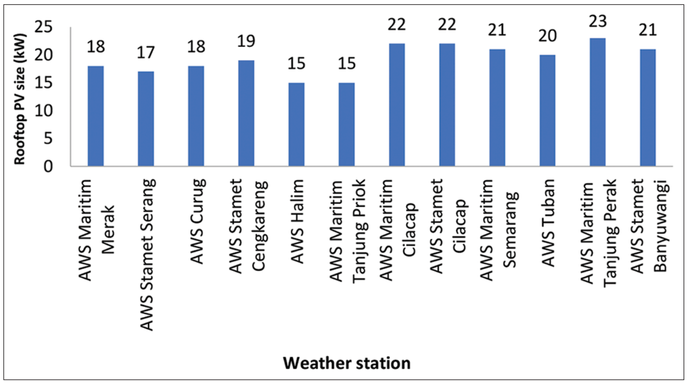


Figure 10: Annual GHI from each AWS

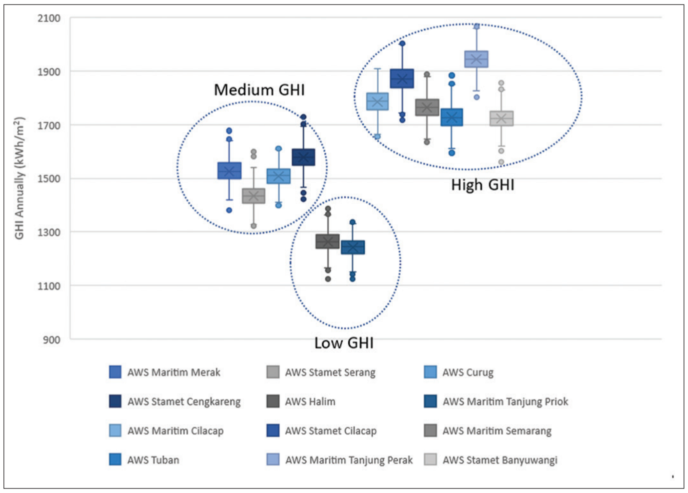


Figure 11: Levelized total energy production of rooftop PV systems

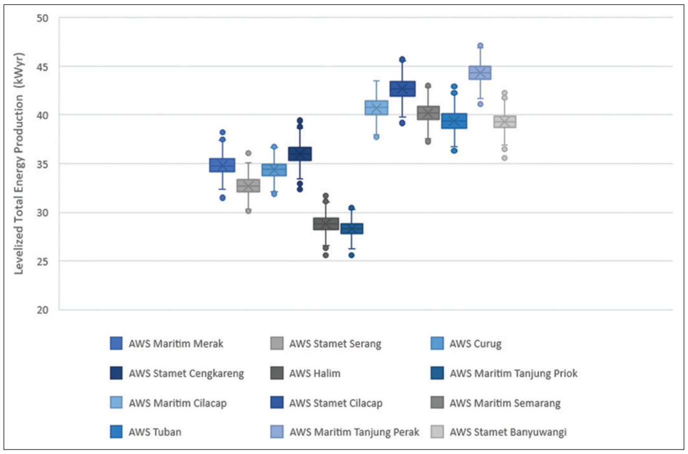


Table 4: Regional electricity generation cost in Java Island (MoEMR, 2019a)

Region	Electricity generation cost (cents USD/kWh)
Jakarta	6.91
Banten	6.91
West Java	6.91
Central Java	6.91
East Java	6.94

Based on the GHI Monte Carlo simulation results, each AWS's annual GHI value can be obtained, as shown in Figure 10. Figure 10 groups the selected cities in Java into low GHI, medium GHI, and high GHI. The only city with a low GHI is Jakarta. Cities with medium GHI include Cilegon, Serang, Tangerang, and Tangerang districts. The cities with a high GHI are Cilacap, Semarang, Tuban, Surabaya, and Banyuwangi. Jakarta has the lowest GHI, while Surabaya has the highest. These GHI values determine the attractiveness of rooftop PV investment.

The GHI details based on the Monte Carlo simulation results and their comparison with the Solargis data are shown in Table 8. The Solargis data differ by <0.7% compared to the average GHI from the Monte Carlo simulation results. This similarity shows the robustness of the Monte Carlo simulation modeling in this research. Based on these results, the average GHI, minimum GHI, and maximum GHI values can be seen. These values show that GHI data variation results in the rooftop PV economic calculation approach with the average GHI being less precise. Therefore, it is necessary to calculate rooftop PV economics considering the uncertainty of GHI.

GHI uncertainty affects the electricity production and LCOE of rooftop PV systems. The total electricity produced during its lifetime is shown in Figure 11. The levelized total energy production has the same data distribution profile as the GHI data distribution profile. This similarity is because GHI is the only input variable that has an element of uncertainty. This total levelized energy production uncertainty has a significant impact on the LCOE. The LCOE data for each AWS is obtained, as shown in Figure 12. The LCOE values vary depending on GHI uncertainty.

Table 5: Techno-economic parameter (Sarjiya et al., 2020)

Area (m^2)	Efficiency (%)	Investment cost ($/kW)	Fixed O&M cost ($/kW)	Variable O&M cost ($/kWyr)	Lifetime (years)
100	20	1100	24.7	3.5	25

Table 6: Financial parameter (Bieri et al., 2017)

Equity portion	Cost of Equity	Debt portion	Cost of Debt	Tax
30%	16%	70%	10.5%	25%

The average LCOE value in the cities ranged from 7.9 cents USD/kWh to 8.5 cents USD/kWh.

The LCOE variations for each city are higher than the power system Gencost in each region but lower than the basic electricity tariff. Therefore, rooftop PV investment results in a loss when the power system Gencost is used as the pricing cost. In contrast, if it is priced according to the BET, rooftop PV investment generates a profit. In other words, on Java Island, it is feasible for the private sector to invest and build rooftop PV systems, but not the utility. Therefore, a new policy that allows the utility to produce electrical energy with a Gencost which is as high as the BET is required for the utility to profit from rooftop PV investment. Without this policy, rooftop PV development depends on the private sector. This dependency creates a new problem for the sustainability of rooftop PV development because the government cannot regulate private sector investment. However, if the government forces PLN as the government utility to build rooftop PV systems without the new policy in place, this will become a new financial burden for the utility because of rooftop PV investment will result in a loss.

In contrast, the private sector can choose its rooftop PV operation scheme. However, it is only feasible for the private sector to operate the rooftop PV system for internal use because 65% of the BET is lower than the rooftop PV system's LCOE. Therefore, the rooftop PV investment generates a profit if it is built by the private sector for internal use only. This condition creates a barrier for rooftop PV acceleration development because the private sector cannot export rooftop PV energy production to the grid. In addition, the current policy regulates that rooftop PV energy production can only be used as net billing, where the private sector secures a profit from its electricity billing saving which is limited by its energy demand. Therefore, although the energy transfer pricing is profitable, the private sector cannot use the rooftop PV system to exceed the private sector energy demand.

LCOE and rooftop PV pricing can be used to determine whether the investment generates a profit or loss. However, it cannot show the level of profit. This research uses NPV and IRR to show the level of profit and attractiveness of rooftop PV investment. The NPV of rooftop PV investment for the internal use scenario (Scenario 2) in each city is shown in Figure 13. The NPV in Scenario 1 and Scenario 3 is not calculated because, based on LCOE analysis, it is clear that it is not profitable. The NPV in each city varies from 1500 to 8600 USD. This NPV has a positive linearity relationship with the energy produced by the rooftop PV system. However, the rooftop PV system cannot produce more energy than that required for internal use because of the pricing differences.

Figure 12: LCOE of rooftop PV systems

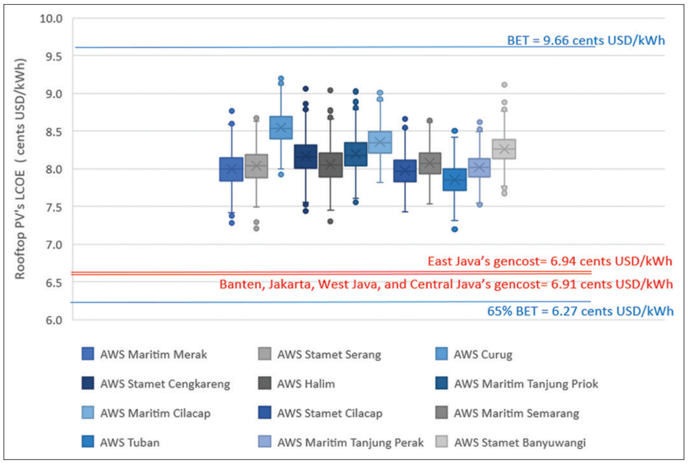
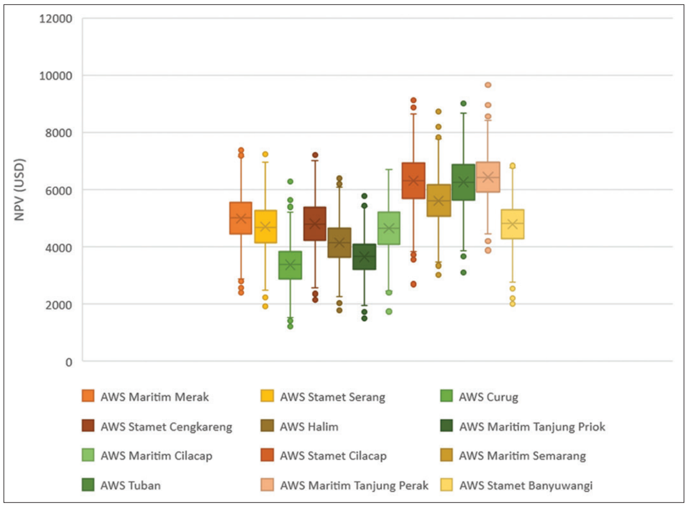


Figure 13: NPV of the rooftop PV system for internal use



The NPV value for each city shows the profit value. However, the NPV value does not show the attractiveness of the investment or the type of investor who may be interested. The IRR value of the investment is needed to assess the investment attractiveness and investor interest. The IRR value of rooftop PV system investment for each city is shown in Figure 14. In the private sector's rooftop PV system for internal use scenario (Scenario 2), all rooftop PV system investments have an IRR above 14%. This value can attract the green capital funds (GCF) and local investors (LI). A strategic investor (SI) would be interested in investing in all cities except for the Tangerang district. The IRR values for the Tangerang district have a probability of 25% to below 15%. An IRR below 15% is not attractive to a SI. Therefore, a SI would consider investment in the Tangerang district to be risky and needs to be reconsidered. However, International finance corporations are interested in investing in Tangerang or Cilacap. This also needs to be considered in other cities because it is likely that the IRR will be below 17% and therefore high risk. Investors of types Equity funds and Institutional investors would not be interested in

Table 7: Rooftop PV capacity in each city and region on Java Island

S. No.	Station	City	Region	Rooftop PV size (kW)
1.	AWS Maritim Merak	Cilegon	Banten	18
2.	AWS Stamet Serang	Serang	Banten	17
3.	AWS Curug	Tangerang District	Banten	18
4.	AWS Stamet Cengkareng	Tangerang	Banten	19
5.	AWS Halim	Jakarta	Jakarta	15
6.	AWS Maritim Tanjung Priok	Jakarta	Jakarta	15
7.	AWS Maritim Cilacap	Cilacap	Central Java	22
8.	AWS Stamet Cilacap	Cilacap	Central Java	22
9.	AWS Maritim Semarang	Semarang	Central Java	21
10.	AWS Tuban	Tuban	East Java	20
11.	AWS Maritim Tanjung Perak	Surabaya	East Java	23
12.	AWS Stamet Banyuwangi	Banyuwangi	East Java	21

PV: Photovoltaic, AWS: Automatic weather system

Table 8: Comparison of Solargis data with the results of the Monte Carlo simulation

Station	Solargis data (kWh/m²)	Monte Carlo simulation results (kWh/m²)			The error produced by Monte Carlo Simulation (%)
		Gencost Scenario			
		Min. GHI	Avg. GHI	Max. GHI	
	a	b	c	d	(c-a)/a
AWS Maritim Merak	1520	1419	1526	1641	0.4%
AWS Stamet Serang	1430	1328	1434	1539	0.3%
AWS Curug	1500	1409	1508	1609	0.5%
AWS Stamet Cengkareng	1570	1465	1578	1693	0.5%
AWS Halim	1260	1165	1263	1362	0.2%
AWS Maritim Tanjung Priok	1240	1150	1241	1330	0.1%
AWS Maritim Cilacap	1780	1664	1786	1908	0.3%
AWS Stamet Cilacap	1860	1744	1871	2001	0.6%
AWS Maritim Semarang	1760	1647	1763	1881	0.2%
AWS Tuban	1720	1611	1727	1851	0.4%
AWS Maritim Tanjung Perak	1940	1827	1945	2058	0.3%
AWS Stamet Banyuwangi	1720	1619	1724	1828	0.2%

GHI: Global horizontal irradiation, AWS: Automatic weather system

Figure 14: IRR of rooftop PV investment in each city

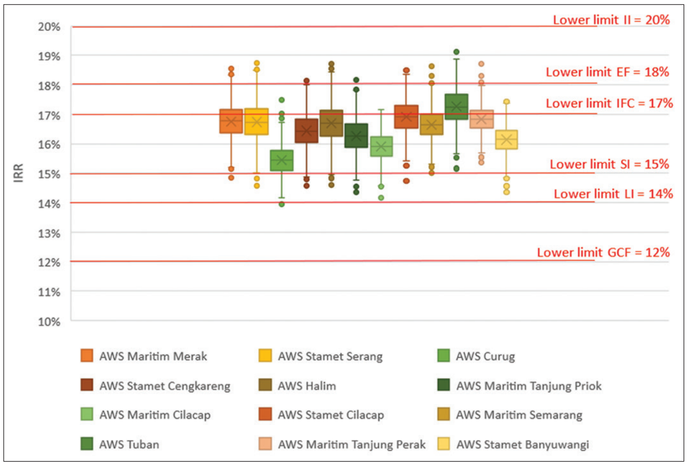
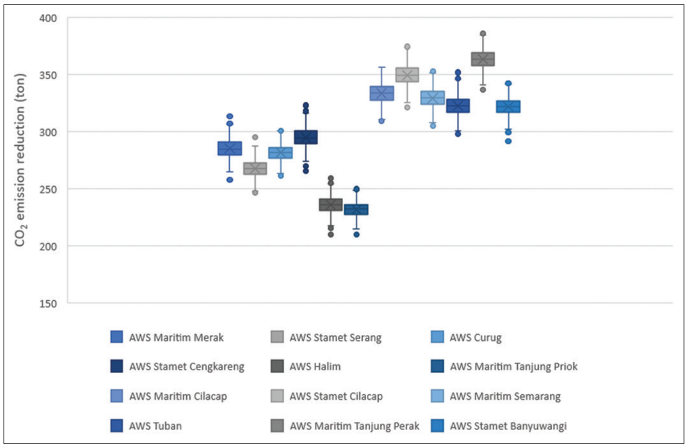


Figure 15: The CO_2 emission reduction using rooftop PV systems



investing in any of these cities because the rooftop PV's investment value has an IRR below 18%.

Based on the IRR analysis, it can be seen that it is profitable for the rooftop PV system to be built by the private sector and the energy generated is for internal use. Therefore, using rooftop PV systems contribute to CO_2 emission reduction in Java. Based on the existing energy mix in Java, the CO_2 emission factor in the Java power system is 0.935 kton/GWh. Using rooftop PV systems to supply the internal electricity demand results in a decrease of electricity production of PLN. Therefore, CO_2 emission is reduced. The emission reductions are shown in Figure 15. The emission reductions from 100 m^2 of rooftop PV systems vary from 214 to 384 tons of CO_2 per year.

As explained in the section on the research method, this proposed method has a limitation in relation to the GHI data used. Detailed GHI data on Java Island can only be obtained from the AWSs.

Therefore, this research used these GHI data to represent the GHI data of a city. These research results can be used as a guideline for the government and private sector to choose their strategy. However, a feasibility study is required to obtain more detailed results. When more detailed GHI data is obtained, this proposed method can still be used to analyze the attractiveness of investing in rooftop PV systems by changing the input data of GHI.

6. CONCLUSION

The proposed model has been successfully implemented in Java. The Monte Carlo simulation can model GHI uncertainty. The techno-economic analysis and financial-economic parameter assessment of rooftop PV investment on Java Island are conducted by considering GHI uncertainty. Using the assumption that the debt-equity ratio is 70:30%, a weighted average cost of capital (WACC) value of 10% is obtained. The WACC value is used as the discount rate value to calculate the LCOE, NPV, and internal rate of return (IRR) value.

The research results show that each selected city's optimal capacity on Java Island is different from one another. The optimal capacity depends on the GHI value in each city. Also, the GHI affects the financial-economic parameters such as LCOE, NPV, and IRR. These parameters show the attractiveness of rooftop PV investment. The rooftop PV system's LCOE shows that a rooftop PV system cannot be built on Java Island by the utility as it is only profitable when built by the private sector and the energy is for internal use only. The positive NPV value further supports these results. The rooftop PV system investments in this scenario provide IRR values above 14%, which shows investors with GCF and LI are interested in investing. The emission reductions from 100 m^2 of rooftop PV systems vary from 214 to 384 ton of CO_2 per year.

The research results show that with the current regulations, it is not optimal to accelerate the development of rooftop PV systems. A new policy is required that allows the private sector to sell the energy produced by rooftop PV systems to the grid at an economical price and that this is not considered as a bill reduction. Therefore, the private sector can build rooftop PV systems larger than its electricity demand and gain a cash income. Simultaneously, a new policy is required that allows the utility to produce electrical energy from rooftop PV systems at a higher cost than power system generation. Therefore, the utility can build rooftop PV systems and secure a profit. It is hoped that the rooftop PV system can be accelerated optimally to achieve the RE targets and SDGs using the new policies.

Furthermore, the proposed model can undertake an analysis and assess the development prospects of rooftop PV systems by considering GHI uncertainty and government policies in other countries. Using this proposed model for other countries requires adjustments to the rooftop pricing mechanism based on their regulations.

7. ACKNOWLEDGMENT

The authors would like to thank The Ministry of Research, Technology and Higher Education of the Republic of Indonesia for the financial support with the contract Number 1660/UN1/DITLIT/Dit-Lit/PT.01.03/2022 through the PDUPT research scheme.

REFERENCES

ADB. (2020), Renewable Energy Tariffs and Incentives in Indonesia: Review and Recommendations. Manila: Asian Development Bank.

Alfi, J., Kubiniec, A., Mani, G., Christopherson, J., He, Y., Bosch, J. (2017), Importance of input data and uncertainty associated with tuning satellite to ground solar irradiation. In: 2017 IEEE 44th Photovoltaic Specialist Conference, PVSC. United States: IEEE. p1-5.

Ali, I., Shafiullah, G.M., Urmee, T. (2018), A preliminary feasibility of roof-mounted solar PV systems in the Maldives. Renewable and Sustainable Energy Reviews, 83, 18-32.

Beltrán, J.C., Aristizábal, A.J., López, A., Castaneda, M., Zapata, S., Ivanova, Y. (2020), Comparative analysis of deterministic and probabilistic methods for the integration of distributed generation in power systems. Energy Reports, 6, 88-104.

Bieri, M., Winter, K., Tay, S., Chua, A., Reindl, T. (2017), An irradiance-neutral view on the competitiveness of life-cycle cost of PV rooftop systems across cities. Energy Procedia, 130, 122-129.

Bódis, K., Kougias, I., Jäger-Waldau, A., Taylor, N., Szabó, S. (2019), A high-resolution geospatial assessment of the rooftop solar photovoltaic potential in the European Union. Renewable and Sustainable Energy Reviews, 114, 109309.

Budi, R.F.S., Sarjiya, Hadi, S.P. (2019), Review on Generation Expansion Planning based on Indonesia as an Archipelagic Country. In: 2019 5th International Conference on Science and Technology. p1-6.

Budi, R.F.S., Sarjiya, Hadi, S.P. (2020), Economic Assessment of Rooftop Photovoltaic Investment by Considering Uncertainty Solar Irradiation : A case Study of Semarang City, Central Java, Indonesia. In 2020 2nd International Conference on Smart Power and Internet Energy System. p520-525.

Budi, R.F.S., Suparman, Salimy, D.H. (2011), The analysis of CO2 emission at the study of electricity generation development planning with nuclear option for bangka belitung (Analisis Emisi CO2 pada Studi Perencanaan Pengembangan Pembangkitan Listrik Wilayah Bangka Belitung dengan Opsi Nuklir). Jurnal Pengembangan Energi Nuklir, 13(1), 44-55.

Chen, J., Wang, X., Li, Z., Qiu, S., Wu, J. (2018), Deploying residential rooftop PV units for office building use: A case study in Shanghai. Energy Procedia, 152, 21-26.

Duman, A.C., Güler, Ö. (2020), Economic analysis of grid-connected residential rooftop PV systems in Turkey. Renewable Energy, 148, 697-711.

Emziane, M., Al Ali, M. (2015), Performance assessment of rooftop PV systems in Abu Dhabi. Energy and Buildings, 108, 101-105.

Fan, M., Huang, L. (2018), Probabilistic Power Reserve Evaluation Algorithm for Power Systems Considering High Solar Energy Penetration. In IEEE Power and Energy Society General Meeting. United States: IEEE. p5-9.

Haegermark, M., Kovacs, P., Dalenbäck, J.O. (2017), Economic feasibility of solar photovoltaic rooftop systems in a complex setting: A Swedish case study. Energy, 127, 18-29.

Hidayatno, A., Setiawan, A.D., Wikananda Supartha, I.M., Moeis, A.O., Rahman, I., Widiono, E. (2020), Investigating policies on improving household rooftop photovoltaics adoption in Indonesia. Renewable Energy, 156, 731-742.

IEA. (2015), Technology Roadmap: Solar Photovoltaic Energy. Paris, France: IEA.

IESR. (2019), Levelized Cost of Electricity in Indonesia: Understanding the Levelized Cost of Electricity Generation. Jakarta: Institute for

Essential Services Reform.

Korsavi, S.S., Zomorodian, Z.S., Tahsildoost, M. (2018), Energy and economic performance of rooftop PV panels in the hot and dry climate of Iran. Journal of Cleaner Production, 174, 1204-1214.

Kosorić, V., Lau, S.K., Tablada, A., Lau, S.S.Y. (2018), General model of Photovoltaic (PV) integration into existing public high-rise residential buildings in Singapore-challenges and benefits. Renewable and Sustainable Energy Reviews, 91, 70-89.

Li, K., Zhang, J., Che, J., Wang, F., Ren, H., Mi, Z. (2018), Capacity Configuration Optimization for Stand-alone Microgrid Considering the Uncertanties of Wind and Solar Resources. In 2018 IEEE Power and Energy Society Innovative Smart Grid Technologies Conference. p1-6.

Mainzer, K., Fath, K., Mckenna, R., Stengel, J., Fichtner, W., Schultmann, F. (2014), A high-resolution determination of the technical potential for residential-roof-mounted photovoltaic systems in Germany. Solar Energy, 105, 715-731.

MoEMR. (2017), Regulation of the Minister of Energy and Mineral Resources No. 50 of 2017. Indonesia: MoEMR.

MoEMR. (2019), Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 16 of 2019. Indonesia: MoEMR.

MoEMR. (2019a), Decree of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 55 K/20/MEM/2019 (Keputusan Menteri Energi dan Sumber Daya Mineral Republik Indonesia Nomor 55 K/20/MEM/2019). Indonesia: MoEMR.

MoEMR. (2020), Pursue the 2025 Energy Mix Target, New and Renewable Energy Investment Needed Up to USD36.95 Billion (Kejar Target Bauran Energi 2025, Dibutuhkan Investasi EBT Hingga USD36,95 Miliar). Available from: http://www.ebtke.esdm.go.id/post/2019/12/06/2419/kejar.target.bauran.energi.2025.dibutuhkan.investasi.ebt.hingga.usd3695.miliar [Last accessed on 2020 Jun 29].

Nuryanti, S. (2015), Probabilistic Analysis on Levelized Unit Electricity Cost (LUEC) Calculation of Small Medium Reactor Nuclear Power Plant (SMR NPP) In Indonesia. In International Conference on Nuclear Energy Technologies and Sciences, 2016, 1-10.

Omar, M.A., Mahmoud, M.M. (2018), Grid connected PV-home systems in Palestine: A review on technical performance, effects and economic feasibility. Renewable and Sustainable Energy Reviews, 82, 2490-2497.

Patelli, E., Broggi, M., Tolo, S., Sadeghi, J. (2017), Cossan software: A multidisciplinary and collaborative software for uncertainty quantification. In UNCECOMP 2017-Proceedings of the 2nd International Conference on Uncertainty Quantification in Computational Sciences and Engineering. p212-224.

President of Republik Indonesia. (2014), Indonesian Government Law No 79 In 2014 About National Energy Policy. Indonesia: President of Republik Indonesia.

PT PLN. (2019), Electricity Supply Business Plan of PT. PLN (PERSERO) 2019-2028 (Rencana Usaha Penyediaan Tenaga Listrik PT. PLN (PERSERO) 2019-2028). Jakarta: PT. PLN. Available from: http://www.djk.esdm.go.id/index.php/rencana-ketenagalistrikan/ruptl-pln

PT. PLN. (2020), Statistik PLN 2019. Indonesia: PT. PLN.

Ritchie, H., Roser, M. (2020), CO_2 and Greenhouse Gas Emissions. Available from: https://www.ourworldindata.org/co2-and-other-greenhouse-gas-emissions%0A

Sarjiya, Budi, R.F.S., Putranto, L.M. (2020), Achieving New and Renewable Energy Target : A Case Study of Java-Bali Power System, Indonesia. In 2020 2nd International Conference on Smart Power and Internet Energy Systems. p1-6.

Schallenberg-Rodríguez, J. (2013), Photovoltaic techno-economical potential on roofs in regions and islands: The case of the Canary Islands. Methodological review and methodology proposal. Renewable and Sustainable Energy Reviews, 20, 219-239.

Stepanov, O.A., Amosov, O.S. (2007), The comparison of the Monte-Carlo method and neural networks algorithms in nonlinear estimation problems. IFAC Proceedings Volumes (IFAC-PapersOnline), 40(13), 392-397.

Sueyoshi, T., Wang, D. (2017), Measuring scale efficiency and returns to scale on large commercial rooftop photovoltaic systems in California. Energy Economics, 65, 389-398.

Tomar, V., Tiwari, G.N. (2017), Techno-economic evaluation of grid connected PV system for households with feed in tariff and time of day tariff regulation in New Delhi-a sustainable approach. Renewable and Sustainable Energy Reviews, 70, 822-835.

USAID-ICED-LPEM FEB UI. (2016), Financing of Solar Power Plant (Pembiayaan Pembangkit Listrik Tenaga Surya). United States: USAID-ICED-LPEM FEB UI.

World Bank Group. (2021). Solar resource maps and GIS data for 200+ countries | Solargis. Available from: https://solargis.com/maps-and-gis-data/download/indonesia. [Last accessed on 2021 Feb 21].

Yin, P., Chen, S. (2017), Simulation Evolution and Optimization for PV Solar Farm Configuration Under Weather and Soiling Uncertainty. In IEEE Symposium Series on Computational Intelligence (SSCI). p1-7.