1. Submitted to the journal "Bulletin of Electrical Engineering and Informatics (BEEI)" via the online submission system: (13 February 2024)
   - Screenshot BEEI online submission website (13 February 2024)
   - Full manuscript draft 8309-19788-1-SM.DOCX (2024-02-13)
2. Email received from BEEI Editor Decision: Major Revisions Required
   - Email from BEEI containing Editor-in-Chief comments and reviewers' comments (24 February 2024)
3. Submitted the revised manuscript and detailed response via the online submission system
   - The detailed response to editors' and reviewers' comments (18 March 2024)
   - The revised manuscript according to the editor and reviewer's comments with yellow highlights – Round 1 (18 March 2024)
4. Email received from BEEI Editor: Revision required
   - Email from BEEI containing reviewer's comments (16 May 2024)
5. Submitted the revised manuscript and detailed correction statement via the online submission system
   - Detailed correction statement (4 June 2024)
   - Revised manuscript according to the editor and reviewer's comments with yellow highlights – Round 2 (4 June 2024)
6. Email received from BEEI: Submission accepted
   - Email from BEEI: submission accepted but with small revisions required (7 August 2024)
7. Email sent to BEEI with attachment of the final revised paper, plagiarism check using iThenticate, and proof of payment for the paper publication
   - Email sent to BEEI (30 August 2024)
   - Revision final paper
   - Plagiarism check using iThenticate as requested by the journal
8. Email correspondence for Layout and Setting
   - Email received from BEEI (22 October 2024)
   - Paper for layout and setting
9. Email sent to BEEI as a response to the paper layout and setting
   - Email sent to BEEI (24 October 2024)
   - Final paper after layout and setting
10. Email correspondence regarding final paper proofreading
    - Email from BEEI (6 November 2024)
    - Final proofread paper
    - Email sent to BEEI for confirmation (7 November 2024)
    - Email from BEEI: Thank you for confirmation (7 November 2024)
11. Certificate of Acknowledgement as Author
    - Email from BEEI (4 December 2024)
    - Certificate of Author

1. Submitted to the journal “Bulletin of Electrical Engineering and Informatics (BEEI)” via the online submission system: (13 February 2024)
    - Screenshot BEEI online submission website (13 February 2024)
    - Full manuscript draft 8309-19788-1-SM.DOCX (2024-02-13)

iaes
Bulletin of Electrical Engineering and Informatics

3.6 CiteScore | 0.284 SJR | 0.689 SNIP

#8309 Summary

Submission

Authors	Yusak Tanoto, Christopher Marvel, Hanny H Tumbelaka
Title	KawanSurya: an Android-based mobile app for assessing the techno-economic potential of rooftop photovoltaic
Original file	8309-19788-1-SM.DOCX 2024-02-13
Supp. files	None
Submitter	Dr. Yusak Tanoto
Date submitted	February 13, 2024 - 11:12 AM
Section	Energy and Power Engineering
Editor	Denis B. Solovev (Review) Mochammad Facta (Review) Xiaojun Li (Review) B. Justus Rabi (Review) Lutfu Saribulut (Review)

Author comments

Dear Prof. Dr. Ir. Tole Sutikno, ASEAN Eng.

Editor-in-Chief Bulletin of Electrical Engineering and Informatics (BEEI)

Please consider attached a revised manuscript entitled "KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV" authored by Yusak Tanoto, Christopher Marvel and Hanny H. Tumbelaka for publication in BEEI.

I believe this article will attract readership from both popular and scientific audiences interested in the role of solar rooftop PV techno-economic tools in emerging economies. The language of this manuscript has been thoroughly checked by an English expert, and I hereby confirm that this manuscript has not been published elsewhere and is not under consideration by another journal.

Finally, I would like to thank the editor and reviewers for their thoughtful criticisms and helpful suggestions on how to improve the paper. I do hope that it is now suitable for publication in BEEI. Thank you very much and I am looking forward to hearing from you soon.

Sincerely yours,

Yusak Tanoto

Electrical Engineering Department

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Abstract Views 288

Status

Status	Published Vol 14, No 1: February 2025
Initiated	2024-11-18
Last modified	2024-11-20

Submission Metadata

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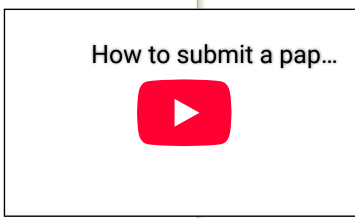
Title and Abstract



Title	KawanSurya: an Android-based mobile app for assessing the techno-economic potential of rooftop photovoltaic
Abstract	Many developing countries, including Indonesia, are progressing poorly in residential rooftop photovoltaic (PV) adoption, including on-grid systems. On the customer side, the decision to implement on-grid rooftop PV or rely only on power from the utility grid has often been made without appropriate knowledge of techno-economic considerations. This includes the impression of high system costs. This paper introduces KawanSurya: PV calculator, a solar rooftop PV techno-economic application for Android mobile phones, designed to help residential customers assess the potential of installing on-grid rooftop PV systems. The tool allows users to select a specific geographic location, calculate daily load profiles, and determine available roof areas. It uses irradiance data from the PVGIS API and HOMER's solar PV output equation to determine hourly PV output power. Simulation results for a typical 2,200 VA household show a payback period of 9.44 years or beyond, significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and similar load profile prolong the payback period, while a 0% billing reduction factor or uncompensated electricity sales may exceed the project's lifetime.

Indexing

Academic discipline and sub-disciplines	Renewable Energy; Solar PV; Electrical Engineering
Keywords	Android application; On-grid; Rooftop photovoltaic; Solar photovoltaic; Techno-economic
Language	en

Supporting Agencies

Agencies	—

Bulletin of Electrical Engineering and Informatics (BEEI)
ISSN: 2089-3191, e-ISSN: 2302-9285
This journal is published by the Institute of Advanced Engineering and Science (IAES) *in collaboration with* Intelektual Pustaka Media Utama (IPMU).

KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV

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Article Info

Article history:

Received month dd, yyyy
Revised month dd, yyyy
Accepted month dd, yyyy

Keywords:

On-grid
Solar PV
Rooftop PV
Techno-economic
Android application

ABSTRACT

Many developing countries, like Indonesia, are still making slow progress with residential rooftop PV adoption. Apart from the challenges associated with regulatory implementation, the potential utilisation of solar PV energy in comparison to total electricity consumption and the investment feasibility justification, are important technical and economic factors that can influence residential customers' decisions on whether to install rooftop PV. This paper introduces KawanSurya: PV Calculator, a solar rooftop PV techno-economic tool for Android mobile phones that can be downloaded for free from Google Play. It focuses on evaluating on-grid rooftop PV potential installations, allowing users to choose a specific geographic location, calculate their daily load profiles, and measure the available roof area. The tool leverages irradiation data from the PVGIS API and HOMER's PV output equation to calculate hourly-based rooftop PV output power. This paper presents the application's design methods and functionality, as well as simulation-based testing and findings. This study makes a methodological contribution to the literature on renewable energy applications, specifically to people's understanding, by offering KawanSurya as an alternate way for evaluating potential rooftop PV installations. While the tool is intended for Indonesia's residential sector, it is equally applicable to other jurisdictions wanting to boost customer education and information.

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1. INTRODUCTION

Climate change has become a global concern, and the Paris Agreement has brought countries together to lower global greenhouse gas emissions to keep global temperature rise below 2°C, and to pursue efforts to keep it below 1.5°C [1]. One of the efforts to reach these aims in the electricity industry is to limit the usage of fossil fuel-based technology and transition to renewable energy-based ones. This approach appears promising because, in 2022, renewable energy accounted for more than 83% of capacity additions, with wind and solar accounting for more than 91%, including rooftop PV [2]. Rooftop solar photovoltaics (PV) will continue to play an essential role in decreasing greenhouse gas emissions from the energy sector, particularly if appropriate legislation and supporting measures are enacted [3].

Progress of residential rooftop PV deployment in many developing countries including Indonesia remains very low. The Indonesian government aims for a 23% renewable energy mix by 2025, including rooftop PV contributions with a target installed capacity of 3.6 GW [4]. However, meeting this target seems to be difficult given that the installed capacity of rooftop PV in Indonesia as of May 2023 was just 95 MWp, servicing 7,075 customers across the country, 72% of those being residential customers [5]. The potential of adopting solar rooftop PV, especially in the residential sector in many developing countries, including Indonesia, appears promising given the benefits of the globally declining costs of PV systems [6]. While the market potential is considered significant, for example, given a large city with approximately 170-186 MWp rooftop capacity only from the residential sector, or around 110 GWp for a province, its capacity deployment requires a broad range of supportive policies, comprehensive information dissemination, and appealing government incentives [7], [8].

Many studies have identified and evaluated barriers to residential rooftop PV adoption. These include economic barriers, which primarily tackle monetary costs and benefits [9], as well as technical barriers, which may encompass knowledge and information aspects [10], in addition to social and regulatory barriers [11]. In Indonesia's context, these include high initial investment costs, lack of access to installation services, lack of availability of information, disadvantageous PV export tariffs and policy inconsistencies, among others [12]. While the proposed solutions to the economic barriers may include the introduction of a solar PV leasing package by the utility and a green financing mechanism or similar form of subsidies to reduce the upfront cost burden, public education through information dissemination, particularly on product knowledge, and policy campaigns is one of the proposed solutions to improve public knowledge and clear up misperceptions about costly technology [9].

Some residential customers may already be aware of the benefits of using clean energy technologies and their potential to lower electricity bills. However, two important technical and economic factors that can influence residential customers' decisions on whether or not to install rooftop PV are the potential utilisation of solar PV energy in comparison to overall electricity consumption, and the investment feasibility justification from exporting PV energy to the grid, respectively. In this context, residential customers require a tool that provides an adequate overview of the system in terms of the techno-economic potential of using rooftop PV. While people, in general, are not expected to evaluate the potential of installing rooftop PV using complicated software or tools designed for academic or research purposes, there are a limited number of handy applications or tools that allow residential customers to assess the techno-economic potential of installing solar rooftop PV in their homes that sufficiently appropriate and ‘independent’, which means they are not designed by or part of the solar PV companies or contractors.

Photovoltaic Geographical Information System (PVGIS) [13] and PVWatts Calculator [14] are examples of such tools. PVGIS is an interactive web-based tool developed by the European Commission (EU) to evaluate the performance of grid or off-grid-connected PV in a specific geographic location, while PVWatts is also a web-based application developed by The National Renewable Energy Laboratory (NREL). A few rooftop PV techno-economic studies have used PVGIS and/or PVWatts as tools, such as to compare the performance of free-standing and rooftop PV for various climatic zones [15] and evaluate the techno-economic aspects of residential PV systems considering a tiered rate and net-metering [16]. While PVGIS provides users with useful simulation outputs such as yearly PV energy production, variability, and electricity cost, monthly energy output of the PV system, and an outline of the horizon, it does not consider the user load profile hence the payback period of the system. that allows users to assess the performance of PV installations with a focus on average monthly solar radiation and system energy output. Meanwhile, PVWatts offers an optional analysis that includes the roof area when evaluating system size, but, like PVGIS, does not take into account for user load profile.

In Indonesia’s context, there is a rooftop PV calculator known as SolarHub [17], that can be used to estimate rooftop PV capacity, monthly PV energy generation, system costs and savings, required roof area, avoided CO_2 emissions, and payback period. While the tool is clearly beneficial in assisting residential customers with rooftop PV investment decisions, users can not specify a location based on a specific geographical coordinate, but rather the province in which they live, as the tool provides an associated solar PV output for that province. Furthermore, the tool does not take into account the household’s electricity use pattern, which could be useful in assessing PV potential.

While existing applications are generally built on a web-based platform and so require a computer to function properly, information dissemination regarding rooftop PV necessitates alternate platforms. Given these circumstances, this paper introduces KawanSurya: PV Calculator (in English means ‘solar friend’, hereafter KawanSurya), a solar rooftop PV techno-economic tool that runs on mobile phones using the Android platform and is available for free on Google Play. The proposed tool focuses on the evaluation of on-grid rooftop PV potential installations while allowing users to select a specific geographic location, and determine their daily load profiles as well as measure the available roof area. The tool uses irradiation data from the PVGIS API [18] and PV output equation from HOMER [19] to calculate hourly-based rooftop PV output power. This paper discusses the application’s design methods and functionality, as well as testing through simulations and the results. This study methodologically contributes to the literature on renewable energy application particularly to people’s understanding, by introducing KawanSurya as an alternative approach for evaluating rooftop PV potential installations. While the tool is aimed towards Indonesia’s residential sector, it is equally applicable to other jurisdictions looking to increase customer education and information dissemination.

The rest of this paper is organised as follows: Section 2 presents the tool's design method; Section 3 presents and elaborates on the results and discussions; Section 4 finally provides some conclusions on the findings and suggestions for future work.

2. METHOD

2.1. Application Flowchart of KawanSurya

Figure 1 depicts the flowchart for KawanSurya. It particularly displays the sequence of steps for utilising the tool, which includes entering required parameters, computing inputs, and presenting results.

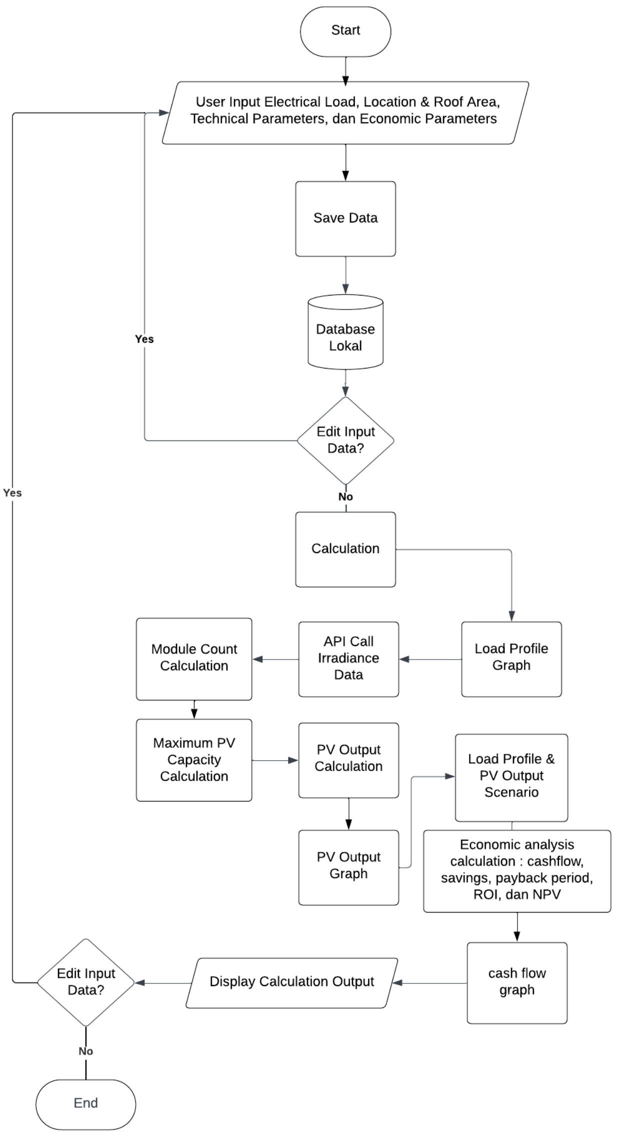


Figure 1. Flowchart of KawanSurya

Description of the tool's application steps is elaborated in more detail as follows: 1) The user enters required information such as the household appliances and their operating hours, as well as technical and economic parameters, the available roof area which defines the maximum number of solar PV modules that can be placed, and the location; 2) The programme retrieves irradiance data using the PVGIS API. KawanSurya uses an irradiance dataset from 2005 to 2016, with a time step of one hour; 3) The tool calculates the energy produced by the rooftop PV system over one year on an hourly basis; 4) The tool generates a daily load curve with a time step of one hour and rooftop PV energy generation curve to show the user the potential utilisation of the energy generated by the PV, i.e., which can be used by the load (appliances), and part of the energy that is exported to the grid; 5) The programme calculates the PV system's output power, portions of the energy consumed by the appliances, and energy exported to the grid, as well as economic analyses such as bill comparison, Net Present Value (NPV), Return on Investment (ROI), payback period, cash flow. Furthermore, the tool measures the required area for rooftop PV installations and the quantity of PV modules needed; 6) The tool displays all the results.

The KawanSurya App is available online and can be obtained using the following link: https://play.google.com/store/apps/details?id=com.christophermarvel.pvcalc or in Google Play for Android mobile phones. KawanSurya is developed using Kotlin. It is a native high-level programming language in Android. The coding for data processing, calculation, and user interface is conducted using Android Studio. The tool can be appropriately accessed in Android version 8 up to 13. Figure 2 depicts the user interface of the tool on an Android mobile phone in English and in Bahasa Indonesia after it has been downloaded and launched.

As shown in Figure 2, the tool functionality is grouped into five main features or pages, i.e., Electrical Load, Location and Area, Technical Parameters, Economic Parameters, and Calculation. Apart from these main pages, there is an Information page containing useful information about the application and its utilisation guide. Each of these features is described in more detail in the sub-sections below.

(a) (b)

Figure 2. The user interface of KawanSurya on an Android mobile phone (a) in English, and (b) in Bahasa Indonesia

The tool is designed to produce both technical and economic types of output to justify the techno-economic feasibility of the on-grid rooftop PV that is going to be installed. Hence, KawanSurya is developed without the existence of storage systems, for example, batteries. Technical outputs comprise the amount and capacity of PV modules, required roof area, curves of daily load profile and PV output power, electricity energy generated by rooftop PV system, electricity exported back to the grid, energy supplied by the grid, and energy saving. Meanwhile, the economic type of outputs includes financial savings, electricity bills after installing PV, cash flow, payback period, ROI, and NPV.

User problems and needs are the foundation of the user interface/user experience design process. The tool is designed using low and high-fidelity wireframes to allow functional and aesthetic blending in the design. This helps to ensure that the final design handles existing problems and effectively satisfies the needs of users.

2.2. The Tool's Navigation and Database

The tool's navigation in KawanSurya allows users to interactively browse, enter, and quit various features within the tool. Moreover, it also ensures a consistent and predictable user experience based on a set of established principles that are particularly developed for the tool. Meanwhile, KawanSurya uses Room Database, a library provided by Android Jetpack [20] that can simplify data management and access within an Android application, to process a local database. Room Database works on top of SQLite [21], a database engine used as the data storage foundation in Android applications.

In this tool, the database contains four different entities, i.e., Task, Dpd, Eko, and Map. By defining these entities, we inform the database that we want to create tables to store data of these types. Hence, there will be separate tables for each entity when the database is created. Figure 3 and Figure 4 present the navigation diagram for KawanSurya and the database developed in this tool, respectively.

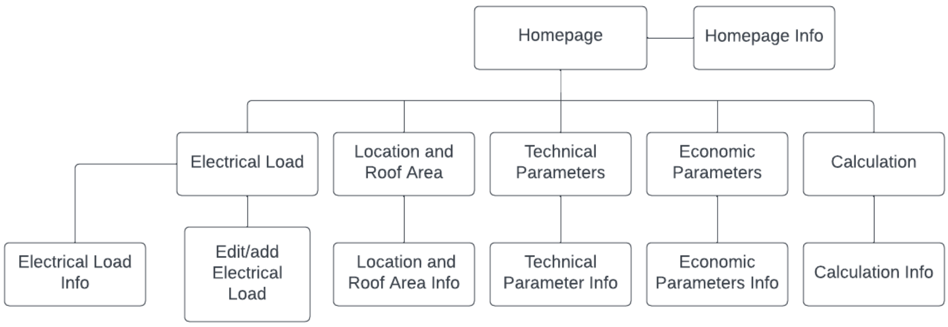


Figure 3. KawanSurya navigation diagram

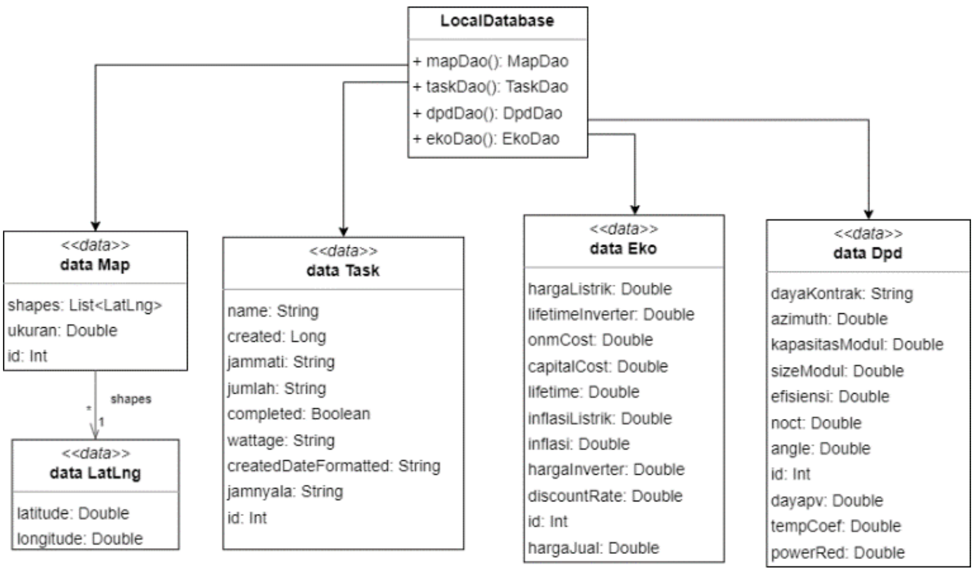


Figure 4. KawanSurya application database

2.3. Electrical Load Page

The Electrical Load page allows users to enter the amount of electrical load or appliances in their houses. To add an appliance, users can click the 'Add' button and enter information such as the appliance's name, amount, active power or wattage, operational hours, and off hours. The data provided will assist the tool in generating the user's daily electrical load data and curve, which helps estimate the amount of self-consumed PV energy and excess energy sent back to the utility grid.

2.4. Technical Parameters Page

On the Technical Parameters page, users can provide numerous technical parameters of the rooftop PV system to be installed, which greatly assists the tool in calculating the rooftop PV output power on an hourly basis and performing economic analyses of the rooftop PV system. The page consists of installed PLN (Indonesia's national electricity utility company) contracted power capacity (VA), maximum rooftop PV capacity (Wp), PV module size (m^2), capacity per module (Wp), PV module efficiency (%), nominal operating cell temperature (°C), temperature coefficient of power (%/°C), tilt angle (°), azimuth (0° = South, 90° = West, -90° = East), and power output reduction per year (%). While the tool allows users to modify the technical parameters entered in their rooftop PV installation plan and while they can specify technical settings, the application also gives default values to assist users in moving forward with the simulation.

Irradiance data is required to calculate the output power of rooftop PV systems. KawanSurya gets irradiance data from the PVGIS API that is retrieved from the PVGIS SARAH-2 Dataset [22]. This dataset comprises sun irradiance data with a one-hour time step from 2005 to 2016. Retrofit will be used to make the API request, which includes parameters such as latitude, longitude, month, output format, local time, global, angle, aspect, and temperatures.

2.5. PV Output Power

KawanSurya calculates rooftop PV output power according to the equation provided in HOMER software. It considers various parameters, including the derating factor and the factors typically involved in calculating PV array temperature, i.e., solar absorptivity and solar transmittance. The derating factor considers issues that may impair the performance of the PV system, such as panel dirt, wire loss, shadowing, snow coverage, and aging, among others. This tool uses an estimated typical value of 0.77 [23] to indicate how much these parameters influence the performance of the rooftop PV system.

Solar absorptivity is the proportion of solar radiation absorbed by a surface, whereas solar transmittance is the proportion of solar radiation transmitted through a surface. The tool considers the product of solar absorptivity and solar transmittance to be 0.9 or 90% [24]. Hence, equations to calculate rooftop PV output power and PV cell temperature are as follows.

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}}\right)[1 + \alpha_p(T_c - T_{C,STC})] \quad (1)$$

where:
P_{PV} : PV output (kW)
Y_{PV} : rated capacity solar PV array in standard test conditions (kW)
f_{PV} : derating factor (%)
$\overline{G_T}$: the solar radiation incident on the PV array in the current time step (kW/m^2)
$\overline{G_{T,STC}}$: the incident radiation at standard test conditions ($1\ kW/m^2$)
α_p : the temperature coefficient of power (%/°C)
T_c : the PV cell temperature in the current time step (°C)
$T_{C,STC}$: the PV cell temperature under standard test conditions (25°C)

$$T_c = \frac{T_a + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(1 - \frac{\eta_{mp,STC}(1-\alpha_p T_{c,STC})}{\tau\alpha}\right)}{1 + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_p \eta_{mp,STC}}{\tau\alpha}\right)} \quad (2)$$

where:
T_c : the PV cell temperature (°C)
T_a : the ambient temperature (°C)
$T_{c,NOCT}$: the nominal operating cell temperature (°C)
$T_{a,NOCT}$: the ambient temperature at which the NOCT is defined (20°C)
G_T : the solar radiation striking the PV array (kW/m^2)
$G_{T,NOCT}$: the solar radiation at which the NOCT is defined ($0.8\ kW/m^2$)
$\eta_{mp,STC}$: the maximum power point efficiency under standard test conditions (%)
α_p : temperature coefficient of power (%)
$T_{C,STC}$: the cell temperature under standard test conditions (25°C)
τ : the solar transmittance of any cover over the PV array (%)

α : the solar absorptance of the PV array (%)

To estimate the electricity output power from solar PV over several years considering the yearly power reduction, the tool uses the following equation.

$$PV_{out\ year\ n} = PV_{out\ yearly} \times (1 - yearly\ rate\ of\ PV_{out} degradation\ (\%)) \times (n-1) \quad (3)$$

2.6. Location and Area Page

On the Location and Area page, users can draw a polygon to estimate the available roof area, i.e., by clicking on the spots on the house's roof where the solar PV modules would be mounted, as illustrated in Figure 5. The programme will read the geographic latitude and longitude of the site and calculate the area of the formed polygon.

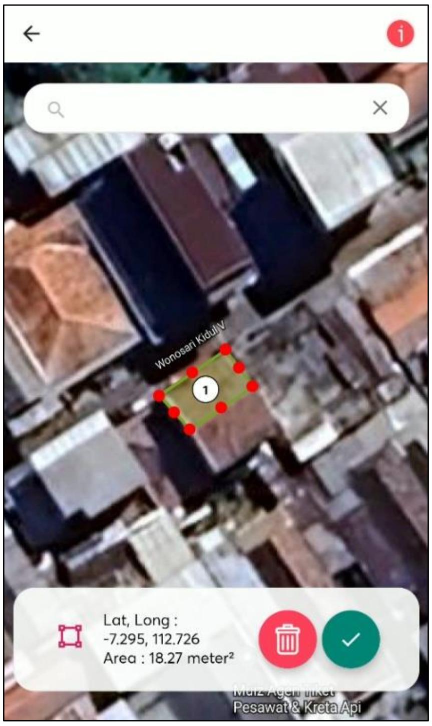


Figure 5. Screenshot of determining location and roof area in KawanSurya

2.7. Solar PV Capacity and Module Quantity

The tool limits the maximum capacity of solar PV modules to up to 100% contracted electricity of a household following the regulation [25]. The size of the roof to be fitted with PV modules is then multiplied by 80% of the total roof area to facilitate installation and maintenance. To determine the number of applicable modules and corresponding PV capacity, the tool chooses a smaller value by comparing the maximum power (Watt-peak) that can be generated by all solar modules required to cover the entire roof surface with the maximum power (Watt-peak) specified by the user or with a 100% permitted capacity that is equal to the household contracted power.

2.8. Economic Parameters Page

The Economic Parameters page allows users to define the economic parameters of the rooftop PV system that will be installed, which is critical for conducting economic analysis of the system. The user provides several financial details on this page, including the inverter price and lifetime, capital cost (excluding inverter price), electricity price, feed-in tariff (PV export tariff to the grid), annual O&M cost, annual electricity price increase, inflation rate, discount rate, and project lifetime. KawanSurya uses payback period analysis, one of the simplest evaluation techniques, to examine the economic feasibility of the system [26], in addition to Return on Investment (ROI) and Net Present Value (NPV). The economic analysis incorporates both the simple and discounted payback periods. The equations for calculating the simple or discounted payback period, ROI, and NPV are as follows.

$$PP = Nb + \frac{ccNb}{ncNa} \tag{4}$$

where:
PP : payback period
Nb : year before recovery
$ccNb$: cummulative cash flow in year before recovery
$ncNa$: net cash flow in year after recovery

The present value (PV) is calculated using an assumed interest rate, also known as the discount rate. The present value can be calculated using the following equation [8].

$$PV = S \times F_{PW} \tag{5}$$

where:
PV : present value of S in year n
S : cash flow in year n
F_{PW} : present worth factor in year n

The DF (Discount Factor) is based on the assumed discount rate and can be determined using the equation below.

$$DF = \left(1 + \frac{d}{100}\right)^{-n} \tag{6}$$

The inflation adjustment factor can be calculated using the inflation factor equation as follows.

$$IF = (1 + i)^n \tag{7}$$

where:
i : inflation rate
d : discount rate
n : year

The present worth factor F_{PW} and the Net Present Value (NPV) can be obtained using Equation 8 and 9, respectively.

$$F_{PW} = \frac{(1 + i)^n}{(1+d)^n} \tag{8}$$

$$NPV = \sum PV_{income} - \sum PV_{cost} \tag{9}$$

The cumulative cash inflow computation considers the cash inflow, discount rate, and project year until the cumulative cash inflow is positive at the present payback period. Finally, Return on Investment (ROI) is calculated using Equation 10. It measures the profitability of a system and is defined as the ratio of net benefits (NPV) to the initial investment. A negative ROI indicates that the investment is not profitable.

$$ROI = \frac{NPV}{Capital\ Cost} \tag{10}$$

3. RESULTS AND DISCUSSION

This section presents the simulation results conducted in the KawanSurya and discusses the findings and implications. Several testings have been conducted to check and validate the application functionality. These include simulating electrical load (appliances) data, processing solar irradiance data through API, and other application features.

3.1. Testing of Electrical Load Data Processing

Electrical data simulation is one of the tests used to assess the process of collecting and processing data for electrical load (appliances). This data is saved in a local database within the application and processed during the calculation phase. The testing aims to ensure that the data can be correctly retrieved and processed during the calculation. This is done by setting the debug log level on the Calculation page. The testing makes use of existing electrical load data from the database. Examples of data entered for processing the electrical load data is presented in Table 1, while Table 2 gives the testing results of electrical load data processing. The results obtained from the tests are then used as a reference for further tests.

Table 1. Examples of data entered for processing the electrical load data

Electrical Load	Quantity	Wattage (W)	Operational Hours	Duration
a	4	99	05:00 – 07:00	2.25 hours
b	5	100	10:00 – 02:00	16 hours

Table 2. Testing results of electrical load data processing

Time	Wattage (W)	Time	Wattage (W)
00:00	500	13:00	500
01:00	500	14:00	500
03:00	0	15:00	500
04:00	0	16:00	500
05:00	0	17:00	500
06:00	396	18:00	500
07:00	396	19:00	500
08:00	99	20:00	500
09:00	0	21:00	500
10:00	0	22:00	500
11:00	500	23:00	500
12:00	500		

3.2. Testing of Solar Irradiance Data Retrieval through API

The test seeks to assess whether the geograpic location being entered into the tool and the retrieval of solar irradiance data were successful by carrying the debug log level. The testing location is at latitude 3.589 and longitude 114.893, with a tilt angle of 30° and the aspect or azimuth of 0°.

The debug log from the tests for providing input location and retrieving irradiance data demonstrates that both are successful, as presented in Table 3. It should be noted that the solar irradiance data obtained from PVGIS are averaged every one-hour time step from 2005 to 2016.

Table 3. Testing results of solar irradiance data retrieval

Time	Gi (W/m^2)	Time	Gi (W/m^2)
00:00	0	12:00	7561.26
01:00	0	14:00	6626.56
02:00	0	15:00	5193.40
03:00	0	16:00	3582.74
04:00	0	17:00	1968.99
05:00	0	18:00	553.57
06:00	0	19:00	0
07:00	83.92	20:00	0
08:00	1519.71	21:00	0
09:00	2898.66	22:00	0
10:00	5058.98	23:00	0
11:00	6803.24		

3.3. Testing of Application Functionality

The simulation begins with entering a list of electrical loads for the house's planned installation. KawanSurya has a capability of taking a large number of electrical loads as the tool does not limit the household maximum power capacity (contracted power). However, for practical purposes, this study considers modelling of low maximum power capacity to reflect the tool's usability among houses and potential techno-economic implications of adopting on-grid rooftop PV systems for those typical houses.

For the case study (Simulation-1), Table 4 shows a range of electrical loads in a household with a contracted power of 2,200 VA. However, it should be noted that the appliances stated in Table 4 are assumed in terms of quantity and power rating. Should the user requires more accurate simulation results, proper measrurement or observation in the premises are required. This study uses a house with a 2,200 VA power contract in Tropodo, Sidoarjo Regency, East Java, as a case study. Figure 5 shows the polygon drawn on the west-facing part of the roof to mount the PV. The findings show that the house's latitude and longitude are obtained at -7.360, 112.754, respectively, and the usable roof space is 23.9 m^2.

Table 4. Electrical loads in a ousehold with a 2,200VA power contract

Electrical load	Quantity	Wattage	On-time	Off-time
Refrigerator	1	80	24 hours	-
Rice cooker	1	300	17:00	17:40
Iron	1	300	09:00	10:00
Water pump	1	600	07:00	08:30
Washing machine	1	150	08:00	09:00
Laptop	2	100	20:00	22:00
Water heater	1	500	05:30	06:30
AC ½ hp	2	375	20:00	05:30
AC 1 hp	1	750	20:00	05:30
TV	1	80	20:00	22:00
Lamp	15	10	17:30	22:00
Lamp	5	10	22:00	05:30

Figure 5. A user interface shows site and roof area

The technical parameter settings are based on the specifications of a 100 Wp monocrystalline solar PV module's specification [27]. The module's datasheet specifies the value of module size, maximum capacity, efficiency, NOCT (Nominal Operating Cell Temperature), and output power reduction per year. In this simulation, the roof tilt angle is fixed to 30°. Aside from that, the azimuth is facing west, as specified by the input API of PVGIS, whih 90° representing the west direction [18]. Table 5 shows the complete technical parameters entered into the tool. Meanwhile, the investment cost for installing rooftop PV per 1 kilowatt peak (kWp) is expected to be IDR 15 million, resulting in a total cost of IDR 33 million. The inverter costs IDR 4,290,000, which is 13% of the overall cost. While this simulation has a discount rate of 5%, the annual growth in electricity price and inflation in this scenario are set to 0%. These settings will be examined further in the subsequent simulation. The O&M (Operation and Maintenance) cost is set to IDR 0, assuming that the PV system maintenance is easy and can be performed independently by the owner. The electricity price is based on the utility tariff for a 2,200 VA power contract, while the sellback rate (electricity export to the grid) is assumed to be maximum at 100% of the electricity price. Regarding the sellback rate, however, it should be noted that the tool can also accommodate 0% sellback rate in anticipation of a changing policy, i.e., if the utility does not allow rooftop PV owners to export the electricity to the network.

Table 5. Technical parameters of Simulation-1

Parameter	Unit	Value
Contracted power capacity	VA	2,200
Maximum rooftop PV capacity	Wp	2,200
Size per PV module	m^2	0.67
Capacity per PV module	Wp	100
PV module efficiency (STC)	%	14.92
Nominal Operating Cell Temperature	°C	45
Temperature coefficient of power	%/°C	-0.39
Tilt angle	deg°	30
Azimuth	deg°	90
Output power reduction per year	%	0.8

Table 6. Economic parameters of Simulation-1

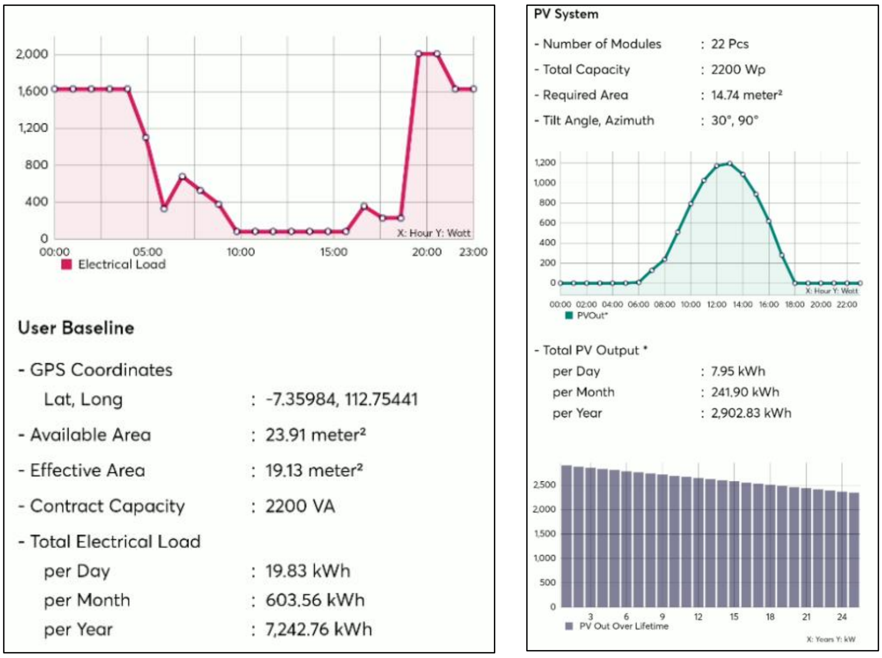
Parameter	Unit	Value
Inverter price	IDR	4,290,000
Interter lifetime	Year	15
System capital cost (exclude inverter price)	IDR	28,710,000
Electricity price	IDR	1,444.7
Export electricity price	IDR	1,444.7
Electricity price increase per year	%	0
Inflation	%	0
O&M cost per year	IDR	0
Discount rate	%	5
Project lifetime	Year	25

KawanSurya classifies the techno-economic analysis results into four sections: 1) User Baseline; 2) PV System; 3) Load Profile Scenario with Daily PV Output; and 4) Investment. The user baseline comprises the daily load curve, the geographic coordinates of the rooftop PV, the available roof size, the contracted power, and the total electrical load per day, month, and year, which are 19.83 kWh, 603.56 kWh, and 7246.76 kWh, respectively. The load curve created from this information serves as the basis for calculating the electricity export, billing, and savings obtained from the PV system.

The PV system section provides simulation results in terms of the number of PV modules, the total capacity of the rooftop PV system, the required area, the tilt angle and azimuth, the hourly PV output curve, and the total PV output over the project lifetime in terms of daily, monthly, and yearly. The PV output curve is calculated using irradiation data from the PVGIS API and technical parameters. The calculation shows that the PV installed capacity is limited to the contracted power of 2,200 VA. The required area is smaller than the available area. An asterisk (*) indicates that the total PV output was estimated prior to any reduction in power output. For this simulation, the total PV output is calculated as 7.95 kWh per day, 241.90 kWh per month, and 2902.83 kWh annually. The graph below the PV output curve depicts the drop in PV output power over the project's lifetime, based on the technical parameter of 0.8% power output reduction per year.

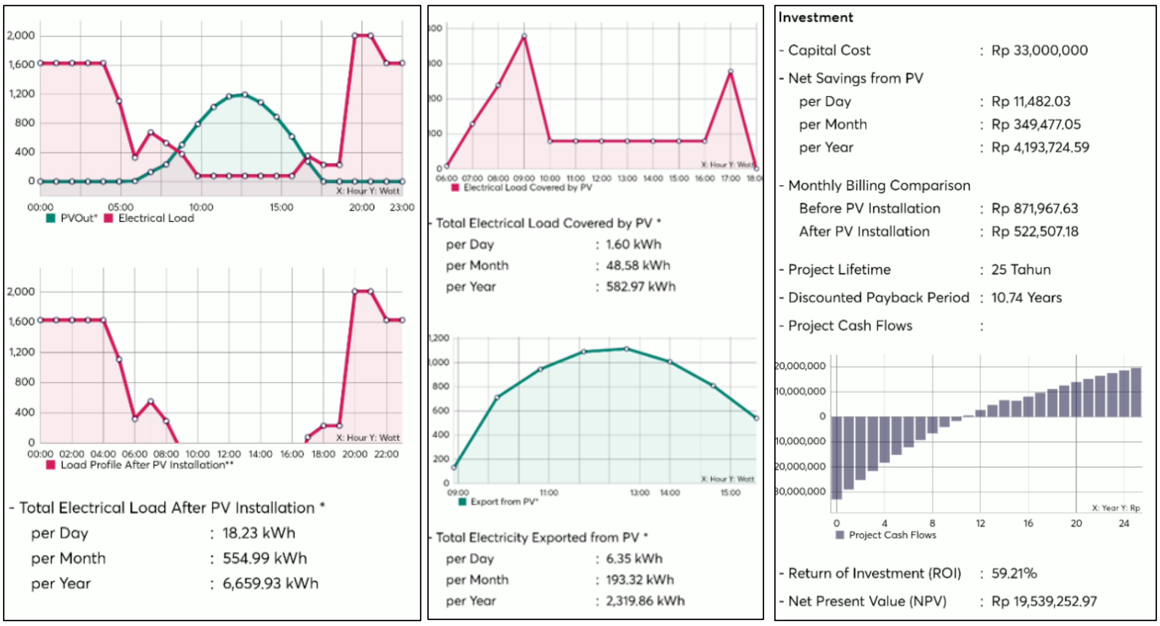
The load curve scenario with daily PV output provides simulation results on the hourly electricity load after PV installation, part of the electricity load covered by PV, and the amount of the electricity exported from PV to grid, denoted by asterisks which means before any power output reduction. In this simulation, the total electrical load after PV installation is 18.23 kWh per day, 554.99 kWh per month, and 6,659.93 kWh per year. PV covers a total electrical load of 1.60 kWh per day, 48.58 kWh per month, and 582.97 kWh annually. The total electricity export is 6.35 kWh per day, 193.32 kWh per month, and 2,319.87 kWh annually.

The investment section summarises results of the economic analysis of the rooftop PV. It shows the capital cost, net savings from PV, monthly bill comparison, project lifetime, payback period, cash flow graph, ROI, and NPV. The net savings from PV installation were calculated to be IDR 11,482 per day, IDR 349,477 per month, and IDR 4,193,725 per year. The monthly electricity bill before installing the rooftop PV is IDR 871,967, while after installing the rooftop PV, it is IDR 522,507. The monthly electricity bill comparison is based on the net savings from PV, as there are no O&M costs. The cash flow graph shows that the computation with a 5% discount rate yields a discounted payback of 10.85 years. The ROI is 59.21%, while the NPV is IDR 19,539,262.80. Figure 6 shows user interface of User Baseline (a) and PV System (b) of Simulation-1, while Figure 7 shows user interface/results for load profile scenario with PV output (a), (b), and investment section (c), all for Simulation-1.



(a) (b)

Figure 6. User interface of (a) User Baseline and (b) PV System of Simulation-1



(a) (b) (c)

Figure 7. User interface/results of (a), (b) Load Profile Scenario with PV Output, and (c) Investment, all for Simulation-1

As described above, the simulation (Simulation-1) resulted in a discounted payback period of 10.74 years at a 5% discount rate and a 100% bill reduction factor. Using Simultion-1 (S-1) as a reference, subsequent scenarios, however, have impacted the system's economic feasibility in terms of discounted payback period of the project. These scenarios include differences in inflation rates and increases in electricity bills. In Simulation-2 (S-2), introducing a 65% bill reduction factor, which means reducing the benefit of exporting electricity from PV to the grid by lowering the power export price to only 65% of the electricity rate per kWh, while leaving all other parameters unchanged from Simulation-1, will result in a (discounted) payback period of 19.79 years, or double the previous payback period.

Simulation-3 (S-3) involves changing the electrical load profile to a constant load while maintaining the 65% bill reduction factor and other parameters from S-1. This has increased the amount of energy provided by the PV system to offset the electrical load, yet the income from PV based on the power export price has decreased. This scenario results in a payback period of 11.79 years, one year longer than S-1. The findings show changes in the amount of electrical load covered by the rooftop PV system and the amount of electricity exported by it. Figure 8 depicts a part of S-3 results, illustrating the constant load profile scenario and total electrical load following PV installation.

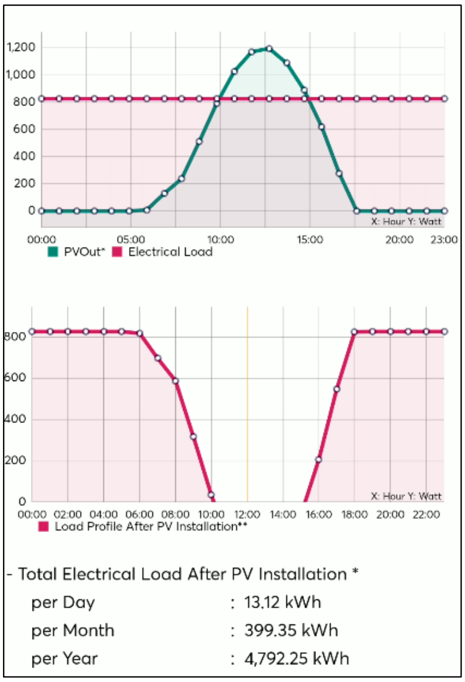


Figure 11. Constant load profile scenario in Simulation-3

Simulation-4 (S-4) considers a 2% inflation rate while keeping all other parameters the same as in S-1. In addition to having a negative economic impact, inflation helps rooftop PV users because inflation lowers the discount rate by increasing the money provided by the rooftop system, i.e., through exporting the electricity to the grid. The payback period shortens, allowing investors to repay their initial investment sooner. Assuming a 2% inflation rate, this simulation calculates a discounted payback period of 9.43 years.

Simulation 5 (S-5) incorporates a 2% annual increase in electricity costs while keeping the other parameters from S-1. Aside from increasing electricity costs, the price increase helps the rooftop PV users because increased electricity costs increase the income generated by the rooftop PV system, given a 100% export rate. This simulation provides a discounted payback period of 9.66 years. It should be noted that the payback period will be less than 9.66 years if the daily electrical load profile changes with increased electricity utilisation during 7 a.m. to 5 p.m. In terms of increasing electricity rates, it is also better for PV users to raise their daytime usage in order to lessen the cost impact on billing caused by high loading during the evening and night.

KawanSurya is also capable of demonstrating a case in which the payback period of an investment exceeds the project lifetime through a scenario in which an investment bacomes no longer financially feasible (see the result of Simulation-6 in Table 7). This is due to the investment in a rooftop PV system that generates power while having the monthly electricity bill below the minimum account threshold. This indicates a specified bottom limit on electricity bills that makes the payback period equal to the project lifetime, and any billing below this limit will render the system uneconomical. The simulation determined that under this case, the discounted payback period cannot be calculated since because it exceeds the project lifespan. Table 7 summarises possible discounted payback periods under different scenarios that involve bill reduction factors, electricity load scenarios, inflation rates, increases in electricity rate, and minimum bill limit.

Table 7. Discounted payback periods due to different scenarios

No.	Scenario	Discounted payback period (year)
1.	Simulation-1 (S-1)	10.74
2.	S-2: with 1 65% bill reduction factor	19.79
3.	S-3: with a 65% bill reduction factor and constant electrical load	11.79
4.	S-4: with a 2% inflation rate	9.43
5.	S-5: with an annual increase of 2% in electricity tariff	9.66
6.	S-6: minimum bill limit	Exceed project lifetime

Various discounted payback periods as presented in Table 7 indicate the capability of KawanSurya in computing various scenarios related to changes in techno-economic parameters of the rooftop PV system. While a variety of payback periods may provide residential consumers with insights into their preferred rooftop PV settings, decision-making based on the system's economic feasibility should also consider the ROI and NPV of various scenarios. Residential customers should expect to select rooftop PV since it has a greater NPV and ROI than other options, as well as a much shorter payback period.

The results in Table 7 further show that the payback period is highly dependent on two factors, i.e., the electrical load profiles and bill reduction factor. When the billing reduction factor is set to 65% and the load profile is the same as in Simulation-1, the discounted payback period increases dramatically. This study implies that if the billing reduction factor is set to 0%, or no compensation is provided to the customer for selling back electricity to the grid, the discounted payback period will surpass the project lifetime. As this is not a favourable scenario for rooftop PV system owners, it is of interest to boost power loading during the daytime in the context of the residential on-grid rooftop PV system.

While users can evaluate the potential techno-economic of rooftop PV using the available parameters that may influence the system's feasibility, including performing the sensitivity analysis of different cases, the assessment may incorporate combinations of important parameters to obtain key results that serve as candidates for rooftop PV investment decision-making. Residential customers, for example, can assess the impacts of various bill reduction factors, i.e., from 0-100%, and electrical load profiles while considering a range of increases in electricity rates and inflation.

While the tool is capable of demonstrating the techno-economic analysis of the potential rooftop PV installation in the residential sector, it is designed to be an entry-level tool for evaluating such potential. As a result, there are several limitations to the tool's functionality, including a lack of detail in technical modelling, particularly on weather conditions and the impact of shades. Furthermore, while the tool recognises the importance of PV output power reduction over time and so incorporates this variable in the model, it does not investigate temperature, dirt, and other variables that influence system performance over time.

4. CONCLUSION

This paper introduces KawanSurya: PV Calculator, a techno-economic analysis tool for assessing the feasibility of on-grid rooftop solar PV installation in the residential sector, and discusses the application's design methods and functionality, as well as testing through simulations and the results. The tool is built on an Android platform and uses the Kotlin programming language. KawanSurya, unlike other commonly used solar PV assessment applications, runs on Android mobile phones rather than a web-based computer platform. The tool intends to supplement the existing tools of rooftop solar PV by providing sufficient information for household sector customers to make sound decisions about the potential techno-economic impacts of installing solar rooftop PV due to different daily load profiles and other technical preferences and economic parameters. The analysis results are divided into four sections, i.e., user baseline, PV system, load curve scenario with daily PV output, and investment. While the tool is aimed towards Indonesia's residential sector, it is equally applicable to other jurisdictions looking to increase customer education and information dissemination.

The proposed Android application is intended to be a basic tool for assessing the technological and economic viability of rooftop solar PV. However, users can still perform other useful evaluations, such as sensitifity analysis of various cases and investigation of combinations of main parameters to acquire key findings for investment decision-making while still allowing for consideration of uncertain future costs, electrical loading, and policy.

While the proposed tool successfully carries out the techno-economic analysis and provides relevant simulation results, there are several limitations to note. First, the accuracy of the rooftop PV calculation results is dependent on the assumptions and estimations utilised. Second, while PV energy generation estimates are influenced by factors such as geographical location, weather conditions, and shading, the application lacks access to specific shading data for particular places. Third, the programme estimates solar energy output power using simplified models that do not account for variables such as temperature, dirt, panel degradation over time, and system efficiency, all of which affect energy production in real-world settings. It is important to note that the tool's given estimates may not fully reflect the actual scenario, therefore gathering appropriate and relevant data will help to improve the accuracy of the findings produced for the decision-making. Understanding these limitations leads to recommendations for future work. These include feature additions like scenario comparison and the inclusion of factors that may influence analysis outcomes.

ACKNOWLEDGEMENTS

We would like to thank the reviewers for their time and effort in reviewing the manuscript. All feedback and recommendations were helpful to help us improve the manuscript's quality.

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2. Email received from BEEI Editor Decision: Major Revisions Required
    - Email from BEEI containing Editor-in-Chief comments and reviewers' comments (24 February 2024)

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[EEI] Editor Decision - Major revisions Required

1 message

Prof. Dr. Ir. Tole Sutikno, ASEAN Eng. <beei@iaescore.com> Sat, Feb 24, 2024 at 5:21 PM
To: "Dr. Yusak Tanoto" <tanyusak@petra.ac.id>
Cc: Christopher Marvel <christopher.marvel19@gmail.com>, Hanny H Tumbelaka <tumbeh@petra.ac.id>

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-- Research Paper: min 25 references (primarily to journal papers) and Review/study/survey Paper: min 50 references (primarily to journal papers)

Dear Prof/Dr/Mr/Mrs. Dr. Yusak Tanoto,

We have reached a decision regarding your submission to Bulletin of Electrical Engineering and Informatics, "KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV", a Scopus (https://www.scopus.com/sourceid/21100826382) and ScimagoJR (https://www.scimagojr.com/journalsearch.php?q=21100826382&tip=sid&clean=0) indexed journal, with CiteScore: 3.0, SNIP: 0.639 and SJR: 0.299.

Our decision is to: Major revisions Required

1. Your revised paper should demonstrate a clear understanding of the key issues related to your topic of choice. The paper should display analysis and not mere summary of the topic under consideration. It should also include evidence to support arguments where necessary. Your paper should demonstrate a connection of the references you mention to the central topic and to each other where necessary throughout the paper.

2. Authors should have made substantial/intellectual contribution (the new findings with contrast to the existing works). Highlight the main theme of the work with the specific goals of the design and development approach. For preparing your paper strictly adhere to the guide of authors, please read the checklist for preparing your paper for publication at: https://beei.org/index.php/EEI/about/editorialPolicies#custom-4. Please try to follow the format as closely as possible.

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I look forward for hearing from you

Thank you

Best Regards,
Prof. Dr. Ir. Tole Sutikno, ASEAN Eng.
Universitas Ahmad Dahlan
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EDITOR-IN-CHIEF COMMENTS:

1. The introduction should contextualize your study and provide any specialized information that the general measurement or control reader may need to understand what follows. It must explain the significance of previous work and the problems your work solves. It should also include a list of comparable works. The introduction should define the article's contribution(s) and show how it is demonstrated in the rest of the manuscript. A typical introduction should be as brief as possible and include the following:
a). An outline of the problem.
b). A review of the relevant literature, noting briefly the major contributors and indicating:
 - What the main contributors did?
 - What the main contributors found?
c). A statement of unsolved problems and/or areas requiring improvement; particularly the one(s) considered in your manuscript.
d). In regard to the above, describe what you will perform that has not been done before (what are your new contributions?).
e). An outline of how the following sections show what you did and how its relevance will be demonstrated.

2. This paper lacks critical discussion, comparison, and interpretation. What are the implications of your findings. What will come in useful in the future?

ASSOCIATE EDITORS COMMENTS:

1. The method section is a detailed step-by-step description of the experimental procedure that includes all of the information needed to replicate the work described in the paper. The Method must include a description of both novel and standard experimental approaches, as well as whatever minimal justification is required to persuade the reader that the methods are correct.
A well-written Method section:
a). Is the "how-to" section of your paper, containing all of the pertinent details for producing your results.
b). Persuades the reader that your approach is correct by providing justification for selecting your methodology, which may include analysis or theoretical justification.
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The Methods section's purpose is to describe how the questions and knowledge gaps raised in the Introduction will be addressed in the Results section.

2. Please look for relevant references at ipmugo.com, download, read, and cite the sources to improve your paper.

Reviewer A:

The paper entitled "KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV" is intriguing, but revisions are required.

Introduction: This first section of the main text should describe the problem, any existing solutions you are aware of, and the major limitations. Also, explain what you hope to achieve through your research.

Method: Every article should have a detailed Method section that provides the reader with enough information to determine whether the study is valid and reproducible. Include sufficient details so that a knowledgeable reader can replicate the experiment. However, use references and supplementary materials to highlight previously published procedures.

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Conclusion: Your conclusion is not simply a summary of what you've already written. It should take your paper a step further by answering any outstanding questions. Summarize what you've shown in your study and suggest potential applications and extensions. The main question in your conclusion should be, "What do my findings mean for the research field and my community?"

Reviewer B:

When it comes to structuring the body of an article, it is critical to keep things organized and coherent. Begin with an effective introduction that captures the reader's attention. Follow it up with a logical sequence of paragraphs that each address a different aspect of the main topic. Use topic sentences to clearly state the main point of each paragraph. Smooth transitions between paragraphs help to keep the flow going. Finally, provide a concise summary or final thoughts that tie everything together.

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5). Implications for future research—how to explore further
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6). Conclusion—summarize content
Example: Recent observations indicate that the ".....". Our findings offer definitive proof that this phenomenon is linked to "....." alteration, rather than being caused by increased quantities of ".....".

Reviewer C:

Does the title of the paper accurately reflect the major focus contribution of this paper? Is the abstract an appropriate and adequate digest of the work? Is the paper clear, concise, and well organized?

Please suggest change of the title as appropriate, and how should authors organize their paper
:

How does this paper show the rate of contribution strength and scientific quality to the field? Do authors place the paper in proper context by citing relevant papers? Is the paper free from obvious errors, misconceptions, or ambiguity? Is the paper written in correct English? Please note grammatical errors and suggest corrections:

Please mark approite scale for the overall grade for this paper?:
Below average

Reviewer's comments and suggestions how to improve the paper
:

1. We advise authors to list author affiliations completely and hierarchically from the lowest to the highest level: Laboratory (if any, or if under a department), Department (if any), Faculty, University, City, Country
2. The references you used for your paper do not use the format suggested. I suggest to the author to readjust the reference writing in your paper to the IEEE format, you can learn more at the following link:
https://ieeeauthorcenter.ieee.org/wp-content/uploads/IEEE-Reference-Guide.pdf

3. The sub figure (Figure 2) of your paper is not mentioned again in the body text. I suggest that you briefly explain each figure and sub figure in the body text of your paper before the figure appears to make your paper better.
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6. Table 6 are not mentioned in the text. I suggest that tables should be explained in the sentence before the table is displayed. All tables must be referenced in the text.
7. I found that some paragraphs in your paper consist of less than 3 sentences. I suggest to the writer to adjust the paragraphs to at least 3 sentences.
8. In your acknowledgments section, I recommend including the contract number of your research (if any).

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3. Submitted the revised manuscript and detailed response via the online submission system
    - The detailed response to editors' and reviewers' comments (18 March 2024)
    - The revised manuscript according to the editor and reviewer's comments with yellow highlights – Round 1 (18 March 2024)

-- Paper ID# 8309
-- Strictly adhere to the guidelines for authors
https://iaescore.com/gfa/beei.docx, also read: https://bit.ly/35R6JTs and
https://bit.ly/2DxU9MI
-- Research Paper: min 25 references (primarily to journal papers) and
Review/study/survey Paper: min 50 references (primarily to journal papers)

Dear Prof/Dr/Mr/Mrs. Dr. Yusak Tanoto,

We have reached a decision regarding your submission to Bulletin of Electrical Engineering and Informatics, "KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV", a Scopus (https://www.scopus.com/sourceid/21100826382) and ScimagoJR (https://www.scimagojr.com/journalsearch.php?q=21100826382&tip=sid&clean=0) indexed journal, with CiteScore: 3.0, SNIP: 0.639 and SJR: 0.299.

Our decision is to: Major revisions Required

1. Your revised paper should demonstrate a clear understanding of the key issues related to your topic of choice. The paper should display analysis and not mere summary of the topic under consideration. It should also include evidence to support arguments where necessary. Your paper should demonstrate a connection of the references you mention to the central topic and to each other where necessary throughout the paper.

2. Authors should have made substantial/intellectual contribution (the new findings with contrast to the existing works). Highlight the main theme of the work with the specific goals of the design and development approach. For preparing your paper strictly adhere to the guide of authors, please read the checklist for preparing your paper for publication at: https://beei.org/index.php/EEI/about/editorialPolicies#custom-4. Please try to follow the format as closely as possible.

3. Attention Please! Method section
The experimental/method section is a straightforward description of what you did in your research and how you did it, clear and detailed at every stage. A detailed method section will make your article reproducible by other researchers, allowing them to trust and build on your work. A detailed explanation of all methodologies, instruments, materials, procedures, measurements, and other variables used in the investigation. A thorough description of the data analysis and decisions for excluding some data and including others.

Please submit your highlighted updated manuscript in MS Word file format (or LATEX source files; ZIP your files if you present your paper in LaTeX). Refer to materials at: https://bit.ly/35R6JTs and https://bit.ly/2DxU9MI for further guidelines, and submit the revised paper within 8 weeks through our online system at the same ID number (NOT as a new submission) on Tab "Review" as an "Author Version" file for re-review by Reviewers. Then, your revised paper will be judged for acceptance, revision, or rejection based on the editor's and Reviewers comments.

I look forward for hearing from you

Thank you

Best Regards,
Prof. Dr. Ir. Tole Sutikno, ASEAN Eng.
Universitas Ahmad Dahlan
beei@iaescore.com

EDITOR-IN-CHIEF COMMENTS:

1. The introduction should contextualize your study and provide any specialized information that the general measurement or control reader may need to understand what follows. It must explain the significance of previous work and the problems your work solves. It should also include a list of comparable works. The introduction should define the article's contribution(s) and show how it is demonstrated in the rest of the manuscript. A typical introduction should be as brief as possible and include the following:
a). An outline of the problem.
b). A review of the relevant literature, noting briefly the major contributors and indicating:
- What the main contributors did?
- What the main contributors found?
c). A statement of unsolved problems and/or areas requiring improvement; particularly the one(s) considered in your manuscript.
d). In regard to the above, describe what you will perform that has not been done before (what are your new contributions?).
e). An outline of how the following sections show what you did and how its relevance will be demonstrated.

Done

2. This paper lacks critical discussion, comparison, and interpretation. What are the implications of your findings. What will come in useful in the future?

Done.

ASSOCIATE EDITORS COMMENTS:

1. The method section is a detailed step-by-step description of the experimental procedure that includes all of the information needed to replicate the work described in the paper. The Method must include a description of both novel and standard experimental approaches, as well as

whatever minimal justification is required to persuade the reader that the
methods are correct.
A well-written Method section:
a). Is the "how-to" section of your paper, containing all of the pertinent details for producing your results.
b). Persuades the reader that your approach is correct by providing justification for selecting your methodology, which may include analysis or theoretical justification.
c). Gives readers the details, algorithms, and techniques necessary to confirm and/or replicate your findings
The Methods section's purpose is to describe how the questions and knowledge gaps raised in the Introduction will be addressed in the Results section.

Done.

2. Please look for relevant references at ipmugo.com, download, read, and cite the sources to improve your paper.

Done. The paper has now cited three relevant papers from ipmugo.com

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Reviewer A:

The paper entitled "KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV" is intriguing, but revisions are required.

Introduction: This first section of the main text should describe the problem, any existing solutions you are aware of, and the major limitations. Also, explain what you hope to achieve through your research.

Done. The problem, any existing solutions, and major limitations have been added in paragraph 1-7. This research's hope to achieve has been added in paragraph 7.

Method: Every article should have a detailed Method section that provides the reader with enough information to determine whether the study is valid and reproducible. Include sufficient details so that a knowledgeable reader can replicate the experiment. However, use references and supplementary materials to highlight previously published procedures.

Done. Enough information about detailed methods has been added so that readers can do similar things.

Results and Discussion: In this section, you will present the essential or primary findings of your research. Summarize major findings in tables; be concise; and use online supplement tables or figures to keep the paper to a manageable length. Here, you should also explain to your readers what the results mean. Do explain how the results relate to the study's objectives and hypotheses, as well as how the findings compare to those from other studies. Explain every possible interpretation of your findings, as well as the study's limitations.

Done. More detailed information and descriptions have been added in the results and discussions section.

Conclusion: Your conclusion is not simply a summary of what you've already written. It should take your paper a step further by answering any outstanding questions. Summarize what you've shown in your study and suggest potential applications and extensions. The main question in your conclusion should be, "What do my findings mean for the research field and my community?"

Done. The research findings and mean for the research field and community have been included in paragraph 1 and 3 of the conclusion section.

Reviewer B:

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Done, the introduction section has been re-arranged to address different aspects of the main topic. All paragraphs have been presented smoothly and coherently, including the review of existing studies/tools, a gap, an introduction to the main research, the main purpose, and contribution of the current research.

Method section: The method should describe how you carried out your research and the experimental procedure. One of the most important things to remember when writing the method section is that it should be detailed enough to allow other researchers in your field to replicate your experiments and findings. You should arrange the steps logically so that your readers can easily follow your description.

Done. Some codes and a diagram have been added into the text. More details and descriptions have been added on the experimental procedure that has been re-arranged.

Results and Discussion section: A great discussion should be well-organized. One of the keys to writing a great paper is having a thorough and concise discussion. It provides a critical platform for interpreting and connecting your findings to the larger scientific context. The structure presented below is a traditional 6-step approach to creating a well-crafted discussion section, which you should carefully consider.

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Done. The six-steps discussions section has been added in Section 3.4.

Reviewer C:

Does the title of the paper accurately reflect the major focus contribution of this paper?

Is the abstract an appropriate and adequate digest of the work?

Is the paper clear, concise, and well organized?

Please suggest change of the title as appropriate, and how should authors organize their paper:

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Please note grammatical errors and suggest corrections:

Please mark approite scale for the overall grade for this paper?: Below average

Reviewer's comments and suggestions how to improve the paper:

1. We advise authors to list author affiliations completely and hierarchically from the lowest to the highest level: Laboratory (if any, or if under a department), Department (if any), Faculty, University, City, Country

Done

2. The references you used for your paper do not use the format suggested. I suggest to the author to readjust the reference writing in your paper to the IEEE format, you can learn more at the following link:
https://ieeeauthorcenter.ieee.org/wp-content/uploads/IEEE-Reference-Guide.pdf

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Done. The order of sequence for all figures and tables has been re-checked.

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Done.

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Done.

7. I found that some paragraphs in your paper consist of less than 3 sentences. I suggest to the writer to adjust the paragraphs to at least 3 sentences.

Done.

8. In your acknowledgments section, I recommend including the contract number of your research (if any).

Done.

KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV

Yusak Tanoto[1], Christopher Marvel[1], Hanny H. Tumbelaka[1]
[1]Electrical Engineering Department, Faculty of Industrial Technology, Petra Christian University, Surabaya, Indonesia

Article Info

Article history:

Received month dd, yyyy
Revised month dd, yyyy
Accepted month dd, yyyy

Keywords:

On-grid
Solar PV
Rooftop PV
Techno-economic
Android application

ABSTRACT

Many developing countries, including Indonesia, are still making poor progress in residential rooftop PV adoption. Aside from the challenges associated with regulatory implementation, the potential utilisation of solar PV energy in comparison to total electricity consumption, and the investment feasibility justification, are important technical and economic factors that can influence residential customers' decisions to install rooftop PV. This paper introduces KawanSurya: PV Calculator, a solar rooftop PV techno-economic application for Android mobile phones that is available for free on Google Play. It focuses on assessing on-grid rooftop PV potential installations, allowing users to select a specific geographic location, calculate their daily load profiles, and determine available roof areas. The tool uses irradiance data from the PVGIS API and HOMER's PV output equation to determine hourly rooftop PV output power. This paper describes the application's design methodologies and functionality, as well as the simulation-based testing and findings. This study adds methodological contribution to the literature on renewable energy applications, specifically to people's understanding, by introducing KawanSurya as an alternative method for evaluating possible rooftop PV installations. While the tool is aimed at Indonesia's residential sector, it is also applicable to other jurisdictions looking to imporve customer education and information.

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1. INTRODUCTION

Climate change has become a global concern, and the Paris Agreement has brought countries together to reduce global greenhouse gas emissions to keep global temperature rise below 2°C and to work towards keeping it below 1.5°C [1]. One of the efforts to reach these aims in the electricity industry is the transition to renewable energy technology. In 2022, renewable energy accounted for more than 83% of additional capacity, with wind and solar accounting for more than 91%, including rooftop PV [2], [3]. Rooftop solar photovoltaics (PV) will continue to play an important role in reducing greenhouse gas emissions from the energy sector, particularly if proper legislation and support measures are implemented [4].

Many developing nations, like Indonesia, are still making slow progress with residential rooftop PV adoption. The Indonesian government plans to achieve a 23% renewable energy mix by 2025, including 3.6 GW of rooftop PV. The Indonesian government plans to achieve a 23% renewable energy mix by 2025, including 3.6 GW rooftop PV [5]. However, attaining this aim appears to be difficult given that the installed capacity of rooftop PV in Indonesia as of May 2023 was just 95 MWp, serving 7,075 customers across the country, 72% of which were residential customers [6]. The potential for solar rooftop PV adoption, especially in the residential sector, appears positive in many developing countries, including Indonesia, given the benefits of worldwide PV system cost reductions [7]. While the market potential is significant, for example, given a large city with approximately 170-186 MWp rooftop capacity from the residential sector, or approximately 110 GWp for a province, capacity deployment necessitates a wide range of supportive policies, comprehensive information dissemination, and appealing government incentives [8], [9].

Many studies have identified and assessed the challenges to residential rooftop PV adoption. These include economic barriers, which largely address monetary costs and benefits [10], technical hurdles, which can involve knowledge and information aspects [11], and social and regulatory barriers [12]. In Indonesia, these include high initial investment costs, lack of access to installation services, lack of availability of information, disadvantageous PV export tariffs and policy inconsistencies, among other things [13]. While the proposed solutions to the economic barriers may include the introduction of a solar PV leasing package by the utility and a green financing mechanism or similar form of subsidies to reduce the upfront cost burden, one of the proposed solutions to improve public knowledge and clear up misperceptions about costly technology tariffs and policy inconsistencies, among others [10].

Some residential customers may already be aware of the advantages of employing sustainable energy technologies and their ability to reduce electricity bills. However, two important technical and economic factors that can influence residential customers' decisions on whether or not to install rooftop PV are the potential utilisation of solar PV energy in comparison to total electricity consumption, and the investment feasibility justification from exporting PV energy to the grid. In this context, residential customers require a tool that provides an adequate overview of the system in terms of the techno-economic potential of rooftop PV. While people are generally not expected to evaluate the potential of installing rooftop PV using complicated software or tools designed for academic or research purposes, there are a limited number of handy applications or tools that allow residential customers to assess the techno-economic potential of installing solar rooftop PV in their homes that are sufficiently appropriate and ‘independent’, which means they are not designed by or part of the solar PV companies or contractors.

Examples of such tools include the Photovoltaic Geographical Information System (PVGIS) [14] and the PVWatts Calculator [15]. PVGIS is an interactive web-based tool created by the European Commission (EU) to assess the performance of grid or off-grid-connected PV in a given geographic region. PVWatts is another web-based application developed by The National Renewable Energy Laboratory (NREL). A few rooftop PV techno-economic studies have used PVGIS and/or PVWatts as tools, such as comparing the performance of free-standing and rooftop PV in different climatic zones [16] and evaluating the techno-economic features of residential PV systems with a tiered rate and net-metering [17]. While PVGIS provides users with relevant simulation outputs such as yearly PV energy output, variability, electricity cost, monthly PV energy output, and an outline of the horizon, it does not consider the user load profile, resulting in the system’s payback period. Users can measure the performance of PV installations based on average monthly solar radiation and system energy output. Meanwhile, PVWatts provides an optional analysis that considers the roof area when determining system size, but, like PVGIS, does not account for user load profile.

In Indonesia’s context, a rooftop PV calculator called SolarHub [18] can be used to estimate rooftop PV capacity, monthly PV energy generation, system costs and savings, necessary roof area, avoided CO_2 emissions, and payback period. While the tool is useful in assisting residential customers with rooftop PV investment decisions, users cannot specify a location based on a specific geographical coordinate, but rather the province in which they live, as the tool calculates the associated solar PV output for that province. Furthermore, the tool does not include the household’s electricity consumption pattern, which could be valuable in determining PV potential.

While existing applications are typically designed on a web-based platform and so require a computer to function, information dissemination about rooftop PV necessitates alternative platforms. Given these circumstances, this paper introduces KawanSurya: PV Calculator (in English means ‘solar friend’, hereafter KawanSurya), a solar rooftop PV techno-economic tool that operates on Android mobile phones and is free on Google Play. The proposed tool focuses on the evaluation of on-grid rooftop PV potential installations, allowing users to select a specific geographic location, calculate their daily load profiles, and measure the available roof area. The programme calculates hourly PV output power using irradiation data from the PVGIS API [19] and HOMER’s PV output equation [20]. Meanwhile, the effect of shading [21] is included directly in the PV output equation through the derating factor. This paper explains the application’s design processes and functionality, as well as simulation-based testing and findings. This study makes a methodological contribution to the literature on renewable energy applications particularly to people’s comprehension, by offering KawanSurya as an alternate way for evaluating rooftop PV potential installations. While the tool is intended for Indonesia’s residential sector, it is also applicable to other jurisdictions seeking to improve customer education and information dissemination. The rest of this paper is structured as follows: Section 2 describes the tool’s design method; Section 3 presents the results and discussions; Section 4 provides some conclusions on the findings and suggestions for future work.

2. METHOD

2.1. Development and Utilisation Procedure of KawanSurya

Figure 1 depicts the flowchart for KawanSurya. It particularly shows the stages for using the tool, which includes entering the appropriate parameters, computing inputs, and presenting outcomes. A more detailed description of the tool's application stages is provided as follows: 1) The user inputs required information such as the household appliances and their operation hours, as well as technical and economic parameters, the available roof area which defines the maximum number of solar PV modules that can be installed, and the location; 2) The programme uses the PVGIS API to retrieve irradiance data. KawanSurya uses an irradiance dataset from 2005 to 2016, with a time step of one hour; 3) The programme calculates the energy produced by the rooftop PV system over one year on an hourly basis; 4) The tool generates a daily load curve with a one-hour time step and a rooftop PV energy generation curve to show the user the possible utilisation of the energy generated by the PV, i.e., which can be consumed by the load (appliances) and part of the energy that is exported to the grid; 5) The programme computes the PV system's output power, the shares of the energy consumed by the appliances, and energy exported to the grid, as well as economic assessments such as bill comparison, Net Present Value (NPV), Return on Investment (ROI), payback period, cash flow. It also calculates the required area for rooftop PV installations and the number of PV modules required; 6) The tool displays all of the results.

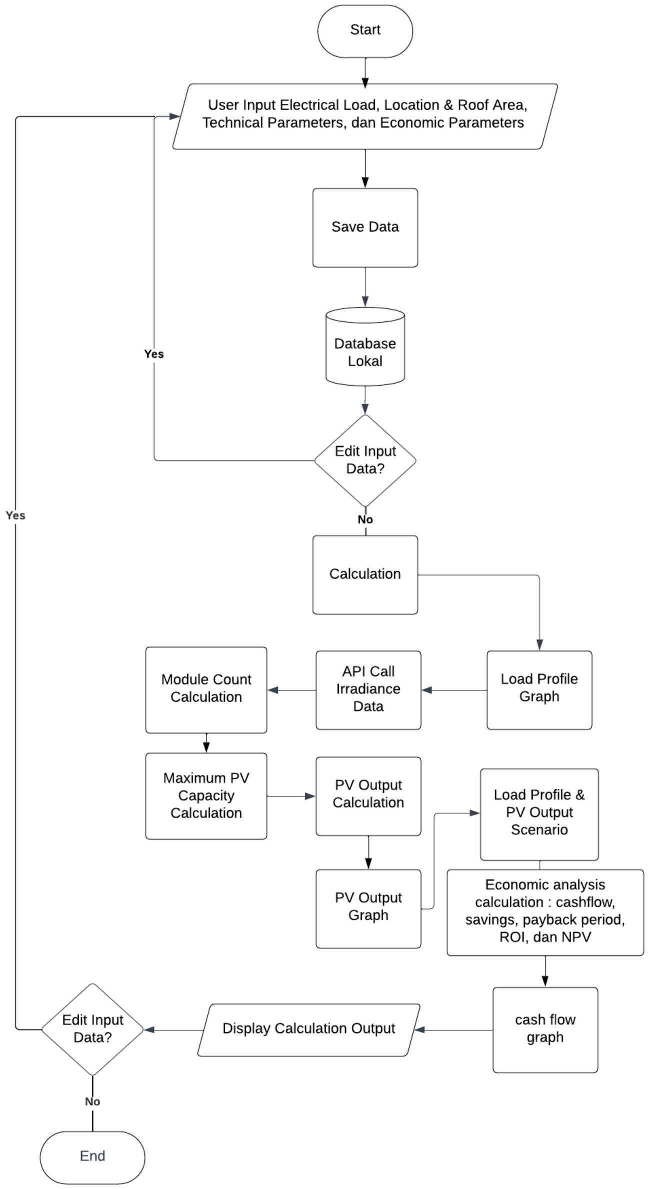


Figure 1. Flowchart of KawanSurya

The KawanSurya App is available online and can be downloaded using the following link: https://play.google.com/store/apps/details?id=com.christophermarvel.pvcalc or in Google Play for Android mobile phones. KawanSurya is built with Kotlin. It is the native high-level programming language for Android. Android Studio is used to code data processing, calculation, and user interface components. The tool is intended for use with Android version 8 up to 13. Figure 2 depicts the tool's user interface on an Android phone in English and Bahasa Indonesia after it has been downloaded and run. The tool interface is organised into five major sections or pages: *Electrical Load*, *Location and Area*, *Technical Parameters*, *Economic Parameters*, and *Calculation*. Aside from these primary pages, there is an Information page with relevant information about the application and a user guide.

(a) (b)

Figure 2. The Android-based user interface of KawanSurya (a) in English, and (b) in Bahasa Indonesia

The tool is intended to generate both technical and economic types of output to demonstrate the techno-economic feasibility of the proposed on-grid rooftop PV installation. As a result, KawanSurya is developed in the absence of energy storage solutions, such as batteries. Technical outputs include the amount and capacity of PV modules, the required roof area, daily load profile and PV output power curves, electricity energy generated by the rooftop PV system, electricity exported back to the grid, grid energy supply, and energy savings. Meanwhile, economic outputs include financial savings, electricity bills after installing PV, cash flow, payback period, ROI, and NPV. The user interface/user experience design approach is built on the understanding of user problems and wants. The tool is created with both low and high-fidelity wireframes to enable practical and aesthetic merging in the design. This helps to ensure that the final design addresses relevant issues and effectively meets the basic needs of the consumers.

2.2. Navigation and Database

The tool's navigation in KawanSurya enables users to interactively browse, enter, and exit numerous functions. Moreover, it offers a uniform and predictable user experience by adhering to a set of established principles designed specifically for the tool. Meanwhile, KawanSurya processes a local database using Room Database, a library supplied by Android Jetpack [22] which simplifies data management and access within an Android app. Room Database is built on top of SQLite [23], a database engine that serves as the data storage basis in Android applications. In this tool, the database has four distinct entities: *Task*, *Dpd*, *Eko*, and *Map*. By establishing these entities, users inform the database that they want to build tables to contain data of this type. As a result, when the database is constructed, it will contain different tables for each entity. Figure 3 and Figure 4 show the navigation diagrams for KawanSurya and the developed database for the tool, respectively. There are several class diagrams developed for KawanSurya. It depicts the system structure that is comprised of classes that are defined for building the whole system. Figure 5 shows a class diagram of the *Location and Area* page.

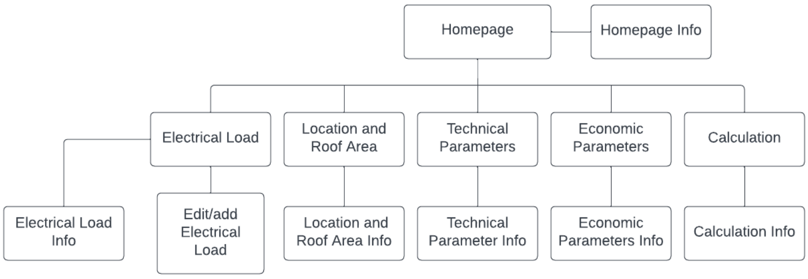


Figure 3. KawanSurya navigation diagram

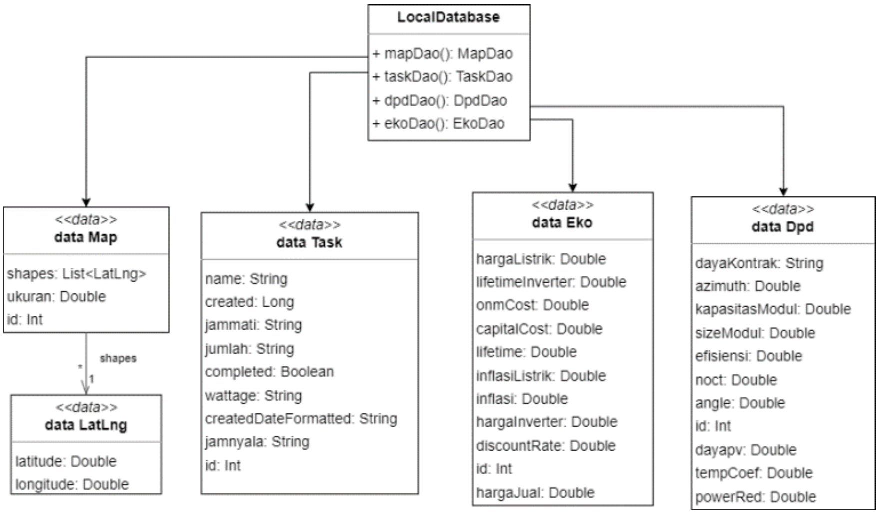


Figure 4. KawanSurya database scheme

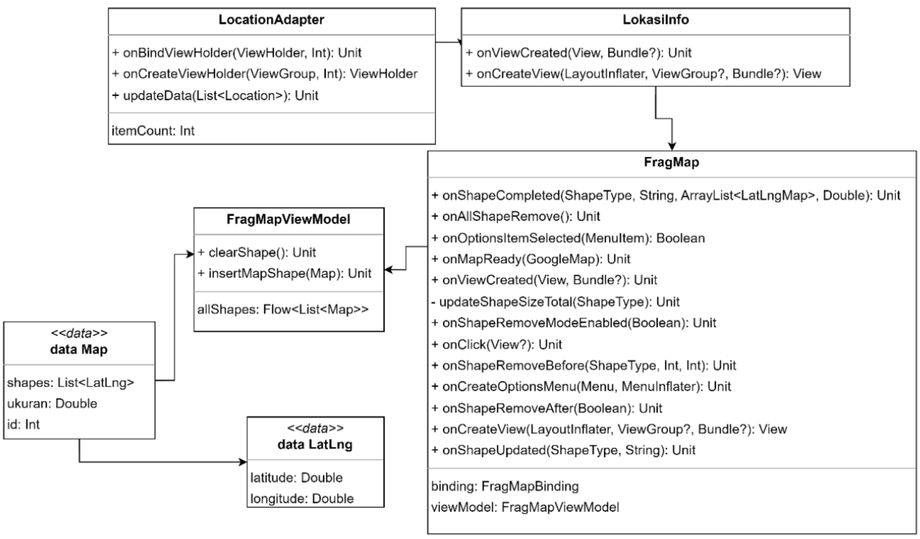


Figure 5. A class diagram of the *Location and Area* page

2.3. Electrical Load Page

The Electrical Load page allows users to specify the number of electrical loads or appliances. Users can add an appliance by clicking the 'Add' button and entering its name, amount, active power or wattage, and operational hours. The tool determines the appliance's operational hours by subtracting the on-time and off-time that users choose. Users can enter different appliance data to have the program gather a 24-hour electrical load of the premise. All the submitted data will let the program generate the user's daily electrical load data and curve, allowing it to estimate the amount of self-consumed PV energy and excess energy sent back to the grid.

2.4. Technical Parameters Page

On the Technical Parameters page, users can enter a variety of technical parameters for the rooftop PV system to be installed, which substantially aids the tool in calculating the rooftop PV output power hourly and performing economic evaluations of the rooftop PV system. The page includes installed PLN (Indonesia's national electricity utility company) contracted power capacity (VA), maximum rooftop PV capacity (Watt-peak, Wp), PV module size (m^2), capacity per module (Wp), PV module efficiency (%), nominal operating cell temperature (°C), and temperature coefficient of power (%/°C). In addition, tilt angle (°), azimuth (0° = South, 90° = West, -90° = East), and annual power output reduction (%) are also incorporated in the Technical Parameters page. While the tool allows users to change the technical parameters entered into their rooftop PV installation plan and define technical settings, it also provides default values to help users go forward with the simulation.

Irradiance data is essential for calculating the output power of rooftop PV systems. KawanSurya obtains irradiance data from the PVGIS API, which is retrieved from the PVGIS SARAH-2 Dataset [24]. This dataset contains sun irradiance data with a one-hour time step spanning 2005 to 2016. Retrofit will be used to create an API request with parameters such as latitude, longitude, month, output format, local time, global, angle, aspect, and temperatures. The following code is applied to request the PVGIS SARAH-2 datasets: https://re.jrc.ec.europa.eu/api/DRcalc?lat=7.131&lon=106.93&month=0&ouputformat=json&localtime=1&global=1&angle=12&aspect=45&showtemperatures=1. Meanwhile, Figure 6 shows a part of the code that is created to retrieve the solar irradiance dataset for a specific place from PVGIS.

```
interface ApiInterface {
        @GET("api/v5_2/DRcalc")

        fun getDatas(  @Query("lat") lat: Double,
                       @Query("lon") lon: Double,
                       @Query("month") month: Int,
                       @Query("ouputformat") ouputFormat: String,
                       @Query("localtime") localtime: Int,
                       @Query("global") global: Int,
                       @Query("angle") angle: Double,
                       @Query("aspect") aspect: Double,
                       @Query("showtemperatures") temp: Int
        ) : Call<ResponseData>
}
object RetrofitHelper {
        val baseUrl = "https://re.jrc.ec.europa.eu/"
        fun getInstance(): Retrofit {
            return Retrofit.Builder().baseUrl(baseUrl)
            .addConverterFactory(GsonConverterFactory.create())
            .build()
            }
}
Private fun getDatas() {
    val api =
RetrofitHelper.getInstance().create(ApiInterface::class.java)
    val viewModel2 =
ViewModelProvider(this)[FragMapViewModel::class.java]
    lifecycleScope.launch {
        var lat: Double
        var lon: Double
        viewModel2.getAllShapes().collect {
            if (it.isNotEmpty()) {
                lat = it[it.size - 1].shapes[0].latitude
                lon = it[it.size - 1].shapes[0].longitude
                binding.tvLatlon.text = "%.5f, %.5f".format(lat, lon)
                var angle: Double
                var aspect: Double
                var dayaKontrak: String
                val viewModel1 =
ViewModelProvider(this@KalkulasiFragment)[DpdViewModel::class.java]
                viewModel1.getDpd()?.observe(viewLifecycleOwner) { dpd ->
                if (dpd != null) {
                    angle = dpd.angle
                    aspect = dpd.azimuth
                    dayaKontrak = dpd.dayaKontrak
                    binding.tvtvangleazimuth.text =
                    "${if (angle % 1 == 0.0) angle.toInt()
                    else angle}°, ${
                    if (aspect % 1 == 0.0) aspect.toInt()
                    else aspect}°"
                    binding.tvDayaKontrak.text = "$dayaKontrak VA"
                    api.getDatas(lat, lon, 0, "json", 1, 1, angle, aspect, 1).enqueue(object:
Callback<ResponseData> {
                    override fun onResponse( call: Call<ResponseData>, response:
Response<ResponseData>
```

Figure 6. A screenshot of coding for retrieving solar irradiance dataset

2.5. Location and Area Page

On the *Location and Area* page, users can estimate the available roof area by drawing a polygon and clicking on the areas on the house's roof where the solar PV modules would be mounted. The programme will read the site's geographic latitude and longitude and compute the area of the resulting polygon. The area measurement makes use of the MapDrawingManager library. The computed roof area that is displayed on the Location and Area page is an effective area that considers 80% of the true size of the measured polygon to help with installation practicality. Figure 7 depicts a screenshot of the house coordinates and roof area in KawanSurya. It especially indicates the house's coordinates of -7.295° (South Latitude) and 112.726° (East Longitude), as well as the roof area of 18.27 m^2. This usable roof space shows 80% of the total area within the polygon for installation feasibility purposes.

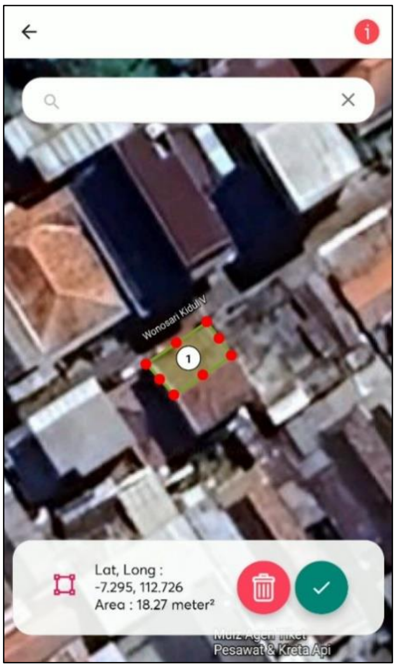


Figure 7. Screenshot of the location and roof area in KawanSurya

2.6. PV Output Power

KawanSurya calculates rooftop PV output power using the HOMER software's given equation. It considers a variety of metrics, including the derating factor and the factors commonly used to calculate PV array temperatures, such as solar absorptivity and solar transmittance. The derating factor considers a variety of factors that affect the PV system's performance, including panel dirt, wire loss, shadowing, snow coverage, and aging. This tool calculates an estimated typical value of 0.77 [25] to determine how much these parameters influence the performance of the rooftop PV system. Solar absorptivity is the percentage of solar radiation that a surface absorbs, whereas solar transmittance is the percentage of solar radiation that passes through a surface. The tool takes the product of solar absorptivity and solar transmittance of 0.9 or 90% [26]. Hence, the equations used to determine rooftop PV output power and PV cell temperature are as follows.

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}}\right) [1 + \alpha_p (T_c - T_{C,STC})] \quad (1)$$

where P_{PV} is PV output (kW); Y_{PV} is rated capacity solar PV array in standard test conditions (kW); f_{PV} is derating factor (%); $\overline{G_T}$ is the solar radiation incident on the PV array in the current time step (kW/m^2); $\overline{G_{T,STC}}$ is the incident radiation at standard test conditions (1 kW/m^2); α_p is the temperature coefficient of power (%/°C); T_c is the PV cell temperature in the current time step (°C); and $T_{C,STC}$ is the PV cell temperature under standard test conditions (25°C).

$$T_c = \frac{T_a + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(1 - \frac{\eta_{mp,STC}(1 - \alpha_p T_{c,STC})}{\tau\alpha}\right)}{1 + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_p \eta_{mp,STC}}{\tau\alpha}\right)} \quad (2)$$

where T_c is the PV cell temperature (°C); T_a is the ambient temperature (°C); $T_{c,NOCT}$ is the nominal operating cell temperature (°C); $T_{a,NOCT}$ is the ambient temperature at which the NOCT is defined (20°C); G_T is the solar radiation striking the PV array (kW/m^2); $G_{T,NOCT}$ is the solar radiation at which the NOCT is defined (0.8 kW/m^2); $\eta_{mp,STC}$ is the maximum power point efficiency under standard test conditions (%); α_p is temperature coefficient of power (%); $T_{C,STC}$ is the cell temperature under standard test conditions (25°C); τ is the solar transmittance of any cover over the PV array (%); α is the solar absorptance of the PV array (%).

The tool employs the following equation to predict the electricity output power from solar PV over multiple years, considering the yearly power loss.

$$PV_{out\ year\ n} = PV_{out\ yearly} \times (1 - yearly\ rate\ of\ PV_{out} degradation\ (\%)) \times (n - 1) \quad (3)$$

2.7. Solar PV Capacity and Module Quantity

The tool limits the maximum capacity of solar PV modules to up to 100% of a household's contracted electricity [27]. The size of the roof to be installed with PV modules is then multiplied by 80% of the total roof area to make installation and maintenance easier. To determine the number of applicable modules and corresponding PV capacity, the tool selects a lower value by comparing the maximum power (Watt-peak) that can be generated by all solar modules required to cover the entire roof surface with the maximum power (Watt-peak) specified by the user or with a 100% permitted capacity equal to the household contracted power.

2.8. Economic Parameters Page

The Economic Parameters page allows users to define the economic parameters of the rooftop PV system that will be installed, which is necessary for performing economic analysis on the system. The user enters several financial details on this page, including the inverter price and lifetime, capital cost (excluding inverter price), electricity price, feed-in tariff (PV export tariff to the grid), annual O&M cost, annual electricity price increase, inflation rate, discount rate, and project lifetime. KawanSurya employs payback period analysis, one of the most used evaluation methodologies to examine the economic feasibility of the monocrystalline silicon-based PV module system [28], [29], in addition to Return on Investment (ROI) and Net Present Value (NPV). The economic study includes both simple and discounted payback periods. The equations for calculating the simple or discounted payback period, ROI, and NPV are as follows.

$$PP = Nb + \frac{ccNb}{ncNa} \quad (4)$$

where PP is payback period; Nb is year before recovery; $ccNb$ is cummulative cash flow in year before recovery; and $ncNa$ is net cash flow in year after recovery.

The present value (PV) is calculated using an assumed interest rate, also known as the discount rate. The present value can be calculated using the following equation [30].

$$PV = S \times F_{PW} \quad (5)$$

where PV is present value of S in year n; S is cash flow in year n; F_{PW} is present worth factor in year n.

The DF (Discount Factor) is based on the assumed discount rate and can be determined using the equation below.

$$DF = \left(1 + \frac{d}{100}\right)^{-n} \quad (6)$$

The inflation adjustment factor can be calculated using the inflation factor equation as follows.

$$IF = (1 + i)^n \quad (7)$$

where i is inflation rate; d is discount rate; n is year.

The present worth factor F_{PW} and the Net Present Value (NPV) can be obtained using Equation 8 and 9, respectively.

$$F_{PW} = \frac{(1+i)^n}{(1+d)^n} \quad (8)$$

$$NPV = \sum PV_{income} - \sum PV_{cost} \quad (9)$$

The cumulative cash inflow computation considers the cash inflow, discount rate, and project year until the cumulative cash inflow is positive at the present payback period. Finally, Return on Investment (ROI) is calculated using Equation 10. It measures the profitability of a system and is defined as the ratio of net benefits (NPV) to the initial investment. A negative ROI indicates that the investment is not profitable.

$$ROI = \frac{NPV}{Capital\ Cost} \quad (10)$$

3. RESULTS AND DISCUSSION

This section presents the results of simulations performed in the KawanSurya and discusses the findings and implications. The analysis consists of two main parts, i.e., testing of features and simulations for obtaining the techno-economic results. Several tests were initially conducted to verify and validate the application's functionality. These include getting and processing electrical load (appliances) data, processing solar irradiance data using an API, and other application functions. The testing of electrical load data processing and solar irradiance data retrieval are briefly described as follows.

3.1. Testing of Electrical Load Data Processing

Electrical load data simulation is one of the tests used to evaluate the process of gathering and processing data for all appliances included in the tool. This information is recorded in a local database within the application and used throughout the computation stage. The testing is intended to confirm that the data can be accurately retrieved and processed during the calculation. This is accomplished by adjusting the debug log level on the Calculation page. The testing makes use of existing electrical load data from the database. Users list all appliances including their quantities, power (wattage), on-time, and off-time. The tool stores this data and determines the electrical load's operating hours based on the on-time and off-time values given by the users. For example, if the on-time value is 1 and the off-time value is 3, the result is 2 hours of operation. Table 1 provides examples of data submitted for processing electrical load data, including the outcome of each appliance's operational period, whereas Table 2 presents an example of the testing results for hourly temporal-based electrical load data processing. The test results are then used as a reference for the next tests.

Table 1. Examples of data entered for processing the electrical load data

Electrical Load	Quantity	Wattage (W)	Operational Hours	Duration
a	4	99	05:00 – 07:00	2.25 hours
b	5	100	10:00 – 02:00	16 hours

Table 2. Testing results of electrical load data processing

Time	Wattage (W)	Time	Wattage (W)	Time	Wattage (W)
00:00	500	08:00	0	16:00	500
01:00	500	09:00	0	17:00	500
02:00	0	10:00	500	18:00	500
03:00	0	11:00	500	19:00	500
04:00	0	12:00	500	20:00	500
05:00	396	13:00	500	21:00	500
06:00	396	14:00	500	22:00	500
07:00	99	15:00	500	23:00	500

3.2. Testing of Solar Irradiance Data Retrieval through API

The test seeks to determine whether the geographical location entered into the tool and the retrieval of solar irradiance data. The tool considers solar irradiation in terms of the average monthly sum of global irradiation (GI) per square meter received by the modules ($W/m^2/month$). It is conducted by carrying out the debug log level. The testing site is at latitude 3.589 and longitude 114.893, with a tilt angle of 30° and azimuth of 0° (South facing). Table 3 shows the debug log results of the location together with the corresponding irradiance data. The GI data originates from PVGIS's default solar characteristics dataset for the region, the PVGIS-SARAH dataset which spans the years 2005 to 2016 and is available on an hourly temporal basis.

Table 3. Testing results of the average monthly sum of global irradiation data retrieval

Time	GI (W/m^2)	Time	GI (W/m^2)	Time	GI (W/m^2)
00:00	0	08:00	1,519.71	16:00	3,582.74
01:00	0	09:00	2,898.66	17:00	1,968.99
02:00	0	10:00	5,058.98	18:00	533.57
03:00	0	11:00	6,803.24	19:00	0
04:00	0	12:00	7,669.45	20:00	0
05:00	0	13:00	7,561.26	21:00	0
06:00	0	14:00	6,626.56	22:00	0
07:00	83.92	15:00	5,193.40	23:00	0

3.3. Simulation Settings and Results

The simulation begins with entering a list of electrical loads for the house's intended installation. KawanSurya can handle a wide range of electrical loads since it does not limit the household's maximum power capacity (contract power). However, for practical purposes, this study examines scenarios of low maximum power capacity to reflect the tool's usefulness among households as well as the potential techno-economic implications of adopting on-grid rooftop PV systems in such typical homes. This paper includes up to six case studies that depict various policy setting scenarios in terms of bill reduction factor, inflation, increased electricity tariffs, and load profile.

Simulation-1 (S-1) serves as a default case study. It considers a household with a contracted power of 2,200 VA and assumes standard household appliances such as refrigerator, rice cooker, ironing device, water pump, washing machine, water heater, air conditioners, television, laptops, and lamps. Table 4 shows a range of electrical loads in a household used as a case in S-1, along with information around quantity, wattage, on-time, and off-time. While this study assumes the quantity and power rating of all appliances as for the testing purposes, users require proper measurement or observation in the premises for more accurate simulation results.

Table 4. Electrical loads in a household with a 2,200VA power contract

Electrical load	Quantity	Wattage	On-time	Off-time
Refrigerator	1	80	24 hours	-
Rice cooker	1	300	17:00	17:40
Iron	1	300	09:00	10:00
Water pump	1	600	07:00	08:30
Washing machine	1	150	08:00	09:00
Laptop	2	100	20:00	22:00
Water heater	1	500	05:30	06:30
AC ½ hp	2	375	20:00	05:30
AC 1 hp	1	750	20:00	05:30
TV	1	80	20:00	22:00
Lamp	15	10	17:30	22:00
Lamp	5	10	22:00	05:30

Table 5 presents the technical parameters entered into the tool for S-1. The parameter settings are based on the specifications of a 100 Wp monocrystalline solar PV module [30]. The datasheet for the module defines its size, maximum capacity, efficiency, NOCT (Nominal Operating Cell Temperature), and annual output power reduction. In this simulation, the roof tilt angle is kept at 30°. Aside from that, the azimuth is facing west, as provided by the PVGIS input API, and 90° represents the west direction [20].

Meanwhile, Table 6 shows the economic parameters for S-1. It consists of the the prices for inverter, system capital cost, electricity price, export electricity price, and operation and maintenance (O&M) cost per year. The inverter costs IDR 4,290,000, or 13% of the total system capital cost. While this simulation has a discount rate of 5%, the annual growth in electricity price and inflation in this scenario are set to 0%. These parameters will be investigated further in the following scenarios. The O&M (Operation and Maintenance) cost is set to IDR 0, assuming that the PV system maintenance is simple and can be carried out independently by the owner. The electricity price is based on the utility tariff for a 2,200 VA power contract, with the sellback rate (electricity export to the grid) set at 100% of the electricity price. Regarding the sellback rate, it should be noted that the tool can also support a 0% sellback rate in the event of a policy change, i.e., if the utility does not allow rooftop PV owners to export the electricity to the network. The investment cost for installing rooftop PV per 1 kilowatt peak (kWp) is estimated to be IDR 15 million, for a total cost of IDR 33 million.

Table 5. Technical parameters of S-1

Parameter	Unit	Value
Contracted power capacity	VA	2,200
Maximum rooftop PV capacity	Wp	2,200
Size per PV module	m^2	0.67
Capacity per PV module	Wp	100
PV module efficiency (STC)	%	14.92
Nominal Operating Cell Temperature	°C	45
Temperature coefficient of power	%/°C	-0.39
Tilt angle	deg°	30
Azimuth	deg°	90
Output power reduction per year	%	0.8

Table 6. Economic parameters of S-1

Parameter	Unit	Value
Inverter price	IDR	4,290,000
Inverter lifetime	Year	15
System capital cost (exclude inverter price)	IDR	28,710,000
Electricity price	IDR	1,444.7
Export electricity price	IDR	1,444.7
Electricity price increase per year	%	0
Inflation	%	0
O&M cost per year	IDR	0
Discount rate	%	5
Project lifetime	Year	25

Meanwhile, Figure 8 shows a user interface for the site and its roof area. This study employs a house with a 2,200 VA power contract in Tropodo, Sidoarjo Regency, East Java, as a case study. It particularly highlights the polygon drawn on the West-facing area of the roof to mount the PV. The user interface displays the house's latitude and longitude (-7.360 and 112.754, respectively), as well as the usable roof area (23.9 m^2).

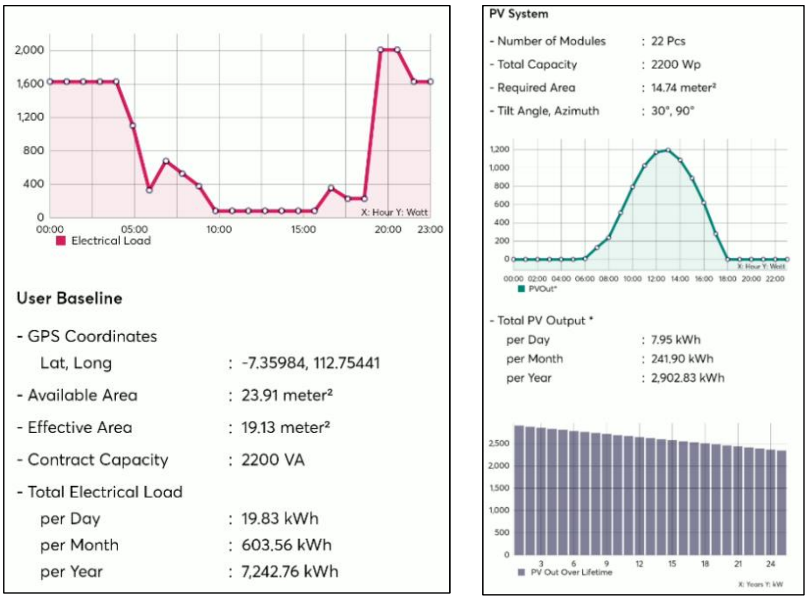
Figure 8. A user interface shows the site and its roof area

KawanSurya divides the techno-economic analysis results into four sections: 1) *User Baseline*; 2) *PV System*; 3) *Load Profile Scenario with Daily PV Output*; and 4) *Investment*. The user baseline includes the daily load curve, the geographic coordinates of the rooftop PV, the available roof size, the contracted power, and the total electrical load per day, month, and year. For the case of S-1 and given Figure 8 as the location, they are 19.83 kWh, 603.56 kWh, and 7246.76 kWh, respectively. The load curve generated from this data is used to calculate electricity export, billing, and savings from the PV system.

The PV system part includes simulation results for the number of PV modules, the total capacity of the rooftop PV system, the needed area, the tilt angle and azimuth, the hourly PV output curve, and the total PV output over the project lifetime in terms of daily, monthly, and yearly. The PV output curve is generated using irradiation data from the PVGIS API and technical parameters. The calculation shows that the PV installed capacity is limited to the contracted power of 2,200 VA. The necessary area is smaller than the available area. An asterisk (*) indicates that the total PV output was calculated before any reduction in power output. For this scenario, the total PV output is determined as 7.95 kWh per day, 241.90 kWh per month, and 2902.83 kWh per year. The graph below the PV output curve displays the decrease in PV output power over the project's lifetime, using a technical parameter of 0.8% power output reduction per year.

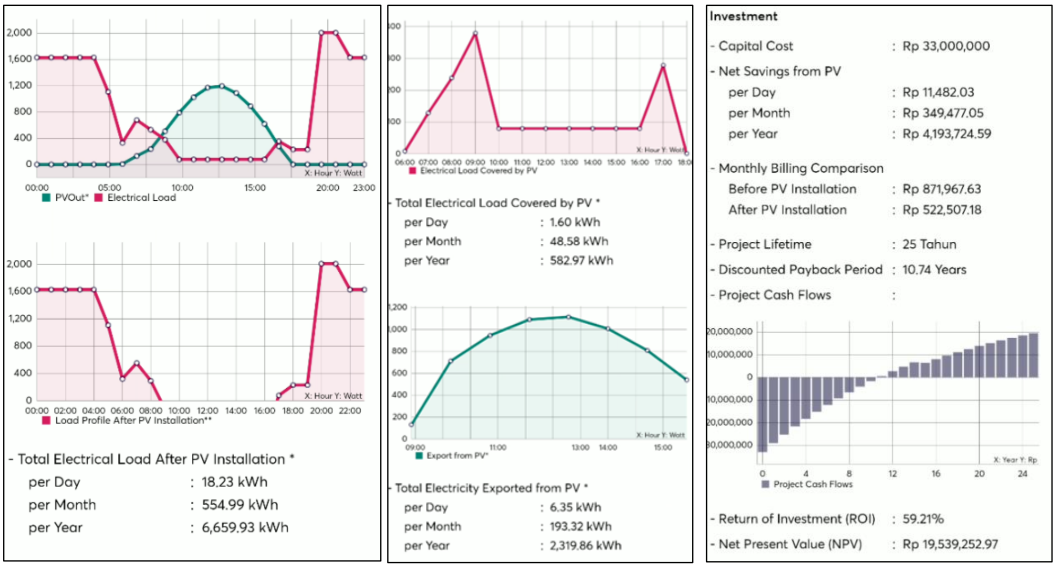
The load curve scenario with daily PV output generates simulation results for the hourly electricity load after PV installation, the part of the electrical load covered by PV, and the amount of electricity exported from PV to the grid, denoted by asterisks, which signifies before any power output reduction. In this simulation, the total electrical load following PV installation is 18.23 kWh per day, 554.99 kWh per month, and 6,659.93 kWh per year. PV meets a total electrical load of 1.60 kWh per day, 48.58 kWh per month, and 582.97 kWh annually. The total electricity export is 6.35 kWh per day, 193.32 kWh per month, and 2,319.87 kWh annually.

The *Investment* section covers the economic analysis of rooftop PV. It displays the capital cost, net savings from PV, monthly bill comparison, project lifetime, payback period, cash flow graph, ROI, and NPV. The net savings from PV installation were estimated to be IDR 11,482 per day, IDR 349,477 per month, and IDR 4,193,725 annually. The monthly electricity bill before installing the rooftop PV is IDR 871,967, but after installation, it is IDR 522,507. The monthly electricity bill comparison is based on the net savings from PV, as there are no O&M costs. The cash flow graph shows that applying a 5% discount rate yields a discounted payback of 10.85 years. The ROI is 59.21%, while the NPV is IDR 19,539,262.80. The S-1 scenario resulted in a discounted payback period of 10.74 years at a 5% discount rate and a 100% bill reduction factor. Using S-1 as a baseline, successive scenarios, however, have influenced the system's economic feasibility in terms of the project's discounted payback period. These scenarios incorporate varrying inflation rates and rising electricity bills. Figure 9 exhibits the results with user interfaces of *User Baseline* (a) and *PV System* (b), while Figure 10 depicts the user interface/results for the load profile scenario with PV output (a), (b), and investment section (c).



(a) (b)

Figure 9. User interface of (a) *User Baseline* and (b) *PV System* of S-1



(a) (b) (c)

Figure 10. User interface/results of (a), (b) *Load Profile Scenario with PV Output*, and (c) *Investment*, all for S-1

Simulation-2 (S-2) applies the same technical and economic parameters as in S-1. This yields a (discounted) payback period of 19.79 years, or twice the prior payback period. The unappealing payback period is principally caused by the implementation of a 65% bill reduction factor, which reduces the power export price to only 65% of the electricity rate per kWh. While the bill reduction factor appears to limit the customer's economic benefit from exporting electricity to the grid, the modelled load profile as in Figure 8 does not support the goal of maximising solar PV energy usage during the day, notably between 09:00 to 15.00.

Simulation-3 (S-3) entails adjusting the electrical load profile to a constant load while retaining the 65% bill reduction factor and other technical and economic parameters from S-1. This scenario appears to enhance the amount of energy supplied by the PV system to offset the electrical load. However, due to this scenario, customer income generated by exporting the electricity from PV has plummeted. This scenario produces a payback period of 11.79 years, one year longer than S-1. The findings reveal that the amount of electrical load covered by the rooftop PV system has changed, as has the amount of power exported. Figure 11 shows a part of the S-3 results, specifically the constant load profile scenario and total electrical load after PV installation. The overall electrical load was calculated to be 13.12 kWh per day, 399.35 kWh per month, and 4,792.25 kWh per year. Because of increased electricity use during the day, the overall electrical load after PV installation is lower than in S-1.

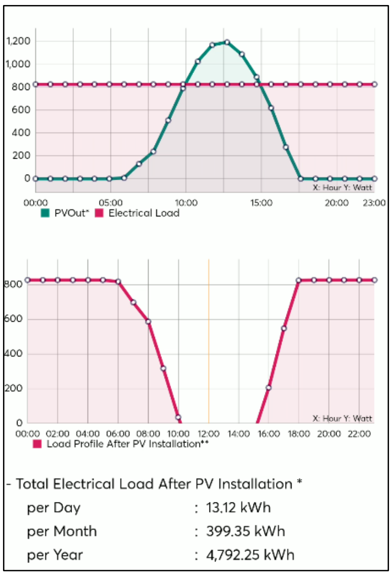


Figure 11. Constant load profile scenario in S-3

Simulation-4 (S-4) assumes a 2% inflation rate while leaving all other parameters same from S-1. In this context, the inclusion of inflation in the simulation is intended to evaluate the effect of inflation on the payback period. In addition to having a negative economic impact, inflation benefits rooftop PV users since it lowers the discount rate by increasing the money provided by the rooftop system, i.e., through power export to the grid. Using a 2% inflation rate, the simulation yields a discounted payback period of 9.43 years. This payback period is found shorter than those in S-1 to S-3. A shorter payback periods enable investors to recover their initial investment sooner.

Simulation 5 (S-5) incorporates a 2% annual increase in electricity tariff while keeping the remaining parameters from S-1. Aside from boosting electricity tariffs, tariff increases benefit rooftop PV users since they increase the income received by rooftop PV systems, assuming a 100% export rate. This simulation calculates a discounted payback period of 9.66 years. It should be noted that if the daily electrical load profile changes to enhance electricity utilisation between 7 a.m. and 5 p.m., the payback period will be smaller than 9.66 years. In light of rising electricity costs, it is also preferable for PV users to increase their daytime usage in order to reduce the cost impact on billing caused by heavy loading during the evening and night.

KawanSurya can also demonstrate a circumstance in which an investment's payback period surpasses the project lifetime by creating a scenario in which an investment becomes no longer financially feasible (see Simulation-6 results in Table 7). This is due to the installation of a rooftop PV system, which provides power while keeping the monthly electricity cost below the minimum account level. This implies a set bottom limit on electricity bills that makes the payback period equal to the project lifetime, and any billing below this limit renders the system uneconomical. The simulation revealed that in this scenario, the discounted payback period cannot be calculated since because it exceeds the project's lifespan. Table 7 summarises possible discounted payback periods under various scenarios considered in this study. These involves bill reduction factors, electricity load scenarios, inflation rates, increases in electricity tariff, and minimum bill limits.

Table 7. Discounted payback periods due to different scenarios

No.	Scenario	Discounted payback period (year)
1.	Simulation-1 (S-1)	10.74
2.	S-2: with 1 65% bill reduction factor	19.79
3.	S-3: with a 65% bill reduction factor and constant electrical load	11.79
4.	S-4: with a 2% inflation rate	9.43
5.	S-5: with an annual increase of 2% in electricity tariff	9.66
6.	S-6: minimum bill limit	Exceed project lifetime

3.4. Discussions

This research sought to improve people's techno-economic knowledge by introducing a solar rooftop PV techno-economic tool that operates on Android mobile phones called KawanSurya. While existing applications or tools are typically designed on a web-based platform and so require a computer to function – in addition to several limitations, information dissemination about rooftop PV necessitates alternative platforms. The tool focuses on the evaluation of on-grid rooftop PV, allowing users to select a specific geographic location, calculate their daily load profiles, and measure the available roof area. It calculates hourly PV output power using irradiation data from the PVGIS API and HOMER's equation. The main purpose is to obtain key results that serve as candidates for rooftop PV investment decision-making.

We found that KawanSurya can work with numerous scenarios based on changes in rooftop PV system techno-economic parameters. Residential clients are more likely to select a rooftop PV system that provides a greater NPV and ROI than other options, as well as a much shorter payback period. While different payback periods might assist residential users in determining their preferred rooftop PV settings, decisions based on the system's economic feasibility must also include the ROI and NPV of various scenarios. Another important consideration is the existing electrical load pattern before PV installation. Higher daytime energy usage is preferred to maximise electricity consumption from the PV modules. While users can assess the potential techno-economic of rooftop PV using the available parameters that may influence the system's feasibility, such as performing sensitivity analyses on various cases, the assessment may also include combinations of important parameters. Residential users, for example, can evaluate the effects of various bill reduction factors, ranging from 0-100%, as well as electrical load profiles while considering a variety of electricity tariff rises and inflation.

Our findings indicate that the discounted payback period is heavily influenced by two factors: electrical load profiles and bill reduction factors. When the bill reduction factor is set to 65% and the load profile is the same as in S-1, the discounted payback period significantly increases. This analysis suggests that if the billing reduction factor is set to 0%, or if the customer is not compensated for selling back electricity to the grid, the discounted payback period will exceed the project lifetime. As this is not a desirable scenario for rooftop PV system owners, it is worthwhile to increase electrical loading during the daytime in the context of a residential on-grid rooftop PV system. Inflation rates may assist the residential sector in getting shorter payback periods without severely impacting the project's financial cash flow, given well-compensated electricity exports regardless of minimal electricity usage during the day. The proposed tool may benefit residential customers by providing greater information about the techno-economic impact of several main parameters evaluated in the analysis before selecting to build an on-grid rooftop PV system.

KawanSurya is intended to be an entry-level tool for assessing such possibilities. As a result, the tool's utility is limited. While the tool recognises the importance of PV output power reduction over time and incorporates it in the model, it does not consider temperature, dirt, or other factors that influence system performance over time, such as weather conditions. Additional and extensive research may be required to improve the tool's capability and confirm its correctness, especially when compared to other similar applications. Our research demonstrated that the rpoposed Android-based application for on-grid rooftop PV installation decision making tool can provide techno-economic results and key parameters essential for residential customer preference in making such an investment. Future research may investigate the possibilities of expanding the tool's capabilities to examine off-grid and hybrid rooftop PV systems, as well as integrating the effect of temperature, dirt, and other factors on system performance. Finally, while the tool is intended for Indonesia's residential sector, it is equally applicable to other jurisdictions wanting to boost customer education and information.

4. CONCLUSION

This paper introduces KawanSurya: PV Calculator, a techno-economic analysis tool for determining the viability of on-grid rooftop solar PV installation in the residential sector. It also explains the application's design methodologies and capabilities, as well as simulation testing and findings. The tool is based on the Android platform and uses the Kotlin programming language. KawanSurya, unlike other popular solar PV assessment software, works on Android mobile phones rather than a web-based computer platform. The tool aims to supplement existing rooftop solar PV tools by providing sufficient information for household sector customers to make sound decisions about the potential techno-economic impacts of installing solar rooftop PV based on different daily load profiles as well as other technical preferences and economic parameters. The analysis results are presented into four sections: user baseline, PV system, load curve scenario with daily PV output, and investment. While the tool is aimed towards Indonesia's residential sector, it is also applicable to other jurisdictions seeking to improve customer education and information dissemination.

The proposed Android application is designed to be a basic tool for determining the technological and economic viability of rooftop solar PV. Users can, however, perform other useful evaluations, such as sensitivity analysis of various cases and investigation of combinations of main parameters. This allows users to gain key findings and essential conclusions for investment decision-making while taking into account unpredictable future costs, electrical loading, and government policy in the analysis.

The proposed tool successfully performs the techno-economic analysis and generates relevant simulation results. However, there are a few limitations to note. First, the accuracy of the rooftop PV calculation results is highly dependent on the assumptions and estimates used. Second, the tool does not provide access to specific shading data for specific locations even though geographical location, weather conditions, and shading all have an impact on PV energy generation results. Third, the tool evaluates solar energy output power using simplified models that do not take into consideration variables such as temperature, dirt, panel degradation over time, and system efficiency, all of which influence energy production in real-world settings. It is important to note that the tool's provided results may not fully reflect the actual scenario; consequently, acquiring adequate and relevant data will aid in improving the accuracy of the findings presented for decision-making. Understanding these limitations leads to suggestions for future work. These include feature additions such as scenario comparison and the incorporation of factors that may influence analysis results.

ACKNOWLEDGEMENTS

This research does not receive any funding. However, we would like to thank the reviewers for their time and effort in reviewing the manuscript. All feedback and recommendations were helpful to help us improve the manuscript's quality.

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4. Email received from BEEI Editor: Revision required
    - Email from BEEI containing reviewer’s comments (16 May 2024)

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[EEI] Editor Decision - Revisions required

1 message

Prof. Dr. Ir. Tole Sutikno, ASEAN Eng. <beei@iaescore.com> Thu, May 16, 2024 at 11:59 PM
To: "Dr. Yusak Tanoto" <tanyusak@petra.ac.id>
Cc: Christopher Marvel <christopher.marvel19@gmail.com>, Hanny H Tumbelaka <tumbeh@petra.ac.id>

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Dear Prof/Dr/Mr/Mrs: Dr. Yusak Tanoto,

We have reached a decision regarding your submission entitled "KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV" to Bulletin of Electrical Engineering and Informatics, a Scopus(Elsevier)/ScimagoJR indexed journal, CiteScore: 3.0, SNIP: 0.639, and SJR: 0.299.

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5. Submitted the revised manuscript and detailed correction statement via the online submission system
    - Detailed correction statement (4 June 2024)
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Bulletin of Electrical Engineering and Informatics
Vol. 99, No. 1, Month 2099, pp. 1~1x
ISSN: 2302-9285, DOI: 10.11591/eei.v99i1.paperID

KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV

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Article Info

Article history:

Received month dd, yyyy
Revised month dd, yyyy
Accepted month dd, yyyy

Keywords:

On-grid
Solar PV
Rooftop PV
Techno-economic
Android application

ABSTRACT

Many developing countries, including Indonesia, are progressing poorly in residential rooftop PV adoption, including on-grid systems. On the customer side, the decision to implement on-grid rooftop PV or rely only on power from the utility grid has often been made without appropriate knowledge of techno-economic considerations. This includes the impression of high system costs. This paper introduces KawanSurya: PV Calculator, a solar rooftop PV techno-economic application for Android mobile phones, designed to help residential customers assess the potential of installing on-grid rooftop PV systems. The tool allows users to select a specific geographic location, calculate daily load profiles, and determine available roof areas. It uses irradiance data from the PVGIS API and HOMER's solar PV output equation to determine hourly PV output power. Simulation results for a typical 2,200 VA household show a payback period of 9.44 years or beyond, significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and similar load profile prolong the payback period, while a 0% billing reduction factor or uncompensated electricity sales may exceed the project's lifetime.

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1. INTRODUCTION

The Paris Agreement aims to reduce global greenhouse gas emissions to keep global temperature rise below 2°C and 1.5°C [1]. The electricity industry is transitioning to renewable energy technology, with renewable energy accounting for over 83% of additional capacity in 2022. Wind and solar, including rooftop PV, account for 91% of additional capacity [2], [3]. Proper legislation and support measures are crucial for rooftop solar photovoltaics to continue playing a significant role in reducing greenhouse gas emissions [4]. Many developing nations, like Indonesia, are making slow progress in residential rooftop PV adoption. The Indonesian government plans to achieve a 23% renewable energy mix by 2025, including 3.6 GW of rooftop PV [5]. However, achieving this target appears to be difficult given the slow progress of the installed capacity of rooftop PV in Indonesia [6]. The potential for solar rooftop PV adoption, particularly in the residential sector, is positive due to cost reductions worldwide [7]. Capacity deployment, however, necessitates a wide range of supportive policies, comprehensive information dissemination, and appealing government incentives [8], [9].

Numerous studies have identified challenges to residential rooftop PV adoption, including economic, technical, and social barriers, primarily focusing on monetary costs and benefits [10], knowledge and information aspects [11], and social and regulatory aspects [12]. In Indonesia, these include high initial investment costs, lack of access to installation services, information availability, disadvantageous PV export tariffs, and policy inconsistencies [13]. Improving public knowledge and clearing up misperceptions about costly technology tariffs and policy inconsistencies are among the important efforts to increase rooftop PV deployment [10]. Residential customers are increasingly considering solar PV energy to reduce electricity bills. However, technical and economic factors like usage compared to total electricity consumption and investment feasibility are crucial. To assess the techno-economic potential of installing rooftop PV, customers need a tool that provides an adequate overview of the system. Limited, independent applications and tools are available to help customers assess the potential of solar rooftop PV in their homes.

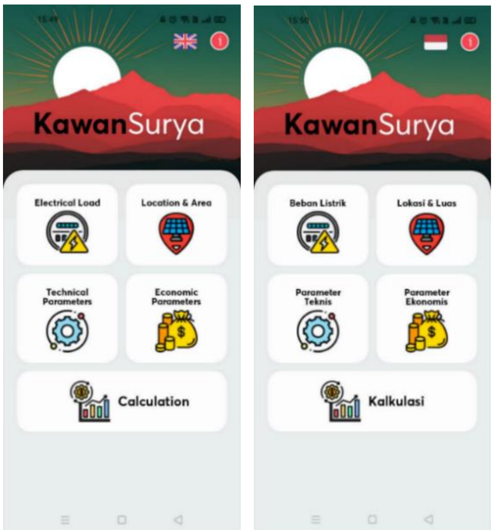
PVGIS [14] and PVWatts Calculator [15] are web-based tools developed by the European Commission and The National Renewable Energy Laboratory to assess the performance of solar power (PV) systems in specific geographic regions. They are used in rooftop PV techno-economic studies to compare the performance of free-standing and rooftop PV systems in different climatic zones and evaluate residential PV systems with tiered rates and net metering [17]. PVGIS provides simulation outputs like yearly PV energy output, variability, electricity cost, monthly PV energy output, and horizon outline, but does not consider user load profile, resulting in the system's payback period. PVWatts offers an optional analysis considering roof area but does not account for user load profile. SolarHub [18], an Indonesian rooftop PV calculator, estimates solar PV capacity, energy generation, system costs, roof area, CO_2 emissions, and payback period.

This paper introduces KawanSurya: PV Calculator (in English means 'solar friend'), a free Android tool for evaluating on-grid rooftop PV potential installations. The tool allows users to select a specific location, calculate daily load profiles, measure roof area, and calculate hourly PV output power using irradiation data from the PVGIS API [19] and HOMER's PV output equation [20], while also including the effect of shading [21] through the derating factor. The tool is designed to be a useful alternative to web-based applications for information dissemination about rooftop PV. The paper aims to offer a methodological contribution to renewable energy literature, focusing on customer education and information dissemination on rooftop solar PV. While it is intended for Indonesia's residential sector, the tool can be used to simulate the installation potential in other jurisdictions seeking to improve residential rooftop PV capacity. The rest of this paper is structured as follows: Section 2 describes the tool's design method; Section 3 presents the results and discussions; Section 4 provides some conclusions on the findings and suggestions for future work.

2. METHOD

2.1. Development, Navigation and Database of KawanSurya

KawanSurya is an Android tool designed for data processing, calculation, and user interface components. It is built using Kotlin, the native high-level programming language for Android, and Android Studio for data processing. The tool is intended for Android versions 8 to 13. The interface is organised into five main sections: Electrical Load, Location and Area, Technical Parameters, Economic Parameters, and Calculation. An Information page and user guide are also available. Figure 1 depicts the Android-based user interface of KawanSurya; (a) in English, and (b) in Bahasa Indonesia after it has been downloaded and run.



(a) (b)

Figure 1. The Android-based user interface of KawanSurya; (a) in English, and (b) in Bahasa Indonesia

The KawanSurya App is available online and can be downloaded from the following link: https://play.google.com/store/apps/details?id=com.christophermarvel.pvcalc. It is a comprehensive tool for estimating the energy output of a rooftop solar PV system that involves several stages including user input, retrieving irradiance data, calculating energy production, generating a daily load curve, computing the PV system's output power, and presenting outcomes. The user inputs information about household appliances, their operation hours, technical and economic parameters, roof area, and location. The PVGIS API is used to retrieve irradiance data from 2005 to 2016, with a one-hour time step. Subsequently, the tool calculates the energy produced by the system over a year, generates a daily load curve, and calculates the required area for rooftop PV installations. The tool also calculates the Net Present Value (NPV), Return on Investment (ROI), payback period, and cash flow. Finally, the tool displays all the results, providing a comprehensive overview of the solar PV system's potential. Figure 2 depicts the flowchart for KawanSurya. It particularly shows the stages for using the tool, which include entering the appropriate parameters, computing inputs, and presenting outcomes.

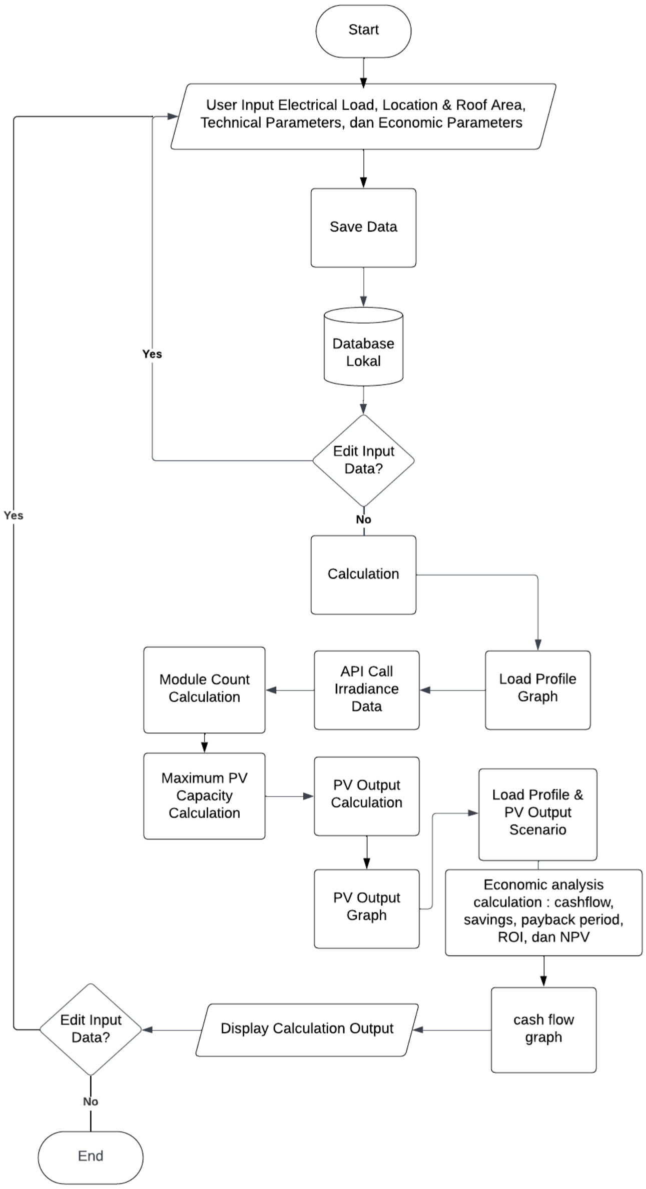


Figure 2. Flowchart of KawanSurya

KawanSurya is designed to demonstrate the techno-economic feasibility of an on-grid rooftop PV installation. It generates technical and economic outputs, including PV module capacity, roof area, daily load profile, and electricity generation. Economic outputs include financial savings, electricity bills, cash flow, payback period, ROI, and net present value (NPV). To ensure the final design addresses relevant issues and meets consumer needs effectively, the tool's user interface is designed with both low and high-fidelity wireframes to merge practical and aesthetic aspects. KawanSurya uses Room Database, a library provided by Android Jetpack [22], to process a local database. Room Database is built on top of SQLite [23], a database engine used in Android applications. The tool has four distinct entities: *Task*, *Dpd*, *Eko*, and *Map*. Users can specify the tables to contain data for each entity. Navigation and class diagrams depict the system structure, with a class diagram of the Location and Area page. Figure 3 and Figure 4 show the navigation diagrams for KawanSurya and the developed database for the tool, respectively. Meanwhile, Figure 5 shows a class diagram of the Location and Area page.

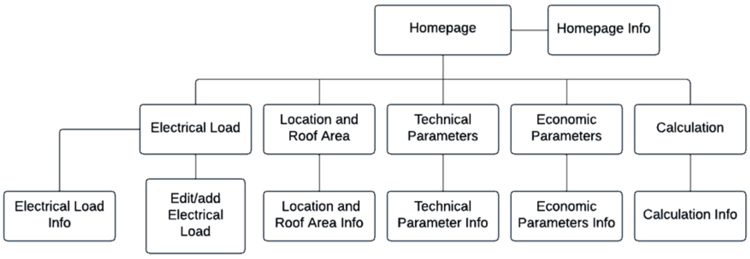


Figure 3. KawanSurya navigation diagram

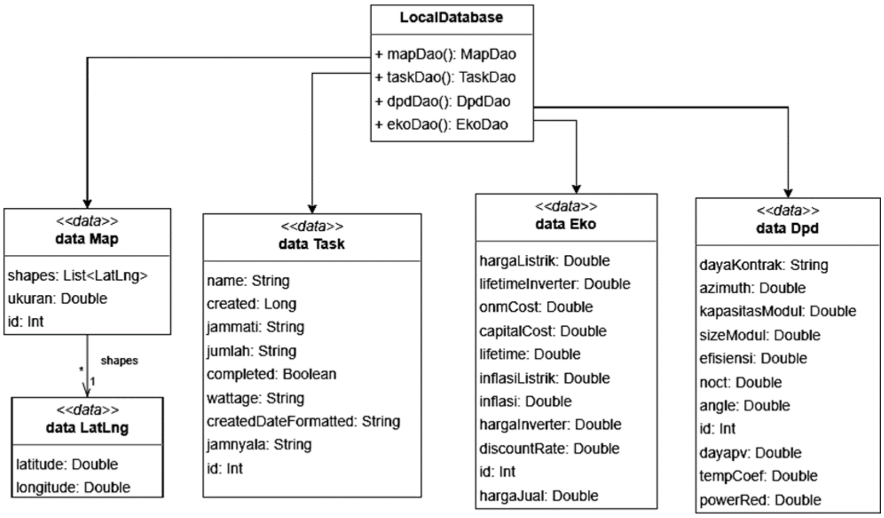


Figure 4. KawanSurya database scheme

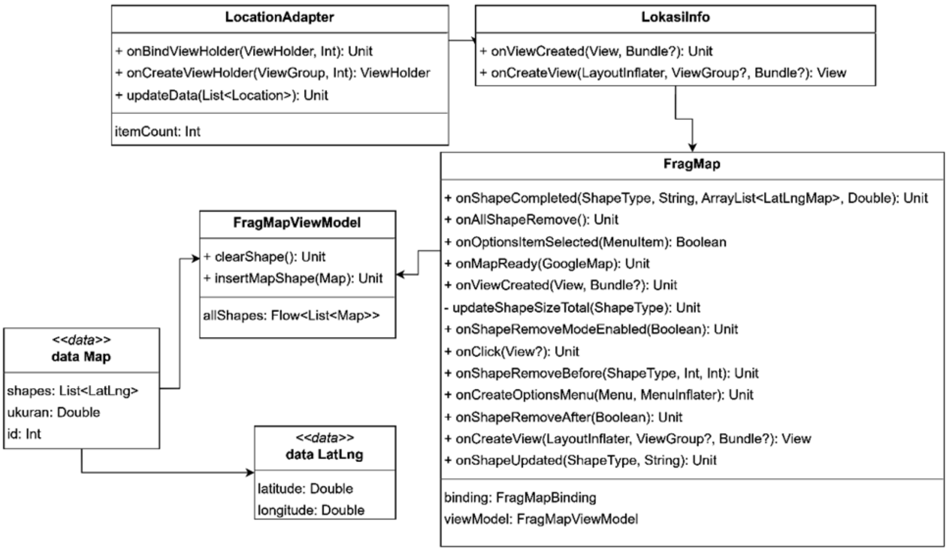


Figure 5. A class diagram of the *Location and Area* page

2.2. Electrical Load Page

The Electrical Load page allows users to add electrical loads or appliances by clicking the ‘Add’ button to enter their name, amount, active power, and operational hours. The tool calculates operational hours by subtracting on-time and off-time. Users can input various appliance data to gather a 24-hour electrical load on their premises. This data generates daily electrical load data and curves, estimating self-consumed PV energy and excess energy sent back to the grid.

2.3. Technical Parameters Page

The Technical Parameters page on the rooftop PV system installation tool allows users to input various technical parameters, including installed PLN contracted power capacity (VA), maximum rooftop PV capacity, (Watt-peak, Wp), module size (m^2), PV module efficiency (%), nominal operating cell temperature (°C), and temperature coefficient of power (%/°C). Other parameters include tilt angle (°), azimuth (0° = South, 90° = West, -90° = East), and annual power output reduction (%). The tool allows users to change the parameters and define settings for their installation plan but also provides default values for simulation. This helps in calculating the system's output power hourly and performing economic evaluations. Irradiance data is crucial for calculating rooftop PV system output power. KawanSurya uses the PVGIS API to obtain data from the PVGIS SARAH-2 dataset [24], which contains sun irradiance data from 2005 to 2016. Retrofit is used to create an API request with parameters like latitude, longitude, month, output format, local time, global, angle, aspect, and temperatures. Figure 6 shows a part of the code created to retrieve the solar irradiance dataset for a specific place from PVGIS.

```
interface ApiInterface {
    @GET("api/v5_2/DRcalc")

    fun getDatas(@Query("lat") lat: Double,
                 @Query("lon") lon: Double,
                 @Query("month") month: Int,
                 @Query("ouputformat") ouputFormat: String,
                 @Query("localtime") localtime: Int,
                 @Query("global") global: Int,
                 @Query("angle") angle: Double,
                 @Query("aspect") aspect: Double,
                 @Query("showtemperatures") temp: Int
    ) : Call<ResponseData>
}
object RetrofitHelper {

    val baseUrl = "https://re.jrc.ec.europa.eu/"

    fun getInstance(): Retrofit {
        return Retrofit.Builder().baseUrl(baseUrl)
            .addConverterFactory(GsonConverterFactory.create())
            .build()
    }
}
private fun getDatas() {
    val api = RetrofitHelper.getInstance().create(ApiInterface::class.java)
    val viewModel2 = ViewModelProvider(this)[FragMapViewModel::class.java]
    lifecycleScope.launch {
        var lat: Double
        var lon: Double
        viewModel2.getAllShapes().collect {
            if (it.isNotEmpty()) {

                lat = it[it.size - 1].shapes[0].latitude
                lon = it[it.size - 1].shapes[0].longitude

                binding.tvLatlon.text = "%.5f, %.5f".format(lat, lon)

                var angle: Double
                var aspect: Double
                var dayaKontrak: String
                val viewModel1 =
                    ViewModelProvider(this@KalkulasiFragment)[DpdViewModel::class.java]
                viewModel1.getDpd()?.observe(viewLifecycleOwner) { dpd ->
                    if (dpd != null) {
                        angle = dpd.angle
                        aspect = dpd.azimuth
                        dayaKontrak = dpd.dayaKontrak
```

Figure 6. A screenshot of coding for retrieving the solar irradiance dataset

2.4. Location and Area Page

The Location and Area page allows users to estimate the available roof area for solar PV modules by drawing a polygon and clicking on the areas on the house's roof. The program uses the MapDrawingManager library to compute the area, which is an effective area considering 80% of the true size of the measured polygon. Figure 7 depicts a screenshot of the house coordinates and roof area in KawanSurya. It especially indicates the house's coordinates of -7.295° (South Latitude) and 112.726° (East Longitude), as well as the calculated usable roof area of 18.27 m^2. This usable roof space shows 80% of the total area within the polygon for installation feasibility purposes. The program uses the site's coordinates and the roof area to provide accurate information.

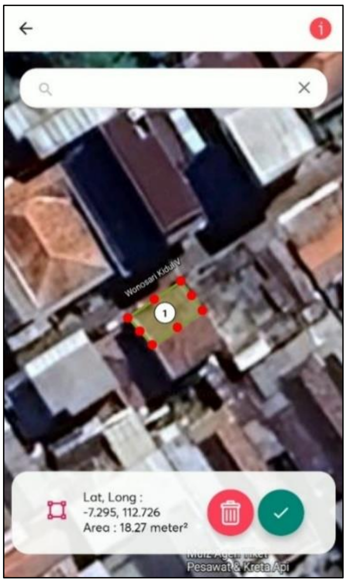


Figure 7. Screenshot of the location and roof area in KawanSurya

2.5. PV Output Power

KawanSurya calculates rooftop PV output power using the HOMER software's equation, considering factors like derating factor and solar absorptivity and transmittance. The derating factor considers factors like panel dirt, wire loss, shadowing, snow coverage, and aging. The tool calculates an estimated value of 0.77 [25] to determine the impact of these parameters on the performance of the rooftop PV system. Solar absorptivity and transmittance are calculated using the product of 0.9 or 90% [26]. The equations used to determine rooftop PV output power and PV cell temperature are as follows.

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}}\right)[1 + \alpha_p(T_c - T_{c,STC})] \qquad (1)$$

where P_{PV} is PV output (kW); Y_{PV} is rated capacity solar PV array in standard test conditions (kW); f_{PV} is a derating factor (%); $\overline{G_T}$ is the solar radiation incident on the PV array in the current time step (kW/m^2); $\overline{G_{T,STC}}$ is the incident radiation at standard test conditions (1 kW/m^2); α_p is the temperature coefficient of power (%/°C); T_c is the PV cell temperature in the current time step (°C); and $T_{c,STC}$ is the PV cell temperature under standard test conditions (25°C).

$$T_c = \frac{T_a + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(1 - \frac{\eta_{mp,STC}(1 - \alpha_p T_{c,STC})}{\tau\alpha}\right)}{1 + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_p \eta_{mp,STC}}{\tau\alpha}\right)} \qquad (2)$$

where T_c is the PV cell temperature (°C); T_a is the ambient temperature (°C); $T_{c,NOCT}$ is the nominal operating cell temperature (°C); $T_{a,NOCT}$ is the ambient temperature at which the NOCT is defined (20°C); G_T is the solar radiation striking the PV array (kW/m^2); $G_{T,NOCT}$ is the solar radiation at which the NOCT is defined (0.8 kW/m^2); $\eta_{mp,STC}$ is the maximum power point efficiency under standard test conditions (%); α_p is temperature coefficient of power (%); $T_{C,STC}$ is the cell temperature under standard test conditions (25°C); τ is the solar transmittance of any cover over the PV array (%); α is the solar absorptance of the PV array (%).

The tool predicts solar PV's electricity output power over multiple years, considering yearly power loss using the following equation.

$$PV_{out\ year\ n} = PV_{out\ yearly} \times (1 - yearly\ rate\ of\ PV_{out} degradation\ (\%)) \times (n-1) \quad (3)$$

2.6. Solar PV Capacity and Module Quantity

The tool limits solar PV module capacity to 100% of a household's contracted electricity [27]. The size of the roof is multiplied by 80% to simplify installation and maintenance. The tool determines the number of modules and PV capacity by comparing the maximum power generated by all solar modules with the user's maximum power (Watt-peak) or with a 100% permitted capacity equal to the household contracted power.

2.7. Economic Parameters Page

The Economic Parameters page allows users to define the economic parameters of a rooftop PV system, including inverter price, lifetime, capital cost, electricity price, feed-in tariff, annual O&M cost, annual electricity price increase, inflation rate, discount rate, and project lifetime, for economic analysis purposes.

KawanSurya uses payback period analysis to evaluate the economic feasibility of monocrystalline silicon-based PV module systems [28], [29], in addition to Return on Investment (ROI) and Net Present Value (NPV). The study includes simple and discounted payback periods, with the present value (PV) calculated using an assumed interest rate [30]. The discount factor (DF) is based on the assumed discount rate. ROI measures the profitability of the system, defined as the ratio of net benefits (NPV) to the initial investment. A negative ROI indicates the investment is not profitable. The equations for calculating the simple or discounted payback period, ROI, and NPV are as follows.

$$PP = Nb + \frac{ccNb}{ncNa};\ PV = S \times F_{PW};\ DF = \left(1 + \frac{d}{100}\right)^{-n};\ IF = (1+i)^n \quad (4)$$

$$F_{PW} = \frac{(1+i)^n}{(1+d)^n};\ NPV = \sum PV_{income} - \sum PV_{cost};\ ROI = \frac{NPV}{Capital\ Cost} \quad (5)$$

where PP is payback period; Nb is the year before recovery; $ccNb$ is cumulative cash flow in the year before recovery; and $ncNa$ is net cash flow in the year after recovery; PV is the present value of S in year n; S is cash flow in the year n; F_{PW} is a present worth factor in the year n; i is inflation rate; d is the discount rate; n is year.

3. RESULTS AND DISCUSSION

This section presents the simulation results conducted on KawanSurya, focusing on testing features and obtaining techno-economic results. Initial tests were performed to verify and validate the application's functionality, including processing electrical load data and retrieving solar irradiance data using an API. The findings and implications of these tests are discussed in detail.

3.1. Preliminary Tests on Electrical Loading and Solar Irradiance Data Retrieval

The electrical loading test evaluates the data gathering and processing for all appliances in a tool. The information is recorded in a local database and used during computation. The testing ensures accurate retrieval and processing of the data by adjusting the debug log level on the Calculation page. The testing uses database-based electrical load data, listing appliances, power, on-time, and off-time. The tool calculates operating hours based on these values, resulting in 2 hours of operation for a given on-time value of 1 and off-time value of 3.

Solar irradiance data retrieval through API is tested to determine whether the geographical location entered the tool and the retrieval of solar irradiance data. The tool considers solar irradiation in terms of the average monthly sum of global irradiation (GI) per square meter received by the modules (W/m2/month). It is conducted by carrying out the debug log level. The testing site is at latitude 3.589 and longitude 114.893, with a tilt angle of 30° and azimuth of 0° (South facing). Table 1 provides examples of data submitted for processing electrical load data, including the outcome of each appliance's operational period, whereas Table 2 presents an example of the testing results for hourly temporal-based electrical load data processing. The test results are then used as a reference for the next tests.

Table 1. Examples of data entered for processing the electrical load data

Electrical Load	Quantity	Wattage (W)	Operational Hours	Duration
a	4	99	05:00 – 07:00	2.25 hours
b	5	100	10:00 – 02:00	16 hours

Table 2. Testing results of electrical load data processing

Time	Wattage (W)	Time	Wattage (W)	Time	Wattage (W)
00:00	500	08:00	0	16:00	500
01:00	500	09:00	0	17:00	500
02:00	0	10:00	500	18:00	500
03:00	0	11:00	500	19:00	500
04:00	0	12:00	500	20:00	500
05:00	396	13:00	500	21:00	500
06:00	396	14:00	500	22:00	500
07:00	99	15:00	500	23:00	500

Table 3 shows the debug log results of the location together with the corresponding irradiance data. The GI data originates from PVGIS's default solar characteristics dataset for the region, the PVGIS-SARAH dataset which spans the years 2005 to 2016 and is available on an hourly temporal basis.

Table 3. Testing results of the average monthly sum of global irradiation data retrieval

Time	GI (W/m^2)	Time	GI (W/m^2)	Time	GI (W/m^2)
00:00	0	08:00	1,519.71	16:00	3,582.74
01:00	0	09:00	2,898.66	17:00	1,968.99
02:00	0	10:00	5,058.98	18:00	533.57
03:00	0	11:00	6,803.24	19:00	0
04:00	0	12:00	7,669.45	20:00	0
05:00	0	13:00	7,561.26	21:00	0
06:00	0	14:00	6,626.56	22:00	0
07:00	83.92	15:00	5,193.40	23:00	0

3.2. Simulation Settings and Results

This study begins with entering a list of electrical loads for the house's intended installation. KawanSurya can handle a wide range of electrical loads since it does not limit the household's maximum power capacity (contract power). It explores low maximum power capacity scenarios in households and the potential techno-economic implications of on-grid rooftop PV systems. It includes six policy-setting scenarios, incorporating bill reduction factors, inflation, increased electricity tariffs, and load profile.

Simulation-1 (S-1) is a case study for a household with a contracted power of 2,200 VA, assuming standard appliances like a refrigerator, rice cooker, ironing device, water pump, washing machine, water heater, air conditioners, television, laptops, and lamps. This study employs a house with a 2,200 VA power contract in Tropodo, Sidoarjo Regency, East Java, as a case study. It particularly highlights the polygon drawn on the West-facing area of the roof to mount the PV. The user interface displays the house's latitude and longitude (-7.360 and 112.754, respectively), as well as the usable roof area (23.9 m^2). Table 4 shows electrical loads in the household, including quantity, wattage, on-time, and off-time. Proper measurements or observations are required for more accurate simulation results.

Table 4. Electrical loads in a household with a 2,200VA power contract

Electrical load	Quantity	Wattage	On-time	Off-time
Refrigerator	1	80	24 hours	-
Rice cooker	1	300	17:00	17:40
Iron	1	300	09:00	10:00
Water pump	1	600	07:00	08:30
Washing machine	1	150	08:00	09:00
Laptop	2	100	20:00	22:00
Water heater	1	500	05:30	06:30
AC ½ hp	2	375	20:00	05:30
AC 1 hp	1	750	20:00	05:30
TV	1	80	20:00	22:00
Lamp	15	10	17:30	22:00
Lamp	5	10	22:00	05:30

The technical and economic parameter settings are based on the specifications of a 100 Wp monocrystalline solar PV module [30]. The module's datasheet outlines its size, capacity, efficiency, NOCT, and annual output power reduction. The simulation uses a 30° roof tilt angle and 90° azimuth, with the azimuth facing west, as provided by the PVGIS input API [20]. Economic parameters include inverter prices, a system capital cost, electricity prices, export electricity prices, and annual operation and maintenance costs.

The economic parameters include inverter prices, system capital costs, electricity prices, export electricity prices, and O&M costs per year. The inverter costs IDR 4,290,000, 13% of the total system capital cost. The discount rate is 5%, annual growth on electricity price is 0%, and inflation is 0%. These parameters will be investigated further in the following scenarios. The O&M cost for a PV system is IDR 0, assuming it's simple and owner-managed. The electricity price is based on a 2,200 VA power contract, with a 100% sellback rate for electricity export to the grid. The tool can support a 0% sellback rate if a policy change prevents rooftop PV owners from exporting electricity to the network. The investment cost for installing 1 kWp of rooftop PV is IDR 15 million, totalling IDR 33 million. Table 5 presents the technical and economic parameters for S-1.

Table 5. Technical and economic parameters of S-1

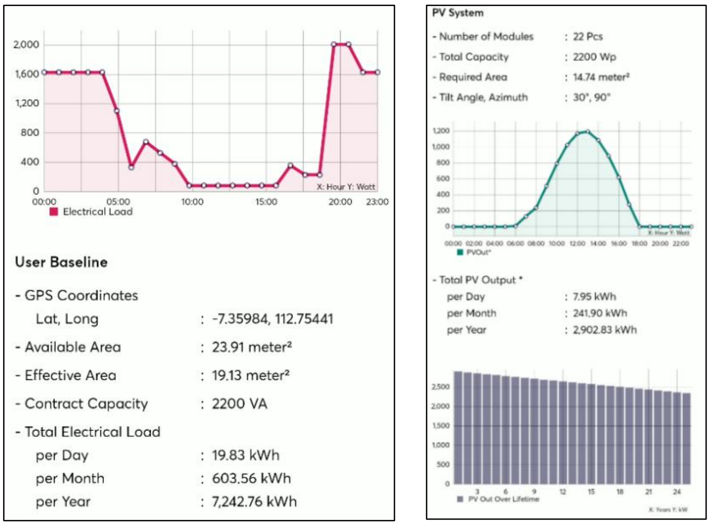
Parameter	Unit	Value
Contracted power capacity	VA	2,200
Maximum rooftop PV capacity	Wp	2,200
Size per PV module	m^2	0.67
Capacity per PV module	Wp	100
PV module efficiency (STC)	%	14.92
Nominal Operating Cell Temperature	°C	45
Temperature coefficient of power	%/°C	-0.39
Tilt angle	deg°	30
Azimuth	deg°	90
Output power reduction per year	%	0.8
Inverter price	IDR	4,290,000
Inverter lifetime	Year	15
System capital cost (exclude inverter price)	IDR	28,710,000
Electricity price	IDR	1,444.7
Export electricity price	IDR	1,444.7
Electricity price increase per year	%	0
Inflation	%	0
O&M cost per year	IDR	0
Discount rate	%	5
Project lifetime	Year	25

KawanSurya's techno-economic analysis is divided into four sections: User Baseline, PV System, Load Profile Scenario with Daily PV Output, and Investment. The user baseline includes the daily load curve, geographic coordinates, roof size, contracted power, and total electrical load per day, month, and year. For the case of S-1 and given the selected location, they are 19.83 kWh, 603.56 kWh, and 7246.76 kWh, respectively. The load curve generated from this data is used to calculate electricity export, billing, and savings from the PV system.

The PV system part includes simulation results for module number, total capacity, needed area, tilt angle, azimuth, hourly output curve, and total output over project lifetime. The output curve is generated using irradiation data from the PVGIS API and technical parameters. The calculation shows that the installed capacity is limited to a contracted power of 2,200 VA. The necessary area is smaller than the available area. An asterisk (*) indicates that the total PV output was calculated before any reduction in power output. The total PV output, calculated before any reduction in power output, is 7.95 kWh/day, 241.90 kWh/month, and 2902.83 kWh/year in this scenario. The graph below shows the decrease in PV output power over the project's lifetime, using a technical parameter of 0.8% power output reduction per year.

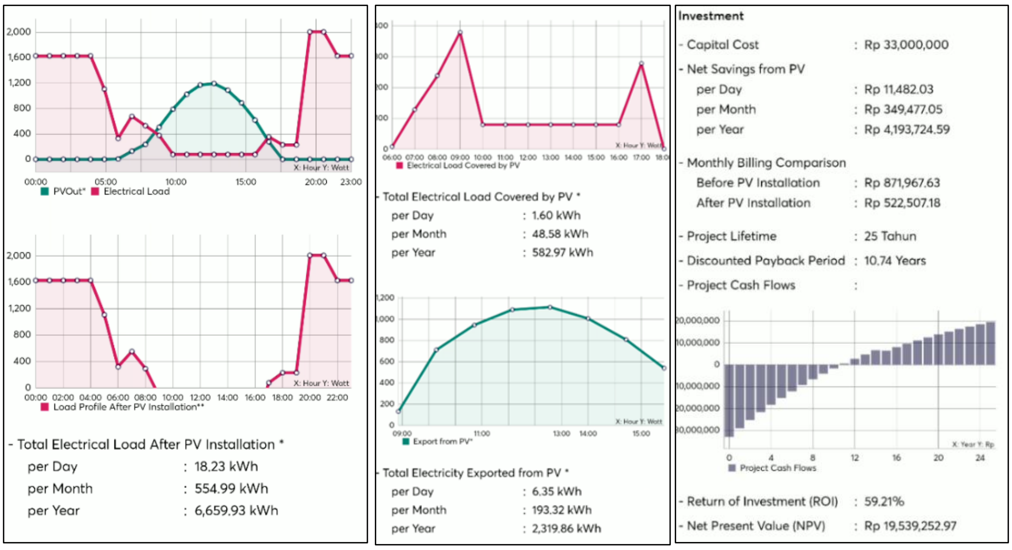
The load curve scenario with daily PV output generates simulation results for the hourly electricity load after PV installation, the portion covered by PV, and the amount of electricity exported from PV to the grid. The total electrical load after PV installation is 18.23 kWh/day, 554.99 kWh per month, and 6,659.93 kWh/year, while PV meets a total electrical load of 1.60 kWh/day, 48.58 kWh/month, and 582.97 kWh annually. The total electricity export is 6.35 kWh/day, 193.32 kWh/month, and 2,319.87 kWh annually.

The investment section analyses the economic feasibility of rooftop PV, revealing net savings of IDR 11,482/day, IDR 349,477/month, and IDR 4,193,725 annually. The monthly electricity bill before and after installation is based on net savings from PV. The cash flow graph shows a discounted payback of 10.85 years at a 5% discount rate, an ROI of 59.21%, and an NPV of IDR 19,539,262.80. The S-1 scenario results in a discounted payback period of 10.74 years at a 5% discount rate and 100% bill reduction factor. However, successive scenarios, including varying inflation rates and rising electricity bills, have influenced the system's discounted payback period. Figure 8 exhibits the S-1 results displaying user interfaces of KawanSurya; (a) User Baseline, and (b) PV System, while Figure 9 depicts the user interface/results for the load profile scenario; (a), (b) showing PV output and load profiles, and (c) investment section.



(a) (b)

Figure 8. The user interface of KawanSurya; (a) User Baseline, and (b) PV System of S-1



(a) (b) (c)

Figure 9. The user interface/results of S-1 for the Load Profile Scenario; (a), (b) showing PV output and load profiles, and (c) Investment

Simulation-2 (S-2) uses the same technical and economic parameters as S-1, resulting in a payback period of 19.79 years, twice the prior period. This is due to a 65% bill reduction factor, which reduces the power export price to 65% of the electricity rate per kWh. The modelled load profile shown in Figure 8 does not support maximising solar PV energy usage during the day, particularly between 09:00 – 15.00.

Simulation-3 (S-3) adjusts the electrical load profile to a constant load while maintaining the 65% bill reduction factor and other parameters from S-1. This scenario increases the energy supplied by the PV system to offset the electrical load but reduces customer income from exporting electricity. The payback period is 11.79 years, or one year longer than S-1. The findings reveal that the amount of electrical load covered by the rooftop PV system has changed, as has the amount of power exported. The overall electrical load is 13.12 kWh/day, 399.35 kWh/month, and 4,792.25 kWh/year. After PV installation, the electrical load is lower than in S-1.

Simulation-4 (S-4) assumes a 2% inflation rate while leaving all other parameters the same as S-1. The inclusion of inflation is intended to evaluate the effect of inflation on the payback period. Inflation can negatively impact the economy but also benefit users by lowering the discount rate through power export to the grid. The simulation results in a discounted payback period of 9.43 years, shorter than S-1 to S-3, allowing investors to recover their initial investment sooner.

Simulation-5 (S-5) introduces a 2% annual increase in electricity tariffs while leaving all other parameters the same as S-1. This scenario benefits rooftop PV users by increasing income received, and calculating a discounted payback period of 9.66 years, assuming a 100% export rate. It should be noted that the payback period for PV users can be reduced by adjusting their daily electrical load profile between 7 a.m. and 5 p.m. and increasing daytime usage to lower the cost impact on billing caused by evening and nighttime loading.

KawanSurya demonstrates that an investment's payback period can exceed the project's lifetime when a rooftop PV system is installed. This is due to a set bottom limit on electricity bills, making the payback period equal to the project lifetime. Any billing below this limit renders the system uneconomical. The simulation shows that the discounted payback period cannot be calculated in this scenario, as it exceeds the project's lifespan. Table 6 presents possible discounted payback periods under various scenarios, including bill reduction factors, electricity load scenarios, inflation rates, increases in electricity tariffs, and minimum bill limits.

Table 6. Discounted payback periods due to different scenarios

No.	Scenario	Discounted payback period (year)
1.	Simulation-1 (S-1)	10.74
2.	S-2: with 1 65% bill reduction factor	19.79
3.	S-3: with a 65% bill reduction factor and constant electrical load	11.79
4.	S-4: with a 2% inflation rate	9.43
5.	S-5: with an annual increase of 2% in electricity tariff	9.66
6.	S-6: minimum bill limit	Exceed project lifetime

3.3. Discussions

KawanSurya evaluates on-grid rooftop PV systems, allowing users to select locations, calculate daily load profiles, and measure roof area. It adapts to various scenarios based on technological and economic parameters. Residential customers prefer systems with higher NPV and ROI, but decisions should also consider the ROI and NPV of different scenarios and electrical load patterns. Higher daytime energy usage is preferred for maximum electricity consumption. It should be noted that the discounted payback period of the simulated on-grid rooftop PV system is significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and the same load profile increase the discounted payback period. However, a 0% billing reduction factor or no compensation for selling back electricity to the grid can exceed the discounted payback period, making it advisable for rooftop PV system owners to increase electrical loading during the daytime. Inflation rates can help residential projects achieve shorter payback periods without significantly impacting financial cash flow, and well-compensated electricity exports are achieved regardless of daytime usage.

KawanSurya is an entry-level tool for assessing rooftop solar PV installation opportunities. Its utility is limited as it does not consider temperature, dirt, shade, and weather conditions. More study is needed to increase its capabilities and accuracy, as well as to broaden its capabilities to include off-grid and hybrid rooftop PV systems and to incorporate other factors influencing system performance.

4. CONCLUSION

The energy end-users understanding of the techno-economic potential of rooftop solar PV systems is one of the important key aspects to increasing renewable energy penetrations, including rooftop solar PV systems. Independent evaluation tools, such as KawanSurya, are essential to help customers assess the potential of rooftop solar PV in their homes, especially in improving public knowledge and clearing up misperceptions about costly technology tariffs. Residential customers can use KawanSurya to assess the techno-economic potential of installing on-grid rooftop PV systems under several scenarios, including daily load profiles, changing maximum allowable installed capacity, inflation, increased electricity tariffs, and billing reduction factors.

The tool has successfully performed the techno-economic analysis and generates relevant simulation results. Simulation results for a typical 2,200 VA household show a payback period of 9.44 years or beyond, significantly influenced by electrical load profiles and bill reduction factors. Allowing inflation rates in the simulations will recover initial investment sooner. The 2% inflation rate resulted in a discounted payback period of 9.43 years, shorter than the default scenario and a 65% billing reduction factor. Meanwhile, the annual increase in electricity tariffs may benefit users by increasing income received, assuming a 100% export rate. The payback period can be reduced by adjusting the daily electrical load profile between 7 a.m. and 5 p.m. and increasing daytime usage. Future work to improve the tool's capability may include factors addition that may influence analysis results scenario comparisons.

ACKNOWLEDGEMENTS

This paper is part of the research conducted at Petra Christian University, No. 01010679/ELK/2023. While the research does not receive any funding, the authors would like to thank the reviewers for their time and effort in reviewing the manuscript. All feedback and recommendations help improve the manuscript's quality.

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BIOGRAPHIES OF AUTHORS

	**Yusak Tanoto** received a Bachelor of Engineering in Electrical Engineering from Petra Christian University (PCU), Indonesia, in 2003. He received a Master of Engineering in Energy-Electric Power System Management from the Asian Institute of Technology (AIT), Thailand, in 2010. He has completed his Ph.D. in Electrical Engineering (Energy Systems) from the School of Electrical Engineering and Telecommunications, University of New South Wales (UNSW), Sydney, Australia, in 2022. He has been a full-time lecturer at the Electrical Engineering Department, PCU, Indonesia since 2005, and currently is an Associate Professor at the same institution. His research interests are sustainable electricity energy generation planning, energy efficiency and management systems, high variable renewable penetration and resources data analytics in the context of emerging economies. He can be contacted at email: tanyusak@petra.ac.id.
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	**Hanny H. Tumbelaka** received a Bachelor of Engineering in Electrical Engineering from Petra Christian University, Indonesia in 1988, a Master of Science in Electric Power Engineering from Rensselaer Polytechnic Institute, New York, USA in 1993, and a Ph.D. in Electrical Engineering from Curtin University of Technology in 2006. Since 1989, he has been a certified lecturer in The Electrical Engineering Department, at Petra Christian University, Indonesia. Currently, he is the Professor in this department. He was a research fellow at Sophia University, Japan (2008) and NREL, Colorado, USA (2016). His research interests are power electronics, power quality, and renewable energy. He is a certified engineer (Insinyur – IPM) and a member of PII and IEEE. He can be contacted at email: tumbeh@petra.ac.id.

CORRECTION STATEMENT

Paper title	KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV
Authors	Yusak Tanoto, Christopher Marvel, Hanny H. Tumbelaka

The authors declare that:

- The manuscript has been revised according to suggestions provided by the reviewers and editor.
- The manuscript has been checked for any spelling and grammatical errors.
- All necessary revisions have been highlighted in yellow.

Response and revisions to the reviewer's comments and suggestions on how to improve the paper:

1. The abstract should be a concise summary of the paper. The abstract should include what you researched such as a brief introduction of your research, Methods, Solution of the proposed problem and briefly explain the results obtained from the research. The abstract should be simple, specific, clear, impartial, honest, concise, precise, self-contained, complete, scientific, (preferably) structured, and not misleading. Stay within the word count limit. Common abstract word limits range from 150 to 200 words.

   Response: The abstract has been revised according to the suggestion provided by the reviewer as follows:

   Abstract: Many developing countries, including Indonesia, are progressing poorly in residential rooftop PV adoption, including on-grid systems. On the customer side, the decision to implement on-grid rooftop PV or rely only on power from the utility grid has often been made without appropriate knowledge of techno-economic considerations. This includes the impression of high system costs. This paper introduces KawanSurya: PV Calculator, a solar rooftop PV techno-economic application for Android mobile phones, designed to help residential customers assess the potential of installing on-grid rooftop PV systems. The tool allows users to select a specific geographic location, calculate daily load profiles, and determine available roof areas. It uses irradiance data from the PVGIS API and HOMER's solar PV output equation to determine hourly PV output power. Simulation results for a typical 2,200 VA household show a payback period of 9.44 years or beyond, significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and similar load profile prolong the payback period, while a 0% billing reduction factor or uncompensated electricity sales may exceed the project's lifetime.

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4. In Figure (9), please add the main caption before the sub caption. Example: Figure 1. ....; (a) ...., and (b) ....

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   Figure 9. The user interface/results of S-1 for the Load Profile Scenario; (a), (b) showing PV output and load profiles, and (c) Investment

5. We found that the Figure 3-6 on the paper you attached, is in a low quality format. I suggest, it is better to convert the Figure to HD quality that can be read clearly.

   Response: Figures 3-6 have been replaced with better-quality figures in the revised manuscript.

6. Rearrange your conclusion. The conclusion is designed to help the reader understand why your research is important to them after they have finished reading the paper. A conclusion is more than just a summary of your points or a restatement of your research problem; it is a synthesis of key points. Most papers require only one well-developed paragraph for a conclusion, but in some cases, two or three paragraphs may be required.

   Response: The conclusion has been revised according to the suggestion, as follows:
   The energy end-users understanding of the techno-economic potential of rooftop solar PV systems is one of the important key aspects to increasing renewable energy penetrations, including rooftop solar PV systems. Independent evaluation tools, such as KawanSurya, are essential to help customers assess the potential of rooftop solar PV in their homes, especially in improving public knowledge and clearing up misperceptions about costly technology tariffs. Residential customers can use KawanSurya to assess the techno-economic potential of installing on-grid rooftop PV systems under several scenarios, including daily load profiles, changing maximum allowable installed capacity, and billing reduction factors.
   The tool has successfully performed the techno-economic analysis and generates relevant simulation results. Simulation results for a typical 2,200 VA household show a payback period of 9.44 years or beyond, significantly influenced by electrical load profiles and bill reduction factors. Allowing inflation rates in the simulations will recover initial investment sooner. The 2% inflation rate resulted in a discounted payback period of 9.43 years, shorter than the default scenario and a 65% billing reduction factor. Meanwhile, the annual increase in electricity tariffs may benefit users by increasing income received, assuming a 100% export rate. The payback period can be reduced by adjusting the daily electrical load profile between 7 a.m. and 5 p.m. and increasing daytime usage. Future work to improve the tool's capability may include factors addition that may influence analysis results scenario comparisons.

7. In your acknowledgments section, I recommend including the contract number of your research (if any).

   Response: We have added the research work number, as follows:
   This paper is part of the research conducted at Petra Christian University, No. 01010679/ELK/2023. While the research does not receive any funding, the authors would like to thank the reviewers for their time and effort in reviewing the manuscript. All feedback and recommendations help improve the manuscript's quality.

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Prof. Dr. Ir. Tole Sutikno, ASEAN Eng. <beei@iaescore.com> Wed, Aug 7, 2024 at 9:26 PM
To: "Dr. Yusak Tanoto" <tanyusak@petra.ac.id>
Cc: Christopher Marvel <christopher.marvel19@gmail.com>, Hanny H Tumbelaka <tumbeh@petra.ac.id>

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Yusak Tanoto <tanyusak@petra.ac.id> Fri, Aug 30, 2024 at 12:02 PM
To: "Prof. Dr. Ir. Tole Sutikno, ASEAN Eng." <beei@iaescore.com>
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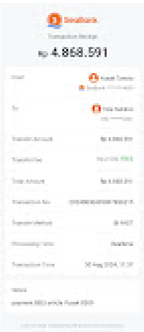
4 attachments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KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV

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Article Info

Article history:

Received month dd, yyyy
Revised month dd, yyyy
Accepted month dd, yyyy

Keywords:

On-grid
Solar PV
Rooftop PV
Techno-economic
Android application

ABSTRACT

Many developing countries, including Indonesia, are progressing poorly in residential rooftop PV adoption, including on-grid systems. On the customer side, the decision to implement on-grid rooftop PV or rely only on power from the utility grid has often been made without appropriate knowledge of techno-economic considerations. This includes the impression of high system costs. This paper introduces KawanSurya: PV Calculator, a solar rooftop PV techno-economic application for Android mobile phones, designed to help residential customers assess the potential of installing on-grid rooftop PV systems. The tool allows users to select a specific geographic location, calculate daily load profiles, and determine available roof areas. It uses irradiance data from the PVGIS API and HOMER's solar PV output equation to determine hourly PV output power. Simulation results for a typical 2,200 VA household show a payback period of 9.44 years or beyond, significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and similar load profile prolong the payback period, while a 0% billing reduction factor or uncompensated electricity sales may exceed the project's lifetime.

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1. INTRODUCTION

The Paris Agreement aims to reduce global greenhouse gas emissions to keep global temperature rise below 2°C and 1.5°C [1]. The electricity industry is transitioning to renewable energy technology, with renewable energy accounting for over 83% of additional capacity in 2022. Wind and solar, including rooftop PV, account for 91% of additional capacity [2], [3]. Proper legislation and support are crucial for rooftop solar photovoltaics to reduce greenhouse gas emissions [4]. Indonesia, like many developing nations, is making slow progress in residential rooftop PV adoption. The Indonesian government aims to achieve a 23% renewable energy mix by 2025, including 3.6 GW of rooftop PV [5]. However, achieving this target is challenging due to slow installed capacity [6]. The potential for solar rooftop PV adoption is positive due to cost reductions worldwide [7]. Capacity deployment requires supportive policies, comprehensive information dissemination, and government incentives [8], [9].

Numerous studies have identified challenges to residential rooftop PV adoption, including economic, technical, and social barriers, primarily focusing on monetary costs and benefits [10], knowledge and information aspects [11], and social and regulatory aspects [12]. In Indonesia, these include high initial investment costs, lack of access to installation services, information availability, disadvantageous PV export tariffs, and policy inconsistencies [13]. Improving public knowledge and clearing up misperceptions about costly technology tariffs and policy inconsistencies are among the important efforts to increase rooftop PV deployment [10]. Residential customers are increasingly considering solar PV energy to reduce electricity bills. However, technical and economic factors like usage compared to total electricity consumption and investment feasibility are crucial. Customers need a tool that provides an adequate system overview to assess the techno-economic potential of installing rooftop PV. Limited, independent applications and tools are available to help customers assess the potential of solar rooftop PV in their homes.

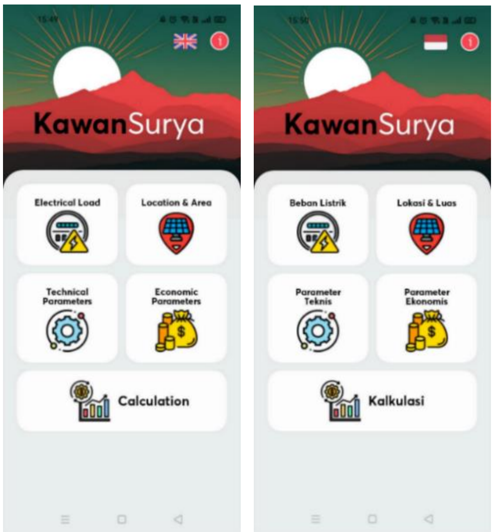
PVGIS [14] and PVWatts Calculator [15] are web-based tools developed by the European Commission and The National Renewable Energy Laboratory to assess the performance of solar power (PV) systems in specific geographic regions. They are used in rooftop PV techno-economic studies to compare the performance of free-standing and rooftop PV systems in different climatic zones [16] and evaluate residential PV systems with tiered rates and net metering [17]. PVGIS provides simulation outputs like yearly PV energy output, variability, electricity cost, monthly PV energy output, and horizon outline, but does not consider user load profile, resulting in the system's payback period. PVWatts offers an optional analysis considering roof area but does not account for user load profile. SolarHub [18], an Indonesian rooftop PV calculator, estimates solar PV capacity, energy generation, system costs, roof area, CO_2 emissions, and payback period.

This paper introduces KawanSurya: PV Calculator (which in English means 'solar friend'), a free Android tool for evaluating potential PV installations on-grid rooftops. The tool allows users to select a specific location, calculate daily load profiles, measure roof area, and calculate hourly PV output power using irradiation data from the PVGIS API [19] and HOMER's PV output equation [20], while also including the effect of shading [21] through the derating factor. The tool is designed to be a useful alternative to web-based applications for information dissemination about rooftop PV. The paper presents a methodological contribution to renewable energy literature, focusing on customer education and information dissemination on rooftop solar PV. It is intended for Indonesia's residential sector but can be used to simulate installation potential in other jurisdictions. The paper is structured into sections, including design method, results, discussions, and conclusions.

2. METHOD

2.1. Development, Navigation and Database of KawanSurya

KawanSurya is an Android tool designed for data processing, calculation, and user interface components. It is built using Kotlin, the native high-level programming language for Android, and Android Studio for data processing. The tool is intended for Android versions 8 to 13. The interface is organised into five main sections: Electrical Load, Location and Area, Technical Parameters, Economic Parameters, and Calculation. An Information page and user guide are also available. Figure 1 depicts the Android-based user interface of KawanSurya; (a) in English, and (b) in Bahasa Indonesia after it has been downloaded and run.



(a) (b)

Figure 1. The Android-based user interface of KawanSurya; (a) in English, and (b) in Bahasa Indonesia

The KawanSurya App is available online and can be downloaded from the following link: https://play.google.com/store/apps/details?id=com.christophermarvel.pvcalc. KawanSurya is a comprehensive tool for estimating the techno-economic potential of an on-grid rooftop solar PV system, involving user input, irradiance data retrieval, energy production calculation, daily load curve generation, PV system output power computation, and outcomes presentation, based on household appliances, operation hours, technical parameters, roof area, and location. The PVGIS API retrieves irradiance data from 2005 to 2016, with a one-hour time step. The tool calculates energy production, generates a daily load curve, and determines the required area for rooftop PV installations. It calculates Net Present Value (NPV), Return on Investment (ROI), payback period, and cash flow. Finally, the tool displays all the results, providing a comprehensive overview of the solar PV system's potential. Figure 2 depicts the flowchart for KawanSurya. It particularly shows stages for using the tool, which include entering the appropriate parameters, computing inputs, and presenting outcomes.

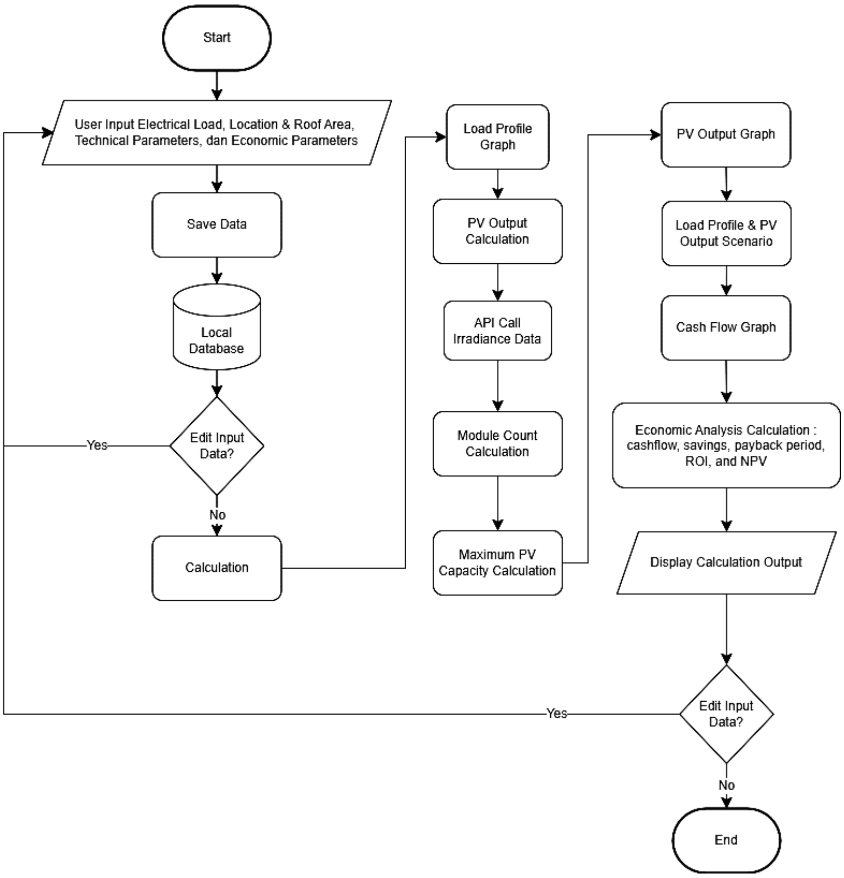


Figure 2. Flowchart of KawanSurya

KawanSurya is designed to demonstrate the techno-economic feasibility of an on-grid rooftop PV installation. Its user interface is designed with either low- or high-fidelity wireframes to merge practical and aesthetic aspects. KawanSurya uses Room Database, a library provided by Android Jetpack [22], to process a local database. Room Database is built on top of SQLite [23], a database engine used in Android applications. The tool has four distinct entities: *Task*, *Dpd*, *Eko*, and *Map*. Users can specify the tables to contain data for each entity. Navigation and class diagrams depict the system structure, with a class diagram of the Location and Area page. Figure 3 and Figure 4 show the navigation diagrams for KawanSurya and the developed database for the tool, respectively. Meanwhile, Figure 5 shows a class diagram of the Location and Area page.

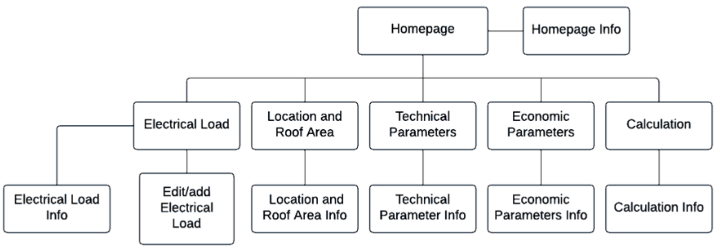


Figure 3. KawanSurya navigation diagram

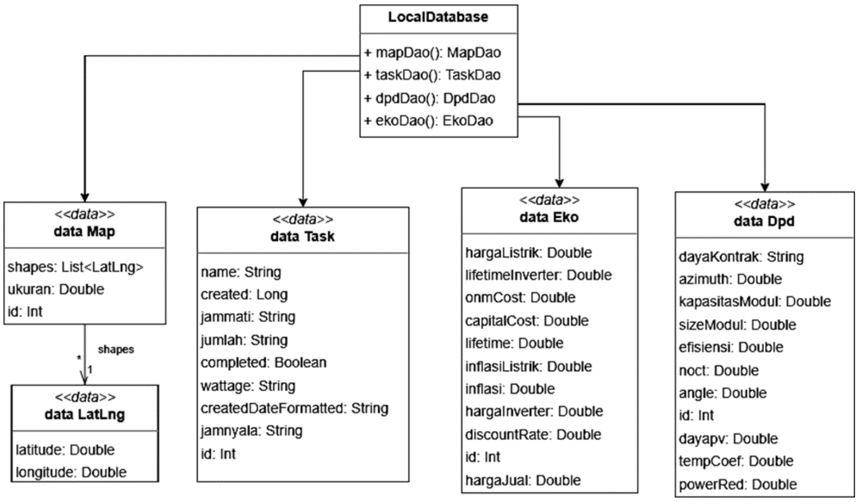


Figure 4. KawanSurya database scheme

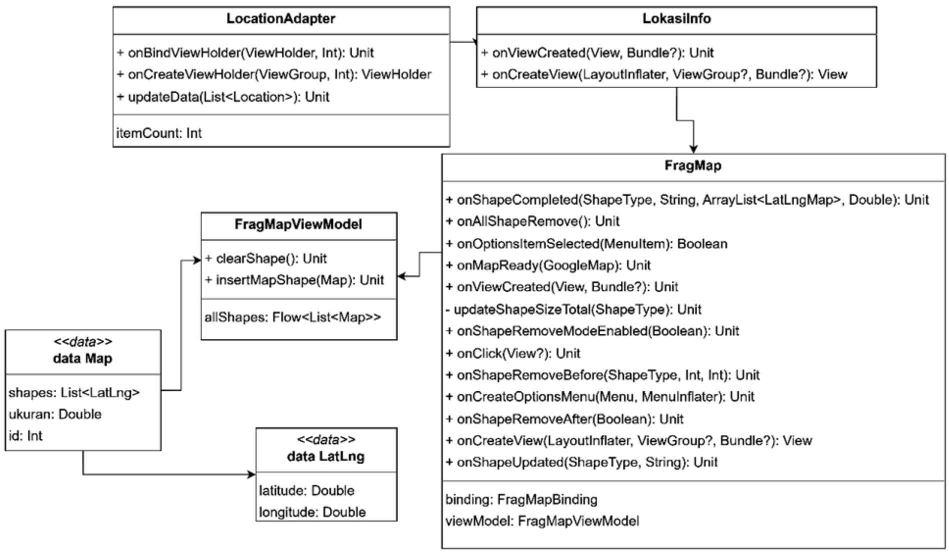


Figure 5. A class diagram of the *Location and Area* page

2.2. Electrical Load Page

The Electrical Load page allows users to add electrical loads or appliances by clicking the 'Add' button to enter their name, amount, active power, and operational hours. The tool calculates operational hours by subtracting On-time and Off-time. Users can input various appliance data to gather a 24-hour electrical load on their premises. This data generates daily electrical load data and curves, estimating self-consumed PV energy and excess energy sent back to the grid.

2.3. Technical Parameters Page

The Technical Parameters page on the rooftop PV system installation tool allows users to input various technical parameters, including installed PLN contracted power capacity (VA), maximum rooftop PV capacity, (Watt-peak, Wp), module size (m^2), PV module efficiency (%), nominal operating cell temperature (°C), and temperature coefficient of power (%/°C). Other parameters include tilt angle (°), azimuth (0° = South, 90° = West, -90° = East), and annual power output reduction (%). The tool allows users to change the parameters and define settings for their installation plan but also provides default values for simulation. This helps in calculating the system's hourly power output and evaluating economic performance. Irradiance data is crucial for calculating rooftop PV system output power. KawanSurya uses the PVGIS API to obtain data from the PVGIS SARAH-2 dataset [24], which contains sun irradiance data from 2005 to 2016. Retrofit is used to create an API request with parameters like latitude, longitude, month, output format, local time, global, angle, aspect, and temperatures. Figure 6 shows a part of the code created to retrieve the solar irradiance dataset for a specific place from PVGIS.

```kotlin
interface ApiInterface {
    @GET("api/v5_2/DRcalc")

    fun getDatas(@Query("lat") lat: Double,
                 @Query("lon") lon: Double,
                 @Query("month") month: Int,
                 @Query("ouputformat") ouputFormat: String,
                 @Query("localtime") localtime: Int,
                 @Query("global") global: Int,
                 @Query("angle") angle: Double,
                 @Query("aspect") aspect: Double,
                 @Query("showtemperatures") temp: Int
    ) : Call<ResponseData>
}
object RetrofitHelper {

    val baseUrl = "https://re.jrc.ec.europa.eu/"

    fun getInstance(): Retrofit {
        return Retrofit.Builder().baseUrl(baseUrl)
            .addConverterFactory(GsonConverterFactory.create())
            .build()
    }
}
private fun getDatas() {
    val api = RetrofitHelper.getInstance().create(ApiInterface::class.java)
    val viewModel2 = ViewModelProvider(this)[FragMapViewModel::class.java]
    lifecycleScope.launch {
        var lat: Double
        var lon: Double
        viewModel2.getAllShapes().collect {
            if (it.isNotEmpty()) {

                lat = it[it.size - 1].shapes[0].latitude
                lon = it[it.size - 1].shapes[0].longitude

                binding.tvLatlon.text = "%.5f, %.5f".format(lat, lon)
```

Figure 6. A screenshot of coding for retrieving the solar irradiance dataset

2.4. PV Output Power, Solar PV Capacity and Module Quantity

KawanSurya calculates rooftop PV output power using the HOMER software's equation, considering factors like derating factor and solar absorptivity and transmittance. The derating factor considers panel dirt, wire loss, shadowing, snow coverage, and aging. The tool calculates an estimated value of 0.77 [25] to determine the impact of these parameters on the performance of the rooftop PV system. Solar absorptivity and transmittance are calculated using the product of 0.9 or 90% [26]. The equations used to determine rooftop PV output power and PV cell temperature are as follows.

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}} \right) [1 + \alpha_p (T_c - T_{C,STC})] \tag{1}$$

where P_{PV} is PV output (kW); Y_{PV} is rated capacity solar PV array in standard test conditions (kW); f_{PV} is a derating factor (%); $\overline{G_T}$ is the solar radiation incident on the PV array in the current time step (kW/m^2); $\overline{G_{T,STC}}$ is the incident radiation at standard test conditions (1 kW/m^2); α_p is the temperature coefficient of power (%/°C); T_c is the PV cell temperature in the current time step (°C); and $T_{C,STC}$ is the PV cell temperature under standard test conditions (25°C).

$$T_c = \frac{T_a + (T_{c,NOCT} - T_{a,NOCT}) \left(\frac{G_T}{G_{T,NOCT}} \right) \left(1 - \frac{\eta_{mp,STC} (1 - \alpha_p T_{c,STC})}{\tau \alpha} \right)}{1 + (T_{c,NOCT} - T_{a,NOCT}) \left(\frac{G_T}{G_{T,NOCT}} \right) \left(\frac{\alpha_p \eta_{mp,STC}}{\tau \alpha} \right)} \tag{2}$$

where T_c is the PV cell temperature (°C); T_a is the ambient temperature (°C); $T_{c,NOCT}$ is the nominal operating cell temperature (°C); $T_{a,NOCT}$ is the ambient temperature at which the NOCT is defined (20°C); G_T is the solar radiation striking the PV array (kW/m^2); $G_{T,NOCT}$ is the solar radiation at which the NOCT is defined (0.8 kW/m^2); $\eta_{mp,STC}$ is the maximum power point efficiency under standard test conditions (%); α_p is temperature coefficient of power (%); $T_{C,STC}$ is the cell temperature under standard test conditions (25°C); τ is the solar transmittance of any cover over the PV array (%); α is the solar absorptance of the PV array (%). The tool predicts solar PV's electricity output power over multiple years, considering yearly power loss using the following equation.

$$PV_{out\ year\ n} = PV_{out\ yearly} \times (1 - yearly\ rate\ of\ PV_{out} degradation\ (\%)) \times (n - 1) \tag{3}$$

The tool limits solar PV module capacity to 100% of a household's contracted electricity [27]. The tool determines the number of modules and PV capacity by comparing the maximum power generated by all solar modules with the user's maximum power (Watt-peak) or a 100% permitted capacity equal to the household contracted power.

2.5. Location and Area Page

The Location and Area page allows users to estimate the available roof area for solar PV modules by drawing a polygon and clicking on the areas on the house's roof. The program uses the MapDrawingManager library to compute the area, which is an effective area considering 80% of the true size of the measured polygon. This usable roof space shows 80% of the total area within the polygon for installation and maintenance purposes. The program uses the site's coordinates and the roof area to provide accurate information. Figure 8 (a) in Section 3.2 shows a screenshot of the house's location and roof area displayed in KawanSurya.

2.6. Economic Parameters Page

The Economic Parameters page allows users to define the economic parameters of a rooftop PV system, including inverter price, lifetime, capital cost, electricity price, feed-in tariff, annual O&M cost, annual electricity price increase, inflation rate, discount rate, and project lifetime, for economic analysis purposes. KawanSurya uses payback period analysis to evaluate the economic feasibility of monocrystalline silicon-based PV module systems [28], [29], in addition to Return on Investment (ROI) and Net Present Value (NPV).

The study includes simple and discounted payback periods, with the present value (PV) calculated using an assumed interest rate [30]. The discount factor (DF) is based on the assumed discount rate. ROI measures the profitability of the system, defined as the ratio of net benefits (NPV) to the initial investment. A negative ROI indicates the investment is not profitable. The equations for calculating the simple or discounted payback period, ROI, and NPV are as follows.

$$PP = Nb + \frac{ccNb}{ncNa};\; PV = S \times F_{PW};\; DF = \left(1 + \frac{d}{100}\right)^{-n};\; IF = (1 + i)^{n} \quad (4)$$

$$F_{PW} = \frac{(1+i)^{n}}{(1+d)^{n}};\; NPV = \sum PV_{income} - \sum PV_{cost};\; ROI = \frac{NPV}{Capital\ Cost} \quad (5)$$

where PP is payback period; Nb is the year before recovery; $ccNb$ is cumulative cash flow in the year before recovery; and $ncNa$ is net cash flow in the year after recovery; PV is the present value of S in year n; S is cash flow in the year n; F_{PW} is a present worth factor in the year n; i is inflation rate; d is the discount rate; n is year.

3. RESULTS AND DISCUSSION

This section presents the simulation results conducted on KawanSurya, focusing on testing features and obtaining techno-economic results. Initial tests were performed to verify and validate the application's functionality, including processing electrical load data and retrieving solar irradiance data using an API. The findings and implications of these tests are discussed in detail.

3.1. Preliminary Tests on Electrical Loading and Solar Irradiance Data Retrieval

The electrical loading test evaluates the data gathering and processing for all appliances in a tool. The information is recorded in a local database and used during computation. The testing ensures accurate retrieval and processing of the data by adjusting the debug log level on the Calculation page. The testing uses database-based electrical load data, listing appliances, power, On-time, and Off-time. The tool calculates operating hours based on these values, resulting in 2 hours of operation for an On-time value of 1 and an Off-time value of 3.

Solar irradiance data retrieval through API is tested to determine whether the geographical location entered the tool and the retrieval of solar irradiance data. The tool considers solar irradiation in terms of the average monthly sum of global irradiation (GI) per square meter received by the modules (W/m^2/month). It is conducted by carrying out the debug log level. The testing site is at latitude 3.589 and longitude 114.893, with a tilt angle of 30° and azimuth of 0° (South facing).

Table 1 and Table 2 provide examples of data submitted for processing electrical load data, including the outcome of each appliance's operational period, and an example of the testing results for hourly temporal-based electrical load data processing, respectively. Meanwhile, Table 3 shows the locations debug log results, along with the corresponding irradiance data. The GI data originates from PVGIS's default solar dataset for the region, the PVGIS-SARAH dataset, which spans 2005 to 2016 and is available on an hourly temporal basis.

Table 1. Examples of data entered for processing the electrical load data

Electrical Load	Quantity	Wattage (W)	Operational Hours	Duration
a	4	99	05:00 – 07:00	2.25 hours
b	5	100	10:00 – 02:00	16 hours

Table 2. Testing results of electrical load data processing

Time	Wattage (W)	Time	Wattage (W)	Time	Wattage (W)
00:00	500	08:00	0	16:00	500
01:00	500	09:00	0	17:00	500
02:00	0	10:00	500	18:00	500
03:00	0	11:00	500	19:00	500
04:00	0	12:00	500	20:00	500
05:00	396	13:00	500	21:00	500
06:00	396	14:00	500	22:00	500
07:00	99	15:00	500	23:00	500

Table 3. Testing results of the average monthly sum of global irradiation data retrieval

Time	GI (W/m^2)	Time	GI (W/m^2)	Time	GI (W/m^2)
00:00	0	08:00	1,519.71	16:00	3,582.74
01:00	0	09:00	2,898.66	17:00	1,968.99
02:00	0	10:00	5,058.98	18:00	533.57
03:00	0	11:00	6,803.24	19:00	0
04:00	0	12:00	7,669.45	20:00	0
05:00	0	13:00	7,561.26	21:00	0
06:00	0	14:00	6,626.56	22:00	0
07:00	83.92	15:00	5,193.40	23:00	0

3.2. Simulation Settings and Results

The study explores the techno-economic implications of on-grid rooftop PV systems in households, considering low maximum power capacity scenarios and six policy-setting scenarios. It considers bill reduction, inflation, increased electricity tariffs, and load profile. Table 4 shows electrical loads in the household, including quantity, wattage, and On-time – Off-time.

Table 4. Electrical loads in a household with a 2,200VA power contract

Electrical load	Quantity	Wattage	On-time	Off-time
Refrigerator	1	80	24 hours	-
Rice cooker	1	300	17:00	17:40
Iron	1	300	09:00	10:00
Water pump	1	600	07:00	08:30
Washing machine	1	150	08:00	09:00
Laptop	2	100	20:00	22:00
Water heater	1	500	05:30	06:30
AC ½ hp	2	375	20:00	05:30
AC 1 hp	1	750	20:00	05:30
TV	1	80	20:00	22:00
Lamp	15	10	17:30	22:00
Lamp	5	10	22:00	05:30

Simulation-1 (S-1) is a case study of a household with a 2,200 VA power contract in Tropodo, Sidoarjo Regency, East Java, with standard household appliances. The study examines the use of a solar power (PV) system on the roof, focusing on the polygon drawn on the West-facing area. The user interface shows the house's latitude and longitude (-7.360 and 112.754, respectively), and its usable roof area (26.49 m^2). The simulation is based on a 100 Wp monocrystalline solar PV module [30], with specifications including size, capacity, efficiency, NOCT, and annual output power reduction. The economic parameters include inverter prices, system capital cost, electricity prices, export electricity prices, and annual operation and maintenance costs, with a 30° roof tilt angle and 90° azimuth, with the azimuth facing west, as provided by the PVGIS input API [20].

The economic parameters of a solar power system include inverter prices, system capital costs, electricity prices, export electricity prices, and O&M costs per year. The inverter costs IDR 4,290,000, 13% of the total system capital cost. The discount rate is 5%, annual growth on electricity price is 0%, and inflation is 0%. The O&M cost for a PV system is IDR 0, and the electricity price is based on a 2,200 VA power contract with a 100% sellback rate for exporting to the grid. The tool can support a 0% sellback rate if a policy change prevents rooftop PV owners from exporting electricity to the network. The investment cost for installing 1 kWp of rooftop PV is IDR 15 million, totalling IDR 33 million.

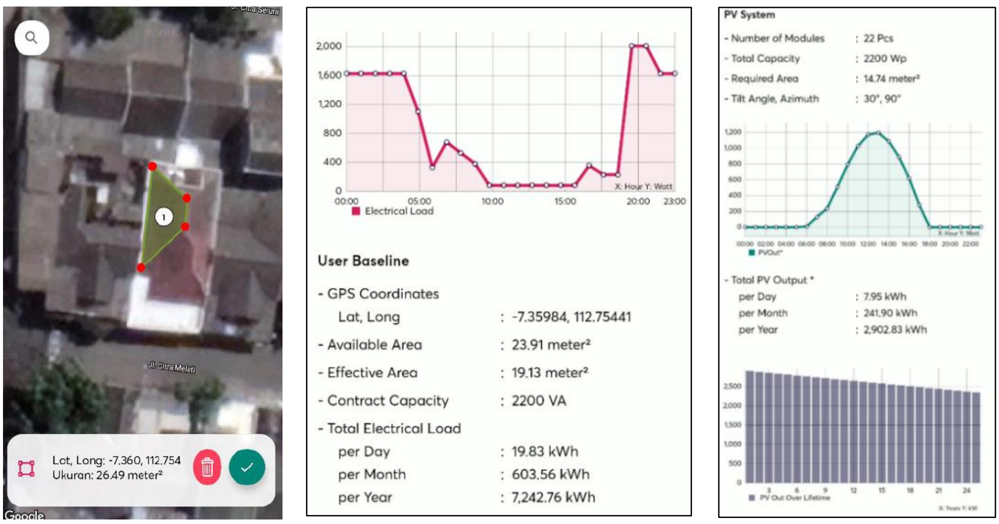
The technical and economic parameters for S-1 are as follows: contracted power capacity is 2,200 VA, maximum rooftop PV capacity is 2,200 Wp, size per module 0.67 m^2, capacity per module is 100 Wp, module efficiency (STC) is 14.92%, nominal operating cell temperature is 45°C, temperature coefficient of power is -0.39%/°C, tilt angle 30°, azimuth 90°, output power reduction per year 0.8%, inverter price is IDR 4,290,000, inverter lifetime 15 year, system capital cost (exclude inverter price) is IDR 28,710,000, electricity price is IDR 1,444.7, export electricity price is IDR 1,444.7, electricity price increase per year IDR 0, discount rate 5%, project lifetime 25 year.

KawanSurya's techno-economic analysis is divided into four sections: User Baseline, PV System, Load Profile Scenario with Daily PV Output, and Investment. The user baseline includes the daily load curve, geographic coordinates, roof size, contracted power, and total electrical load per day, month, and year. For the case of S-1 and given the selected location, they are 19.83 kWh, 603.56 kWh, and 7246.76 kWh, respectively. The generated load curve is then used to calculate electricity export, billing, and savings from the PV system.

The PV system part includes simulation results for module number, total capacity, needed area, tilt angle, azimuth, hourly output curve, and total output over project lifetime. The output curve is generated using irradiation data from the PVGIS API and technical parameters. The calculation shows that the installed capacity is limited to a contracted power of 2,200 VA. The necessary area is smaller than the available area. An asterisk (*) indicates that the total PV output was calculated before any reduction in power output. The total PV output, calculated before any reduction in power output, is 7.95 kWh/day, 241.90 kWh/month, and 2,902.83 kWh/year in this scenario. The graph below shows the decrease in PV output power over the project's lifetime, using a technical parameter of 0.8% power output reduction per year.

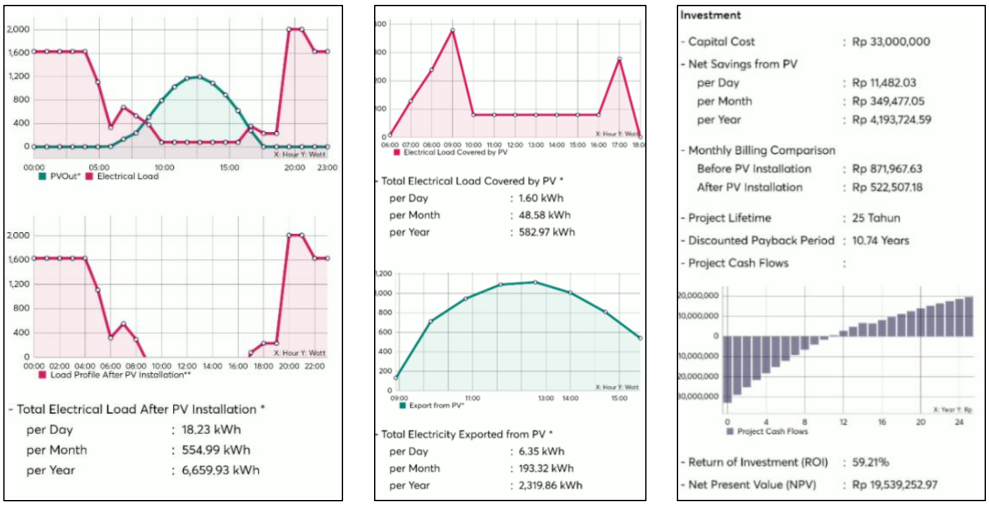
Figure 8 exhibits the S-1 results displaying user interfaces of KawanSurya; (a) The screenshot of the location and roof area, (b) the user baseline, and (c) the PV System. As previously stated in Section 2.5, Figure 8 (a) depicts a screenshot of the house coordinates and roof area in KawanSurya. It shows the house's coordinates of -7.360° (South Latitude), 112.754° (East Longitude), and the calculated usable roof area of 26.49 m^2. The load curve scenario with daily PV output generates simulation results for the hourly electricity load after PV installation, the portion covered by PV, and the amount of electricity exported from PV to the grid.

Figure 9 depicts the user interface/results for the load profile scenario; (a), (b) showing PV output and load profiles, and (c) investment section. As shown in Figure 9, the total electrical load after PV installation is 18.23 kWh/day, 554.99 kWh per month, and 6,659.93 kWh/year, while PV meets a total electrical load of 1.60 kWh/day, 48.58 kWh/month, and 582.97 kWh annually. The total electricity export is 6.35 kWh/day, 193.32 kWh/month, and 2,319.87 kWh annually. the investment section analyses the economic feasibility of rooftop PV, revealing net savings of IDR 11,482/day, IDR 349,477/month, and IDR 4,193,725 annually. The monthly electricity bill before and after installation is based on net savings from PV. The cash flow graph shows a discounted payback of 10.85 years at a 5% discount rate, an ROI of 59.21%, and an NPV of IDR 19,539,262.80. The S-1 scenario results in a discounted payback period of 10.74 years at a 5% discount rate and 100% bill reduction factor. However, successive scenarios, including varying inflation rates and rising electricity bills, have influenced the system's discounted payback period.



(a) (b) (c)

Figure 8. The user interface of KawanSurya; (a) The screenshot of the location and roof area, (b) the user baseline, and (c) the PV System of S-1



(a) (b) (c)

Figure 9. The user interface/results of S-1 for the Load Profile Scenario; (a), (b) showing PV output and load profiles, and (c) Investment

Simulation-2 (S-2) uses the same technical and economic parameters as S-1, resulting in a payback period of 19.79 years, twice the prior period. This is due to a 65% bill reduction factor, which reduces the power export price to 65% of the electricity rate per kWh. The modelled load profile shown in Figure 8 does not support maximising solar PV energy usage during the day, particularly between 09:00 – 15.00. Simulation-3 (S-3) adjusts the electrical load profile to a constant load while maintaining the 65% bill reduction factor from S-1. This scenario increases the energy supplied by the PV system to offset the load but reduces customer income from exporting electricity. The payback period is 11.79 years, one year longer than S-1. The overall electrical load changes, with 13.12 kWh/day, 399.35 kWh/month, and 4,792.25 kWh/year after PV installation.

Simulation-4 (S-4) assumes a 2% inflation rate while leaving all other parameters the same as S-1. The inclusion of inflation is intended to assess the impact of inflation on the payback period. Inflation can harm the economy but could benefit users by lowering the discount rate for power exported to the grid. The simulation yields a discounted payback period of 9.43 years or shorter than S-1 to S-3, allowing investors to recoup their initial investment faster. Simulation-5 (S-5) introduces a 2% annual increase in electricity tariffs while leaving all other parameters the same as S-1. This scenario benefits rooftop PV users by increasing income received, and calculating a discounted payback period of 9.66 years, assuming a 100% export rate. It should be noted that the payback period for PV users can be reduced by adjusting their daily electrical load profile between 7 a.m. and 5 p.m. and increasing daytime usage to lower the cost impact on billing caused by evening and nighttime loading. Table 5 presents possible discounted payback periods under various scenarios, including bill reduction factors, electricity load, inflation rates, increases in electricity tariffs, and minimum bill limits.

Table 5. Discounted payback periods due to different scenarios

No.	Scenario	Discounted payback period (year)
1.	Simulation-1 (S-1)	10.74
2.	S-2: with 1 65% bill reduction factor	19.79
3.	S-3: with a 65% bill reduction factor and constant electrical load	11.79
4.	S-4: with a 2% inflation rate	9.43
5.	S-5: with an annual increase of 2% in electricity tariff	9.66
6.	S-6: minimum bill limit	Exceed project lifetime

3.3. Discussions

Residential customers prefer systems with higher NPV and ROI, but decisions should also consider the ROI and NPV of different scenarios and electrical load patterns. Higher daytime energy usage is preferred for maximum electricity consumption. It should be noted that the discounted payback period of the simulated on-grid rooftop PV system is significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and the same load profile increase the discounted payback period. However, a 0% billing reduction factor or no compensation for selling back electricity to the grid can exceed the discounted payback period, making it advisable for rooftop PV system owners to increase electrical loading during the daytime. Inflation rates can help residential projects achieve shorter payback periods without significantly impacting financial cash flow, and well-compensated electricity exports are achieved regardless of daytime usage. KawanSurya reveals that a rooftop PV system's payback period can exceed the project's lifetime due to a set electricity bill limit, making the system uneconomical. Meanwhile, the accuracy and capability of the tool can be improved because it does not account for variables such as temperature, dirt, shade, and weather conditions.

4. CONCLUSION

Understanding the techno-economic potential of rooftop solar PV systems is crucial for increasing renewable energy penetration. Independent evaluation tools like KawanSurya help customers assess the potential of these systems, improving public knowledge and addressing misconceptions about costly technology tariffs. KawanSurya can be used to evaluate the techno-economic potential of installing on-grid rooftop PV under various scenarios, including daily load profiles, inflation, increased electricity tariffs, and billing reduction factors.

This study generated simulation results for a typical 2,200 VA household, resulting in a payback period of 9.44 years or longer. While the results are influenced by electrical load profiles and bill reduction factors, incorporating inflation rates in the simulations can help recover initial investment sooner. The 2% inflation rate resulted in a discounted payback period of 9.43 years, shorter than the default scenario and a 65% billing reduction factor. Adjusting the daily load profile and increasing daytime usage between 7 a.m. and 5 p.m. can reduce the payback period, while increased electricity tariffs may benefit users assuming a 100% export rate. Future work may include studies to enhance KawanSurya's capabilities and accuracy, as well as to broaden its capabilities to include off-grid and hybrid rooftop PV systems and to incorporate other factors influencing system performance.

ACKNOWLEDGEMENTS

This paper is part of the research contract no. 01010679/ELK/2023 conducted at Petra Christian University. The authors thank the reviewers for their time and effort in reading the manuscript. All comments and suggestions help to improve the manuscript's quality.

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KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV

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Bulletin of Electrical Engineering and Informatics
Vol. 99, No. 1, Month 2099, pp. 1~1x
ISSN: 2302-9285, DOI: 10.11591/eei.v99i1.paperID

KawanSurya: An Android-based mobile app for assessing the techno-economic potential of rooftop PV

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Article Info

Article history:

Received month dd, yyyy
Revised month dd, yyyy
Accepted month dd, yyyy

Keywords:

On-grid
Solar PV
Rooftop PV
Techno-economic
Android application

ABSTRACT

Many developing countries, including Indonesia, are progressing poorly in residential rooftop PV adoption, including on-grid systems. On the customer side, the decision to implement on-grid rooftop PV or rely only on power from the utility grid has often been made without appropriate knowledge of techno-economic considerations. This includes the impression of high system costs. This paper introduces KawanSurya: PV Calculator, a solar rooftop PV techno-economic application for Android mobile phones, designed to help residential customers assess the potential of installing on-grid rooftop PV systems. The tool allows users to select a specific geographic location, calculate daily load profiles, and determine available roof areas. It uses irradiance data from the PVGIS API and HOMER's solar PV output equation to determine hourly PV output power. Simulation results for a typical 2,200 VA household show a payback period of 9.44 years or beyond, significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and similar load profile prolong the payback period, while a 0% billing reduction factor or uncompensated electricity sales may exceed the project's lifetime.

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1. INTRODUCTION

The Paris Agreement aims to reduce global greenhouse gas emissions to keep global temperature rise below 2°C and 1.5°C [1]. The electricity industry is transitioning to renewable energy technology, with renewable energy accounting for over 83% of additional capacity in 2022. Wind and solar, including rooftop PV, account for 91% of additional capacity [2], [3]. Proper legislation and support are crucial for rooftop solar photovoltaics to reduce greenhouse gas emissions [4]. Indonesia, like many developing nations, is making slow progress in residential rooftop PV adoption. The Indonesian government aims to achieve a 23% renewable energy mix by 2025, including 3.6 GW of rooftop PV [5]. However, achieving this target is challenging due to slow installed capacity [6]. The potential for solar rooftop PV adoption is positive due to cost reductions worldwide [7]. Capacity deployment requires supportive policies, comprehensive information dissemination, and government incentives [8], [9].

Numerous studies have identified challenges to residential rooftop PV adoption, including economic, technical, and social barriers, primarily focusing on monetary costs and benefits [10], knowledge and information aspects [11], and social and regulatory aspects [12]. In Indonesia, these include high initial investment costs, lack of access to installation services, information availability, disadvantageous PV export tariffs, and policy inconsistencies [13]. Improving public knowledge and clearing up misperceptions about costly technology tariffs and policy inconsistencies are among the important efforts to increase rooftop PV deployment [10]. Residential customers are increasingly considering solar PV energy to reduce electricity bills. However, technical and economic factors like usage compared to total electricity consumption and investment feasibility are crucial. Customers need a tool that provides an adequate system overview to assess the techno-economic potential of installing rooftop PV. Limited, independent applications and tools are available to help customers assess the potential of solar rooftop PV in their homes.

PVGIS [14] and PVWatts Calculator [15] are web-based tools developed by the European Commission and The National Renewable Energy Laboratory to assess the performance of solar power (PV) systems in specific geographic regions. They are used in rooftop PV techno-economic studies to compare the performance of free-standing and rooftop PV systems in different climatic zones [16] and evaluate residential PV systems with tiered rates and net metering [17]. PVGIS provides simulation outputs like yearly PV energy output, variability, electricity cost, monthly PV energy output, and horizon outline, but does not consider user load profile, resulting in the system's payback period. PVWatts offers an optional analysis considering roof area but does not account for user load profile. SolarHub [18], an Indonesian rooftop PV calculator, estimates solar PV capacity, energy generation, system costs, roof area, CO_2 emissions, and payback period.

This paper introduces KawanSurya: PV Calculator (which in English means 'solar friend'), a free Android tool for evaluating potential PV installations on-grid rooftops. The tool allows users to select a specific location, calculate daily load profiles, measure roof area, and calculate hourly PV output power using irradiation data from the PVGIS API [19] and HOMER's PV output equation [20], while also including the effect of shading [21] through the derating factor. The tool is designed to be a useful alternative to web-based applications for information dissemination about rooftop PV. The paper presents a methodological contribution to renewable energy literature, focusing on customer education and information dissemination on rooftop solar PV. It is intended for Indonesia's residential sector but can be used to simulate installation potential in other jurisdictions. The paper is structured into sections, including design method, results, discussions, and conclusions.

2. METHOD

2.1. Development, Navigation and Database of KawanSurya

KawanSurya is an Android tool designed for data processing, calculation, and user interface components. It is built using Kotlin, the native high-level programming language for Android, and Android Studio for data processing. The tool is intended for Android versions 8 to 13. The interface is organised into five main sections: Electrical Load, Location and Area, Technical Parameters, Economic Parameters, and Calculation. An Information page and user guide are also available. Figure 1 depicts the Android-based user interface of KawanSurya; (a) in English, and (b) in Bahasa Indonesia after it has been downloaded and run.

(a) (b)

Figure 1. The Android-based user interface of KawanSurya; (a) in English, and (b) in Bahasa Indonesia

The KawanSurya App is available online and can be downloaded from the following link: https://play.google.com/store/apps/details?id=com.christophermarvel.pvcalc. KawanSurya is a comprehensive tool for estimating the techno-economic potential of an on-grid rooftop solar PV system, involving user input, irradiance data retrieval, energy production calculation, daily load curve generation, PV system output power computation, and outcomes presentation, based on household appliances, operation hours, technical parameters, roof area, and location. The PVGIS API retrieves irradiance data from 2005 to 2016, with a one-hour time step. The tool calculates energy production, generates a daily load curve, and determines the required area for rooftop PV installations. It calculates Net Present Value (NPV), Return on Investment (ROI), payback period, and cash flow. Finally, the tool displays all the results, providing a comprehensive overview of the solar PV system's potential. Figure 2 depicts the flowchart for KawanSurya. It particularly shows stages for using the tool, which include entering the appropriate parameters, computing inputs, and presenting outcomes.

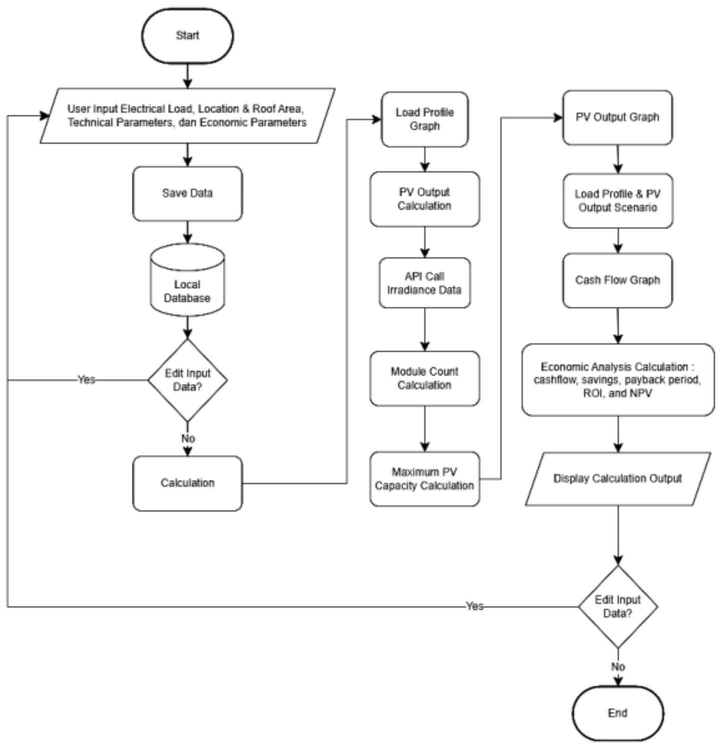


Figure 2. Flowchart of KawanSurya

KawanSurya is designed to demonstrate the techno-economic feasibility of an on-grid rooftop PV installation. Its user interface is designed with either low- or high-fidelity wireframes to merge practical and aesthetic aspects. KawanSurya uses Room Database, a library provided by Android Jetpack [22], to process a local database. Room Database is built on top of SQLite [23], a database engine used in Android applications. The tool has four distinct entities: *Task*, *Dpd*, *Eko*, and *Map*. Users can specify the tables to contain data for each entity. Navigation and class diagrams depict the system structure, with a class diagram of the Location and Area page. Figure 3 and Figure 4 show the navigation diagrams for KawanSurya and the developed database for the tool, respectively. Meanwhile, Figure 5 shows a class diagram of the Location and Area page.

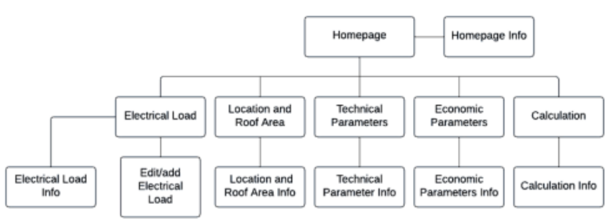


Figure 3. KawanSurya navigation diagram

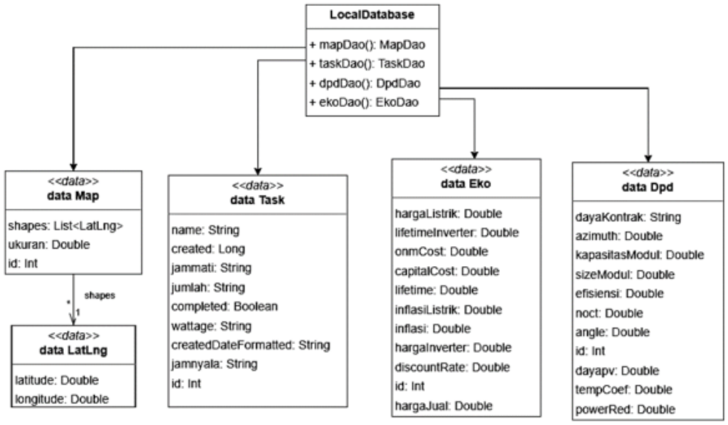


Figure 4. KawanSurya database scheme

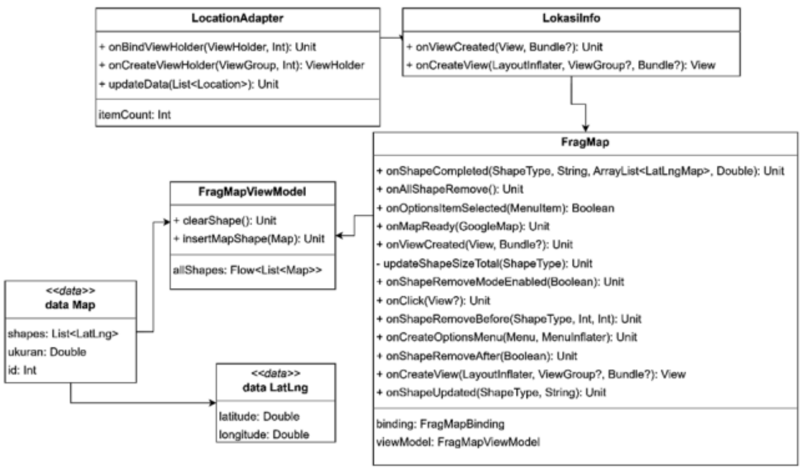


Figure 5. A class diagram of the *Location and Area* page

2.2. Electrical Load Page

The Electrical Load page allows users to add electrical loads or appliances by clicking the ‘Add’ button to enter their name, amount, active power, and operational hours. The tool calculates operational hours by subtracting On-time and Off-time. Users can input various appliance data to gather a 24-hour electrical load on their premises. This data generates daily electrical load data and curves, estimating self-consumed PV energy and excess energy sent back to the grid.

2.3. Technical Parameters Page

The Technical Parameters page on the rooftop PV system installation tool allows users to input various technical parameters, including installed PLN contracted power capacity (VA), maximum rooftop PV capacity, (Watt-peak, Wp), module size (m^2), PV module efficiency (%), nominal operating cell temperature (°C), and temperature coefficient of power (%/°C). Other parameters include tilt angle (°), azimuth (0° = South, 90° = West, -90° = East), and annual power output reduction (%). The tool allows users to change the parameters and define settings for their installation plan but also provides default values for simulation. This helps in calculating the system's hourly power output and evaluating economic performance. Irradiance data is crucial for calculating rooftop PV system output power. KawanSurya uses the PVGIS API to obtain data from the PVGIS SARAH-2 dataset [24], which contains sun irradiance data from 2005 to 2016. Retrofit is used to create an API request with parameters like latitude, longitude, month, output format, local time, global, angle, aspect, and temperatures. Figure 6 shows a part of the code created to retrieve the solar irradiance dataset for a specific place from PVGIS.

```kotlin
interface ApiInterface {
    @GET("api/v5_2/DRcalc")

    fun getDatas(@Query("lat") lat: Double,
                 @Query("lon") lon: Double,
                 @Query("month") month: Int,
                 @Query("ouputformat") ouputFormat: String,
                 @Query("localtime") localtime: Int,
                 @Query("global") global: Int,
                 @Query("angle") angle: Double,
                 @Query("aspect") aspect: Double,
                 @Query("showtemperatures") temp: Int
    ) : Call<ResponseData>
}
object RetrofitHelper {

    val baseUrl = "https://re.jrc.ec.europa.eu/"

    fun getInstance(): Retrofit {
        return Retrofit.Builder().baseUrl(baseUrl)
            .addConverterFactory(GsonConverterFactory.create())
            .build()
    }
}
private fun getDatas() {
    val api = RetrofitHelper.getInstance().create(ApiInterface::class.java)
    val viewModel2 = ViewModelProvider(this)[FragMapViewModel::class.java]
    lifecycleScope.launch {
        var lat: Double
        var lon: Double
        viewModel2.getAllShapes().collect {
            if (it.isNotEmpty()) {

                lat = it[it.size - 1].shapes[0].latitude
                lon = it[it.size - 1].shapes[0].longitude

                binding.tvLatlon.text = "%.5f, %.5f".format(lat, lon)
```

Figure 6. A screenshot of coding for retrieving the solar irradiance dataset

2.4. PV Output Power, Solar PV Capacity and Module Quantity

KawanSurya calculates rooftop PV output power using the HOMER software's equation, considering factors like derating factor and solar absorptivity and transmittance. The derating factor considers panel dirt, wire loss, shadowing, snow coverage, and aging. The tool calculates an estimated value of 0.77 [25] to determine the impact of these parameters on the performance of the rooftop PV system. Solar absorptivity and transmittance are calculated using the product of 0.9 or 90% [26]. The equations used to determine rooftop PV output power and PV cell temperature are as follows.

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) [1 + \alpha_p (T_c - T_{C,STC})] \quad (1)$$

where P_{PV} is PV output (kW); Y_{PV} is rated capacity solar PV array in standard test conditions (kW); f_{PV} is a derating factor (%); $\bar{G}_T$ is the solar radiation incident on the PV array in the current time step (kW/m^2); $\bar{G}_{T,STC}$ is the incident radiation at standard test conditions (1 kW/m^2); α_p is the temperature coefficient of power (%/°C); T_c is the PV cell temperature in the current time step (°C); and $T_{C,STC}$ is the PV cell temperature under standard test conditions (25°C).

$$T_c = \frac{T_a + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(1 - \frac{\eta_{mp,STC}(1 - \alpha_p T_{c,STC})}{\tau\alpha}\right)}{1 + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_p \eta_{mp,STC}}{\tau\alpha}\right)} \quad (2)$$

where T_c is the PV cell temperature (°C); T_a is the ambient temperature (°C); $T_{c,NOCT}$ is the nominal operating cell temperature (°C); $T_{a,NOCT}$ is the ambient temperature at which the NOCT is defined (20°C); G_T is the solar radiation striking the PV array (kW/m^2); $G_{T,NOCT}$ is the solar radiation at which the NOCT is defined (0.8 kW/m^2); $\eta_{mp,STC}$ is the maximum power point efficiency under standard test conditions (%); α_p is temperature coefficient of power (%); $T_{C,STC}$ is the cell temperature under standard test conditions (25°C); τ is the solar transmittance of any cover over the PV array (%); α is the solar absorptance of the PV array (%). The tool predicts solar PV's electricity output power over multiple years, considering yearly power loss using the following equation.

$$PV_{out\ year\ n} = PV_{out\ yearly} \times (1 - yearly\ rate\ of\ PV_{out} degradation\ (\%)) \times (n - 1) \quad (3)$$

The tool limits solar PV module capacity to 100% of a household's contracted electricity [27]. The tool determines the number of modules and PV capacity by comparing the maximum power generated by all solar modules with the user's maximum power (Watt-peak) or a 100% permitted capacity equal to the household contracted power.

2.5. Location and Area Page

The Location and Area page allows users to estimate the available roof area for solar PV modules by drawing a polygon and clicking on the areas on the house's roof. The program uses the MapDrawingManager library to compute the area, which is an effective area considering 80% of the true size of the measured polygon. This usable roof space shows 80% of the total area within the polygon for installation and maintenance purposes. The program uses the site's coordinates and the roof area to provide accurate information. Figure 8 (a) in Section 3.2 shows a screenshot of the house's location and roof area displayed in KawanSurya.

2.6. Economic Parameters Page

The Economic Parameters page allows users to define the economic parameters of a rooftop PV system, including inverter price, lifetime, capital cost, electricity price, feed-in tariff, annual O&M cost, annual electricity price increase, inflation rate, discount rate, and project lifetime, for economic analysis purposes. KawanSurya uses payback period analysis to evaluate the economic feasibility of monocrystalline silicon-based PV module systems [28], [29], in addition to Return on Investment (ROI) and Net Present Value (NPV).

The study includes simple and discounted payback periods, with the present value (PV) calculated using an assumed interest rate [30]. The discount factor (DF) is based on the assumed discount rate. ROI measures the profitability of the system, defined as the ratio of net benefits (NPV) to the initial investment. A negative ROI indicates the investment is not profitable. The equations for calculating the simple or discounted payback period, ROI, and NPV are as follows.

$$PP = Nb + \frac{ccNb}{ncNa};\ PV = S \times F_{PW};\ DF = \left(1 + \frac{d}{100}\right)^{-n};\ IF = (1 + i)^{n} \quad (4)$$

$$F_{PW} = \frac{(1+i)^{n}}{(1+d)^{n}};\ NPV = \sum PV_{income} - \sum PV_{cost};\ ROI = \frac{NPV}{Capital\ Cost} \quad (5)$$

where PP is payback period; Nb is the year before recovery; $ccNb$ is cumulative cash flow in the year before recovery; and $ncNa$ is net cash flow in the year after recovery; PV is the present value of S in year n; S is cash flow in the year n; F_{PW} is a present worth factor in the year n; i is inflation rate; d is the discount rate; n is year.

3. RESULTS AND DISCUSSION

This section presents the simulation results conducted on KawanSurya, focusing on testing features and obtaining techno-economic results. Initial tests were performed to verify and validate the application's functionality, including processing electrical load data and retrieving solar irradiance data using an API. The findings and implications of these tests are discussed in detail.

3.1. Preliminary Tests on Electrical Loading and Solar Irradiance Data Retrieval

The electrical loading test evaluates the data gathering and processing for all appliances in a tool. The information is recorded in a local database and used during computation. The testing ensures accurate retrieval and processing of the data by adjusting the debug log level on the Calculation page. The testing uses database-based electrical load data, listing appliances, power, On-time, and Off-time. The tool calculates operating hours based on these values, resulting in 2 hours of operation for an On-time value of 1 and an Off-time value of 3.

Solar irradiance data retrieval through API is tested to determine whether the geographical location entered the tool and the retrieval of solar irradiance data. The tool considers solar irradiation in terms of the average monthly sum of global irradiation (GI) per square meter received by the modules (W/m^2/month). It is conducted by carrying out the debug log level. The testing site is at latitude 3.589 and longitude 114.893, with a tilt angle of 30° and azimuth of 0° (South facing).

Table 1 and Table 2 provide examples of data submitted for processing electrical load data, including the outcome of each appliance's operational period, and an example of the testing results for hourly temporal-based electrical load data processing, respectively. Meanwhile, Table 3 shows the locations debug log results, along with the corresponding irradiance data. The GI data originates from PVGIS's default solar dataset for the region, the PVGIS-SARAH dataset, which spans 2005 to 2016 and is available on an hourly temporal basis.

Table 1. Examples of data entered for processing the electrical load data

Electrical Load	Quantity	Wattage (W)	Operational Hours	Duration
a	4	99	05:00 – 07:00	2.25 hours
b	5	100	10:00 – 02:00	16 hours

Table 2. Testing results of electrical load data processing

Time	Wattage (W)	Time	Wattage (W)	Time	Wattage (W)
00:00	500	08:00	0	16:00	500
01:00	500	09:00	0	17:00	500
02:00	0	10:00	500	18:00	500
03:00	0	11:00	500	19:00	500
04:00	0	12:00	500	20:00	500
05:00	396	13:00	500	21:00	500
06:00	396	14:00	500	22:00	500
07:00	99	15:00	500	23:00	500

Table 3. Testing results of the average monthly sum of global irradiation data retrieval

Time	GI (W/m^2)	Time	GI (W/m^2)	Time	GI (W/m^2)
00:00	0	08:00	1,519.71	16:00	3,582.74
01:00	0	09:00	2,898.66	17:00	1,968.99
02:00	0	10:00	5,058.98	18:00	533.57
03:00	0	11:00	6,803.24	19:00	0
04:00	0	12:00	7,669.45	20:00	0
05:00	0	13:00	7,561.26	21:00	0
06:00	0	14:00	6,626.56	22:00	0
07:00	83.92	15:00	5,193.40	23:00	0

3.2. Simulation Settings and Results

The study explores the techno-economic implications of on-grid rooftop PV systems in households, considering low maximum power capacity scenarios and six policy-setting scenarios. It considers bill reduction, inflation, increased electricity tariffs, and load profile. Table 4 shows electrical loads in the household, including quantity, wattage, and On-time – Off-time.

Table 4. Electrical loads in a household with a 2,200VA power contract

Electrical load	Quantity	Wattage	On-time	Off-time
Refrigerator	1	80	24 hours	-
Rice cooker	1	300	17:00	17:40
Iron	1	300	09:00	10:00
Water pump	1	600	07:00	08:30
Washing machine	1	150	08:00	09:00
Laptop	2	100	20:00	22:00
Water heater	1	500	05:30	06:30
AC ½ hp	2	375	20:00	05:30
AC 1 hp	1	750	20:00	05:30
TV	1	80	20:00	22:00
Lamp	15	10	17:30	22:00
Lamp	5	10	22:00	05:30

Simulation-1 (S-1) is a case study of a household with a 2,200 VA power contract in Tropodo, Sidoarjo Regency, East Java, with standard household appliances. The study examines the use of a solar power (PV) system on the roof, focusing on the polygon drawn on the West-facing area. The user interface shows the house's latitude and longitude (-7.360 and 112.754, respectively), and its usable roof area (26.49 m^2). The simulation is based on a 100 Wp monocrystalline solar PV module [30], with specifications including size, capacity, efficiency, NOCT, and annual output power reduction. The economic parameters include inverter prices, system capital cost, electricity prices, export electricity prices, and annual operation and maintenance costs, with a 30° roof tilt angle and 90° azimuth, with the azimuth facing west, as provided by the PVGIS input API [20].

The economic parameters of a solar power system include inverter prices, system capital costs, electricity prices, export electricity prices, and O&M costs per year. The inverter costs IDR 4,290,000, 13% of the total system capital cost. The discount rate is 5%, annual growth on electricity price is 0%, and inflation is 0%. The O&M cost for a PV system is IDR 0, and the electricity price is based on a 2,200 VA power contract with a 100% sellback rate for exporting to the grid. The tool can support a 0% sellback rate if a policy change prevents rooftop PV owners from exporting electricity to the network. The investment cost for installing 1 kWp of rooftop PV is IDR 15 million, totalling IDR 33 million.

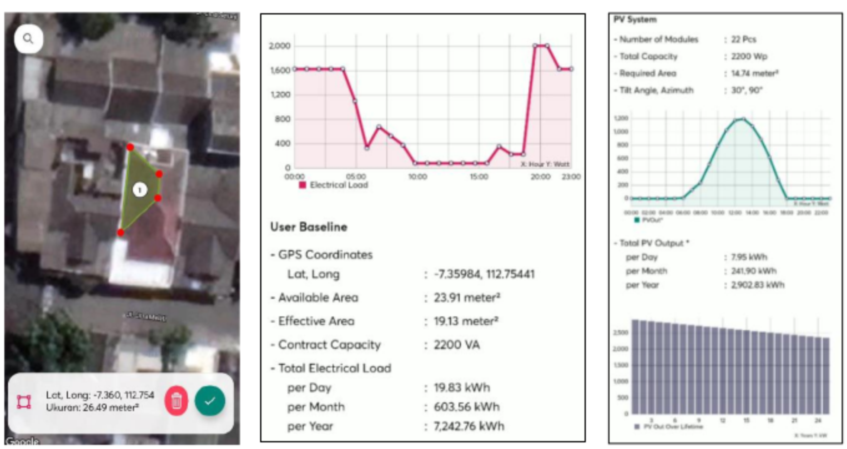
The technical and economic parameters for S-1 are as follows: contracted power capacity is 2,200 VA, maximum rooftop PV capacity is 2,200 Wp, size per module 0.67 m^2, capacity per module is 100 Wp, module efficiency (STC) is 14.92%, nominal operating cell temperature is 45°C, temperature coefficient of power is -0.39%/°C, tilt angle 30°, azimuth 90°, output power reduction per year 0.8%, inverter price is IDR 4,290,000, inverter lifetime 15 year, system capital cost (exclude inverter price) is IDR 28,710,000, electricity price is IDR 1,444.7, export electricity price is IDR 1,444.7, electricity price increase per year IDR 0, discount rate 5%, project lifetime 25 year.

KawanSurya's techno-economic analysis is divided into four sections: User Baseline, PV System, Load Profile Scenario with Daily PV Output, and Investment. The user baseline includes the daily load curve, geographic coordinates, roof size, contracted power, and total electrical load per day, month, and year. For the case of S-1 and given the selected location, they are 19.83 kWh, 603.56 kWh, and 7246.76 kWh, respectively. The generated load curve is then used to calculate electricity export, billing, and savings from the PV system.

The PV system part includes simulation results for module number, total capacity, needed area, tilt angle, azimuth, hourly output curve, and total output over project lifetime. The output curve is generated using irradiation data from the PVGIS API and technical parameters. The calculation shows that the installed capacity is limited to a contracted power of 2,200 VA. The necessary area is smaller than the available area. An asterisk (*) indicates that the total PV output was calculated before any reduction in power output. The total PV output, calculated before any reduction in power output, is 7.95 kWh/day, 241.90 kWh/month, and 2,902.83 kWh/year in this scenario. The graph below shows the decrease in PV output power over the project's lifetime, using a technical parameter of 0.8% power output reduction per year.

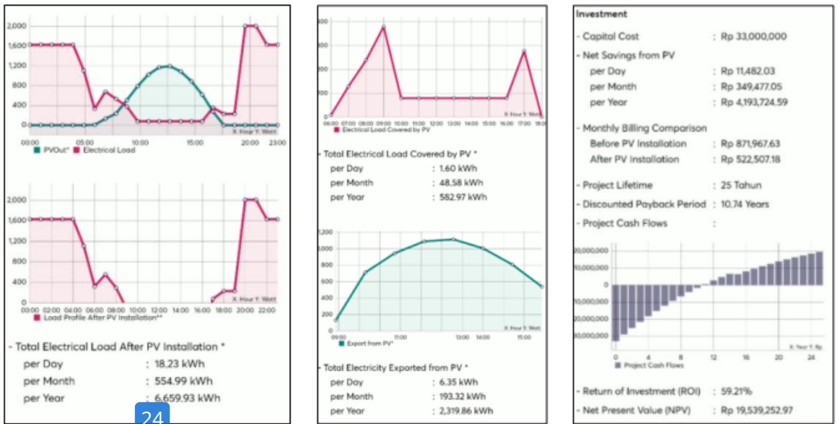
Figure 8 exhibits the S-1 results displaying user interfaces of KawanSurya; (a) The screenshot of the location and roof area, (b) the user baseline, and (c) the PV System. As previously stated in Section 2.5, Figure 8 (a) depicts a screenshot of the house coordinates and roof area in KawanSurya. It shows the house's coordinates of -7.360° (South Latitude), 112.754° (East Longitude), and the calculated usable roof area of 26.49 m^2. The load curve scenario with daily PV output generates simulation results for the hourly electricity load after PV installation, the portion covered by PV, and the amount of electricity exported from PV to the grid.

Figure 9 depicts the user interface/results for the load profile scenario; (a), (b) showing PV output and load profiles, and (c) investment section. As shown in Figure 9, the total electrical load after PV installation is 18.23 kWh/day, 554.99 kWh per month, and 6,659.93 kWh/year, while PV meets a total electrical load of 1.60 kWh/day, 48.58 kWh/month, and 582.97 kWh annually. The total electricity export is 6.35 kWh/day, 193.32 kWh/month, and 2,319.87 kWh annually. the investment section analyses the economic feasibility of rooftop PV, revealing net savings of IDR 11,482/day, IDR 349,477/month, and IDR 4,193,725 annually. The monthly electricity bill before and after installation is based on net savings from PV. The cash flow graph shows a discounted payback of 10.85 years at a 5% discount rate, an ROI of 59.21%, and an NPV of IDR 19,539,262.80. The S-1 scenario results in a discounted payback period of 10.74 years at a 5% discount rate and 100% bill reduction factor. However, successive scenarios, including varying inflation rates and rising electricity bills, have influenced the system's discounted payback period.



(a) (b) (c)

Figure 8. The user interface of KawanSurya; (a) The screenshot of the location and roof area, (b) the user baseline, and (c) the PV System of S-1



(a) (b) (c)

Figure 9. The user interface/results of S-1 for the Load Profile Scenario; (a), (b) showing PV output and load profiles, and (c) Investment

Simulation-2 (S-2) uses the same technical and economic parameters as S-1, resulting in a payback period of 19.79 years, twice the prior period. This is due to a 65% bill reduction factor, which reduces the power export price to 65% of the electricity rate per kWh. The modelled load profile shown in Figure 8 does not support maximising solar PV energy usage during the day, particularly between 09:00 – 15.00. Simulation-3 (S-3) adjusts the electrical load profile to a constant load while maintaining the 65% bill reduction factor from S-1. This scenario increases the energy supplied by the PV system to offset the load but reduces customer income from exporting electricity. The payback period is 11.79 years, one year longer than S-1. The overall electrical load changes, with 13.12 kWh/day, 399.35 kWh/month, and 4,792.25 kWh/year after PV installation.

Simulation-4 (S-4) assumes a 2% inflation rate while leaving all other parameters the same as S-1. The inclusion of inflation is intended to assess the impact of inflation on the payback period. Inflation can harm the economy but could benefit users by lowering the discount rate for power exported to the grid. The simulation yields a discounted payback period of 9.43 years or shorter than S-1 to S-3, allowing investors to recoup their initial investment faster. Simulation-5 (S-5) introduces a 2% annual increase in electricity tariffs while leaving all other parameters the same as S-1. This scenario benefits rooftop PV users by increasing income received, and calculating a discounted payback period of 9.66 years, assuming a 100% export rate. It should be noted that the payback period for PV users can be reduced by adjusting their daily electrical load profile between 7 a.m. and 5 p.m. and increasing daytime usage to lower the cost impact on billing caused by evening and nighttime loading. Table 5 presents possible discounted payback periods under various scenarios, including bill reduction factors, electricity load, inflation rates, increases in electricity tariffs, and minimum bill limits.

Table 5. Discounted payback periods due to different scenarios

No.	Scenario	Discounted payback period (year)
1.	Simulation-1 (S-1)	10.74
2.	S-2: with 1 65% bill reduction factor	19.79
3.	S-3: with a 65% bill reduction factor and constant electrical load	11.79
4.	S-4: with a 2% inflation rate	9.43
5.	S-5: with an annual increase of 2% in electricity tariff	9.66
6.	S-6: minimum bill limit	Exceed project lifetime

3.3. Discussions

Residential customers prefer systems with higher NPV and ROI, but decisions should also consider the ROI and NPV of different scenarios and electrical load patterns. Higher daytime energy usage is preferred for maximum electricity consumption. It should be noted that the discounted payback period of the simulated on-grid rooftop PV system is significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and the same load profile increase the discounted payback period. However, a 0% billing reduction factor or no compensation for selling back electricity to the grid can exceed the discounted payback period, making it advisable for rooftop PV system owners to increase electrical loading during the daytime. Inflation rates can help residential projects achieve shorter payback periods without significantly impacting financial cash flow, and well-compensated electricity exports are achieved regardless of daytime usage. KawanSurya reveals that a rooftop PV system's payback period can exceed the project's lifetime due to a set electricity bill limit, making the system uneconomical. Meanwhile, the accuracy and capability of the tool can be improved because it does not account for variables such as temperature, dirt, shade, and weather conditions.

4. CONCLUSION

Understanding the techno-economic potential of rooftop solar PV systems is crucial for increasing renewable energy penetration. Independent evaluation tools like KawanSurya help customers assess the potential of these systems, improving public knowledge and addressing misconceptions about costly technology tariffs. KawanSurya can be used to evaluate the techno-economic potential of installing on-grid rooftop PV under various scenarios, including daily load profiles, inflation, increased electricity tariffs, and billing reduction factors.

This study generated simulation results for a typical 2,200 VA household, resulting in a payback period of 9.44 years or longer. While the results are influenced by electrical load profiles and bill reduction factors, incorporating inflation rates in the simulations can help recover initial investment sooner. The 2% inflation rate resulted in a discounted payback period of 9.43 years, shorter than the default scenario and a 65% billing reduction factor. Adjusting the daily load profile and increasing daytime usage between 7 a.m. and 5 p.m. can reduce the payback period, while increased electricity tariffs may benefit users assuming a 100% export rate. Future work may include studies to enhance KawanSurya's capabilities and accuracy, as well as to broaden its capabilities to include off-grid and hybrid rooftop PV systems and to incorporate other factors influencing system performance.

ACKNOWLEDGEMENTS

This paper is part of the research contract no. 01010679/ELK/2023 conducted at Petra Christian University. The authors thank the reviewers for their time and effort in reading the manuscript. All comments and suggestions help to improve the manuscript's quality.

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KawanSurya: an Android-based mobile app for assessing the techno-economic potential of rooftop PV

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Article Info

Article history:

Received month dd, yyyy
Revised month dd, yyyy
Accepted month dd, yyyy

Keywords:

Android application
On-grid
Rooftop PV
Solar PV
Techno-economic

ABSTRACT

Many developing countries, including Indonesia, are progressing poorly in residential rooftop PV adoption, including on-grid systems. On the customer side, the decision to implement on-grid rooftop PV or rely only on power from the utility grid has often been made without appropriate knowledge of techno-economic considerations. This includes the impression of high system costs. This paper introduces KawanSurya: PV calculator, a solar rooftop PV techno-economic application for Android mobile phones, designed to help residential customers assess the potential of installing on-grid rooftop PV systems. The tool allows users to select a specific geographic location, calculate daily load profiles, and determine available roof areas. It uses irradiance data from the PVGIS API and HOMER's solar PV output equation to determine hourly PV output power. Simulation results for a typical 2,200 VA household show a payback period of 9.44 years or beyond, significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and similar load profile prolong the payback period, while a 0% billing reduction factor or uncompensated electricity sales may exceed the project's lifetime.

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1. INTRODUCTION

The Paris Agreement aims to reduce global greenhouse gas emissions to keep global temperature rise below 2°C and 1.5°C [1]. The electricity industry is transitioning to renewable energy technology, with renewable energy accounting for over 83% of additional capacity in 2022. Wind and solar, including rooftop PV, account for 91% of additional capacity [2], [3]. Proper legislation and support are crucial for rooftop solar photovoltaics to reduce greenhouse gas emissions [4]. Indonesia, like many developing nations, is making slow progress in residential rooftop PV adoption. The Indonesian government aims to achieve a 23% renewable energy mix by 2025, including 3.6 GW of rooftop PV [5]. However, achieving this target is challenging due to slow installed capacity [6]. The potential for solar rooftop PV adoption is positive due to cost reductions worldwide [7]. Capacity deployment requires supportive policies, comprehensive information dissemination, and government incentives [8], [9].

Numerous studies have identified challenges to residential rooftop PV adoption, including economic, technical, and social barriers, primarily focusing on monetary costs and benefits [10], knowledge and information aspects [11], and social and regulatory aspects [12]. In Indonesia, these include high initial investment costs, lack of access to installation services, information availability, disadvantageous PV export tariffs, and policy inconsistencies [13]. Improving public knowledge and clearing up misperceptions about

costly technology tariffs and policy inconsistencies are among the important efforts to increase rooftop PV deployment [10]. Residential customers are increasingly considering solar PV energy to reduce electricity bills. However, technical and economic factors like usage compared to total electricity consumption and investment feasibility are crucial. Customers need a tool that provides an adequate system overview to assess the techno-economic potential of installing rooftop PV. Limited, independent applications and tools are available to help customers assess the potential of solar rooftop PV in their homes.

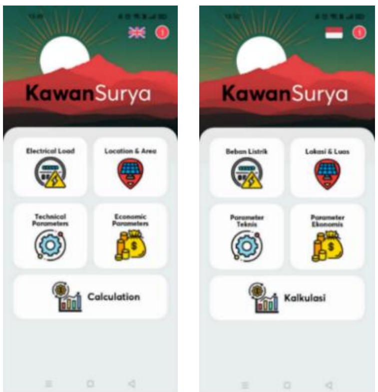
Photovoltaic geographical information system (PVGIS) [14] and PVWatts calculator [15] are web-based tools developed by the European Commission and The National Renewable Energy Laboratory to assess the performance of solar power (PV) systems in specific geographic regions. They are used in rooftop PV techno-economic studies to compare the performance of free-standing and rooftop PV systems in different climatic zones [16] and evaluate residential PV systems with tiered rates and net metering [17]. PVGIS provides simulation outputs like yearly PV energy output, variability, electricity cost, monthly PV energy output, and horizon outline, but does not consider user load profile, resulting in the system's payback period. PVWatts offers an optional analysis considering roof area but does not account for user load profile. SolarHub [18], an Indonesian rooftop PV calculator, estimates solar PV capacity, energy generation, system costs, roof area, CO_2 emissions, and payback period.

This paper introduces KawanSurya: PV calculator (which in English means 'solar friend'), a free Android tool for evaluating potential PV installations on-grid rooftops. The tool allows users to select a specific location, calculate daily load profiles, measure roof area, and calculate hourly PV output power using irradiation data from the PVGIS API [19] and HOMER's PV output equation [20], while also including the effect of shading [21] through the derating factor. The tool is designed to be a useful alternative to web-based applications for information dissemination about rooftop PV. The paper presents a methodological contribution to renewable energy literature, focusing on customer education and information dissemination on rooftop solar PV. It is intended for Indonesia's residential sector but can be used to simulate installation potential in other jurisdictions. The paper is structured into sections, including design method, results, discussions, and conclusions.

2. METHOD

2.1. Development, navigation, and database of KawanSurya

KawanSurya is an Android tool designed for data processing, calculation, and user interface components. It is built using Kotlin, the native high-level programming language for Android, and Android Studio for data processing. The tool is intended for Android versions 8 to 13. The interface is organised into five main sections: electrical load, location and area, technical parameters, economic parameters, and calculation. An Information page and user guide are also available. Figure 1 depicts the Android-based user interface of KawanSurya; Figure 1(a) in English, and Figure 1(b) in Indonesia after it has been downloaded and run.



(a) (b)

Figure 1. The Android-based user interface of KawanSurya; (a) in English and (b) in Indonesia

The KawanSurya App is available online and can be downloaded from the following link: https://play.google.com/store/apps/details?id=com.christophermarvel.pvcalc. KawanSurya is a comprehensive tool for estimating the techno-economic potential of an on-grid rooftop solar PV system, involving user input, irradiance data retrieval, energy production calculation, daily load curve generation, PV system output power computation, and outcomes presentation, based on household appliances, operation hours, technical parameters, roof area, and location. The PVGIS API retrieves irradiance data from 2005 to 2016, with a one-hour time step. The tool calculates energy production, generates a daily load curve, and determines the required area for rooftop PV installations. It calculates net present value (NPV), return on investment (ROI), payback period, and cash flow. Finally, the tool displays all the results, providing a comprehensive overview of the solar PV system's potential. Figure 2 depicts the flowchart for KawanSurya. It particularly shows stages for using the tool, which include entering the appropriate parameters, computing inputs, and presenting outcomes.

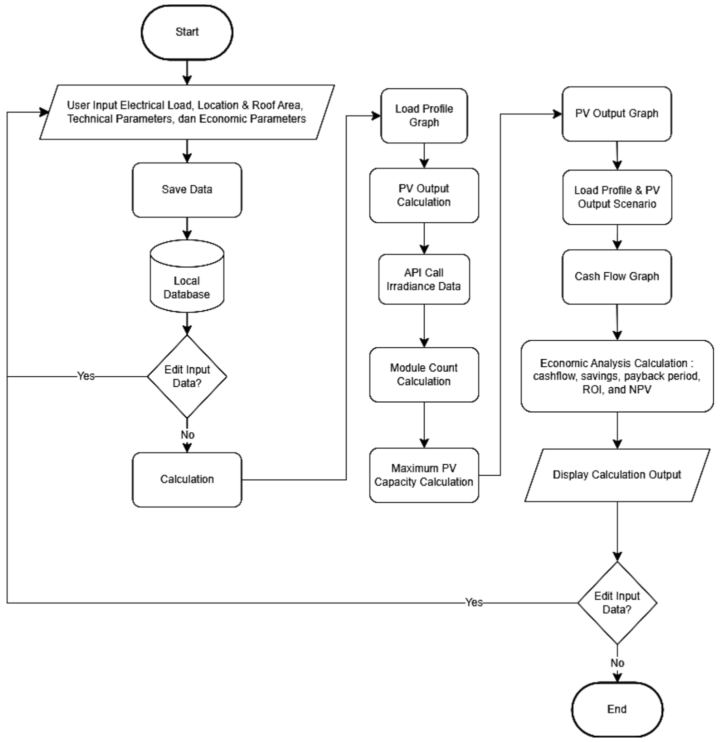


Figure 2. Flowchart of KawanSurya

KawanSurya is designed to demonstrate the techno-economic feasibility of an on-grid rooftop PV installation. It is user interface is designed with either low- or high-fidelity wireframes to merge practical and aesthetic aspects. KawanSurya uses room database, a library provided by Android Jetpack [22], to process a local database. Room Database is built on top of SQLite [23], a database engine used in Android applications. The tool has four distinct entities: Task, Dpd, Eko, and Map. Users can specify the tables to contain data for each entity. Navigation and class diagrams depict the system structure, with a class diagram of the location and area page. Figures 3 and 4 show the navigation diagrams for KawanSurya and the developed database for the tool, respectively. Meanwhile, Figure 5 shows a class diagram of the location and area page.

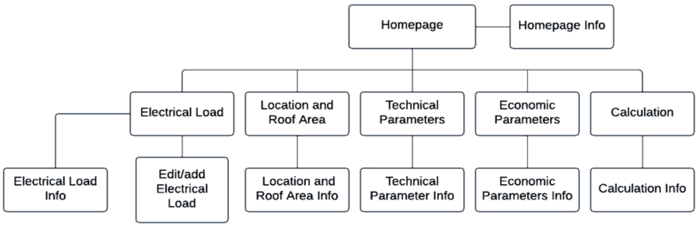


Figure 3. KawanSurya navigation diagram

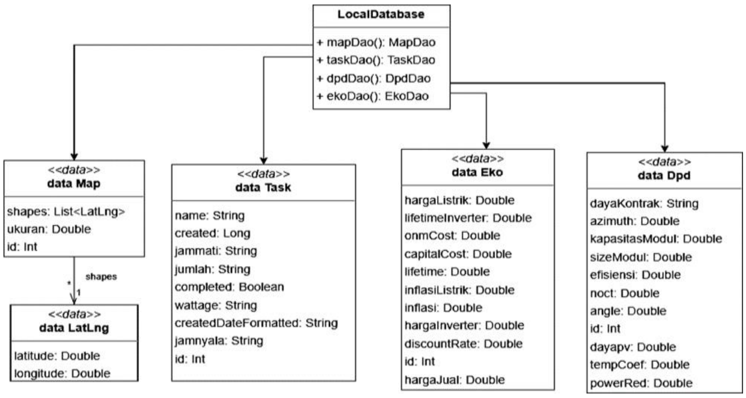


Figure 4. KawanSurya database scheme

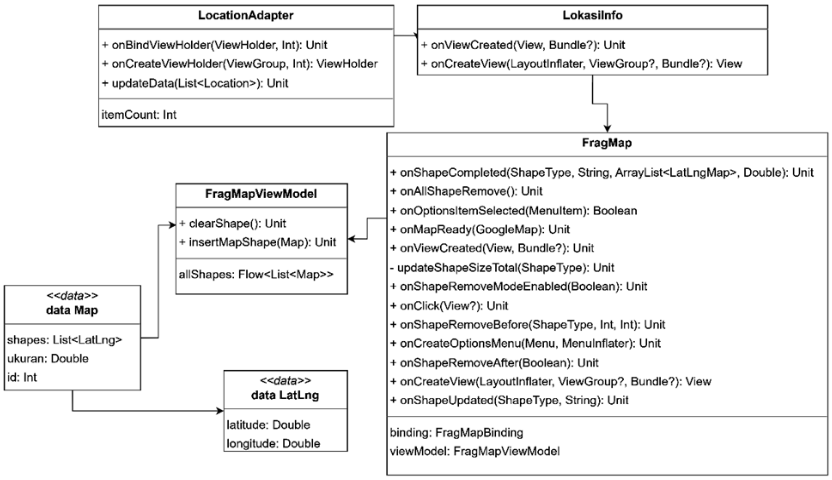


Figure 5. A class diagram of the location and area page

2.2. Electrical load page

The electrical load page allows users to add electrical loads or appliances by clicking the 'Add' button to enter their name, amount, active power, and operational hours. The tool calculates operational hours by subtracting on-time and off-time. Users can input various appliance data to gather a 24-hour electrical load on their premises. This data generates daily electrical load data and curves, estimating self-consumed PV energy and excess energy sent back to the grid.

2.3. Technical parameters page

The technical parameters page on the rooftop PV system installation tool allows users to input various technical parameters, including installed PLN contracted power capacity (VA), maximum rooftop PV capacity, (Watt-peak, Wp), module size (m^2), PV module efficiency (%), nominal operating cell temperature (°C), and temperature coefficient of power (%/°C). Other parameters include tilt angle (°), azimuth (0°=South, 90°=West, -90°=East), and annual power output reduction (%). The tool allows users to change the parameters and define settings for their installation plan but also provides default values for simulation. This helps in calculating the system's hourly power output and evaluating economic performance. Irradiance data is crucial for calculating rooftop PV system output power. KawanSurya uses the PVGIS API to obtain data from the PVGIS SARAH-2 dataset [24], which contains sun irradiance data from 2005 to 2016. Retrofit is used to create an API request with parameters like latitude, longitude, month, output format, local time, global, angle, aspect, and temperatures. Figure 6 shows a part of the code created to retrieve the solar irradiance dataset for a specific place from PVGIS.

```
interface ApiInterface {
    @GET("api/v5_2/DRcalc")

    fun getDatas(@Query("lat") lat: Double,
                 @Query("lon") lon: Double,
                 @Query("month") month: Int,
                 @Query("ouputformat") ouputFormat: String,
                 @Query("localtime") localtime: Int,
                 @Query("global") global: Int,
                 @Query("angle") angle: Double,
                 @Query("aspect") aspect: Double,
                 @Query("showtemperatures") temp: Int
    ) : Call<ResponseData>
}
object RetrofitHelper {

    val baseUrl = "https://re.jrc.ec.europa.eu/"

    fun getInstance(): Retrofit {
        return Retrofit.Builder().baseUrl(baseUrl)
            .addConverterFactory(GsonConverterFactory.create())
            .build()
    }
}
private fun getDatas() {
    val api = RetrofitHelper.getInstance().create(ApiInterface::class.java)
    val viewModel2 = ViewModelProvider(this)[FragMapViewModel::class.java]
    lifecycleScope.launch {
        var lat: Double
        var lon: Double
        viewModel2.getAllShapes().collect {
            if (it.isNotEmpty()) {

                lat = it[it.size - 1].shapes[0].latitude
                lon = it[it.size - 1].shapes[0].longitude

                binding.tvLatlon.text = "%.5f, %.5f".format(lat, lon)
```

Figure 6. A screenshot of coding for retrieving the solar irradiance dataset

2.4. PV output power, solar PV capacity and module quantity

KawanSurya calculates rooftop PV output power using the HOMER software's equation, considering factors like derating factor and solar absorptivity and transmittance. The derating factor considers panel dirt, wire loss, shadowing, snow coverage, and aging. The tool calculates an estimated value of 0.77 [25] to determine the impact of these parameters on the performance of the rooftop PV system. Solar absorptivity and transmittance are calculated using the product of 0.9 or 90% [26]. The equations used to determine rooftop PV output power and PV cell temperature are as (1):

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}}\right) [1 + \alpha_p (T_c - T_{C,STC})] \quad (1)$$

where P_{PV} is PV output (kW); Y_{PV} is rated capacity solar PV array in standard test conditions (kW); f_{PV} is a derating factor (%); $\overline{G_T}$ is the solar radiation incident on the PV array in the current time step (kW/m^2); $\overline{G_{T,STC}}$ is the incident radiation at standard test conditions (1 kW/m^2); α_p is the temperature coefficient of power (%/°C); T_c is the PV cell temperature in the current time step (°C); and $T_{C,STC}$ is the PV cell temperature under standard test conditions (25°C).

$$T_c = \frac{T_a + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(1 - \frac{\eta_{mp,STC}(1 - \alpha_p T_{c,STC})}{\tau\alpha}\right)}{1 + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_p \eta_{mp,STC}}{\tau\alpha}\right)} \quad (2)$$

where T_c is the PV cell temperature (°C); T_a is the ambient temperature (°C); $T_{c,NOCT}$ is the nominal operating cell temperature (°C); $T_{a,NOCT}$ is the ambient temperature at which the NOCT is defined (20°C); G_T is the solar radiation striking the PV array (kW/m^2); $G_{T,NOCT}$ is the solar radiation at which the NOCT is defined (0.8 kW/m^2); $\eta_{mp,STC}$ is the maximum power point efficiency under standard test conditions (%); α_p is temperature coefficient of power (%); $T_{C,STC}$ is the cell temperature under standard test conditions (25°C); τ is the solar transmittance of any cover over the PV array (%); and α is the solar absorptance of the PV array (%). The tool predicts solar PV's electricity output power over multiple years, considering yearly power loss using (3):

$$PV_{out\ year\ n} = PV_{out\ yearly} \times (1 - yearly\ rate\ of\ PV_{out} degradation\ (\%)) \times (n-1) \quad (3)$$

The tool limits solar PV module capacity to 100% of a household's contracted electricity [27]. The tool determines the number of modules and PV capacity by comparing the maximum power generated by all solar modules with the user's maximum power (Watt-peak) or a 100% permitted capacity equal to the household contracted power.

2.5. Location and area page

The location and area page allows users to estimate the available roof area for solar PV modules by drawing a polygon and clicking on the areas on the house's roof. The program uses the MapDrawingManager library to compute the area, which is an effective area considering 80% of the true size of the measured polygon. This usable roof space shows 80% of the total area within the polygon for installation and maintenance purposes. The program uses the site's coordinates and the roof area to provide accurate information.

2.6. Economic parameters page

The economic parameters page allows users to define the economic parameters of a rooftop PV system, including inverter price, lifetime, capital cost, electricity price, feed-in tariff, annual O&M cost, annual electricity price increase, inflation rate, discount rate, and project lifetime, for economic analysis purposes. KawanSurya uses payback period analysis to evaluate the economic feasibility of monocrystalline silicon-based PV module systems [28], [29], in addition to return on investment (ROI) and NPV.

The study includes simple and discounted payback periods, with the present value (PV) calculated using an assumed interest rate [30]. The discount factor (DF) is based on the assumed discount rate. ROI measures the profitability of the system, defined as the ratio of net benefits (NPV) to the initial investment. A negative ROI indicates the investment is not profitable. The equations for calculating the simple or discounted payback period, ROI, and NPV are as (4) and (5):

$$PP = Nb + \frac{ccNb}{ncNa};\ PV = S \times F_{PW};\ DF = \left(1 + \frac{d}{100}\right)^{-n};\ IF = (1 + i)^n \quad (4)$$

$$F_{PW} = \frac{(1+i)^n}{(1+d)^n};\ NPV = \sum PV_{income} - \sum PV_{cost};\ ROI = \frac{NPV}{Capital\ Cost} \quad (5)$$

where PP is payback period; Nb is the year before recovery; $ccNb$ is cumulative cash flow in the year before recovery; and $ncNa$ is net cash flow in the year after recovery; PV is the present value of S in year n; S is cash flow in the year n; F_{PW} is a present worth factor in the year n; i is inflation rate; d is the discount rate; and n is year.

3. RESULTS AND DISCUSSION

This section presents the simulation results conducted on KawanSurya, focusing on testing features and obtaining techno-economic results. Initial tests were performed to verify and validate the application's functionality, including processing electrical load data and retrieving solar irradiance data using an API. The findings and implications of these tests are discussed in detail.

3.1. Preliminary tests on electrical loading and solar irradiance data retrieval

The electrical loading test evaluates the data gathering and processing for all appliances in a tool. The information is recorded in a local database and used during computation. The testing ensures accurate retrieval and processing of the data by adjusting the debug log level on the calculation page. The testing uses database-based electrical load data, listing appliances, power, on-time, and off-time. The tool calculates operating hours based on these values, resulting in 2 hours of operation for an on-time value of 1 and an off-time value of 3.

Solar irradiance data retrieval through API is tested to determine whether the geographical location entered the tool and the retrieval of solar irradiance data. The tool considers solar irradiation in terms of the average monthly sum of global irradiation (GI) per square meter received by the modules (W/m^2/month). It is conducted by carrying out the debug log level. The testing site is at latitude 3.589 and longitude 114.893, with a tilt angle of 30° and azimuth of 0° (South facing).

Tables 1 and 2 provide examples of data submitted for processing electrical load data, including the outcome of each appliance’s operational period, and an example of the testing results for hourly temporal-based electrical load data processing, respectively. Meanwhile, Table 3 shows the locations debug log results, along with the corresponding irradiance data. The GI data originates from PVGIS’s default solar dataset for the region, the PVGIS-SARAH dataset, which spans 2005 to 2016 and is available on an hourly temporal basis.

Table 1. Examples of data entered for processing the electrical load data

Electrical load	Quantity	Wattage (W)	Operational hours	Duration
a	4	99	05:00-07:00	2.25 hours
b	5	100	10:00-02:00	16 hours

Table 2. Testing results of electrical load data processing

Time	Wattage (W)	Time	Wattage (W)	Time	Wattage (W)
00:00	500	08:00	0	16:00	500
01:00	500	09:00	0	17:00	500
02:00	0	10:00	500	18:00	500
03:00	0	11:00	500	19:00	500
04:00	0	12:00	500	20:00	500
05:00	396	13:00	500	21:00	500
06:00	396	14:00	500	22:00	500
07:00	99	15:00	500	23:00	500

Table 3. Testing results of the average monthly sum of global irradiation data retrieval

Time	GI (W/m^2)	Time	GI (W/m^2)	Time	GI (W/m^2)
00:00	0	08:00	1,519.71	16:00	3,582.74
01:00	0	09:00	2,898.66	17:00	1,968.99
02:00	0	10:00	5,058.98	18:00	533.57
03:00	0	11:00	6,803.24	19:00	0
04:00	0	12:00	7,669.45	20:00	0
05:00	0	13:00	7,561.26	21:00	0
06:00	0	14:00	6,626.56	22:00	0
07:00	83.92	15:00	5,193.40	23:00	0

3.2. Simulation settings and results

The study explores the techno-economic implications of on-grid rooftop PV systems in households, considering low maximum power capacity scenarios and six policy-setting scenarios. It considers bill reduction, inflation, increased electricity tariffs, and load profile. Table 4 shows electrical loads in the household, including quantity, wattage, and on-time-off-time.

Table 4. Electrical loads in a household with a 2,200VA power contract

Electrical load	Quantity	Wattage	On-time	Off-time
Refrigerator	1	80	24 hours	-
Rice cooker	1	300	17:00	17:40
Iron	1	300	09:00	10:00
Water pump	1	600	07:00	08:30
Washing machine	1	150	08:00	09:00
Laptop	2	100	20:00	22:00
Water heater	1	500	05:30	06:30
AC ½ hp	2	375	20:00	05:30
AC 1 hp	1	750	20:00	05:30
TV	1	80	20:00	22:00
Lamp	15	10	17:30	22:00
Lamp	5	10	22:00	05:30

Simulation-1 (S-1) is a case study of a household with a 2,200 VA power contract in Tropodo, Sidoarjo Regency, East Java, with standard household appliances. The study examines the use of a solar power (PV) system on the roof, focusing on the polygon drawn on the West-facing area. The user interface shows the house's latitude and longitude (-7.360 and 112.754, respectively), and it is usable roof area (26.49 m^2). The simulation is based on a 100 Wp monocrystalline solar PV module [30], with specifications including size, capacity, efficiency, NOCT, and annual output power reduction. The economic parameters include inverter prices, system capital cost, electricity prices, export electricity prices, and annual operation and maintenance costs, with a 30° roof tilt angle and 90° azimuth, with the azimuth facing west, as provided by the PVGIS input API [20].

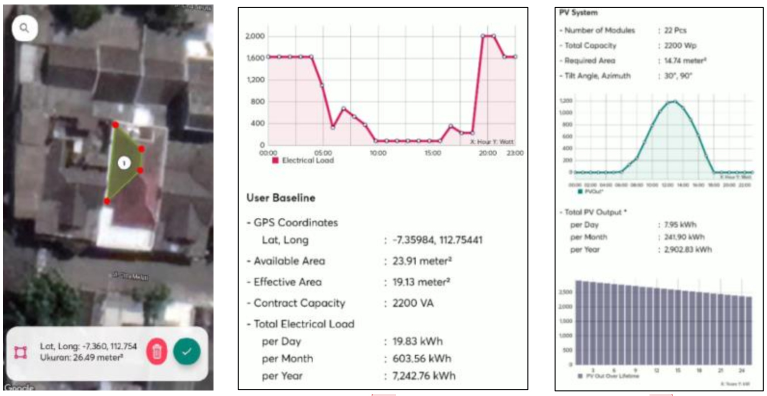
The economic parameters of a solar power system include inverter prices, system capital costs, electricity prices, export electricity prices, and O&M costs per year. The inverter costs IDR 4,290,000, 13% of the total system capital cost. The discount rate is 5%, annual growth on electricity price is 0%, and inflation is 0%. The O&M cost for a PV system is IDR 0, and the electricity price is based on a 2,200 VA power contract with a 100% sellback rate for exporting to the grid. The tool can support a 0% sellback rate if a policy change prevents rooftop PV owners from exporting electricity to the network. The investment cost for installing 1 kWp of rooftop PV is IDR 15 million, totalling IDR 33 million.

The technical and economic parameters for S-1 are as follows: contracted power capacity is 2,200 VA, maximum rooftop PV capacity is 2,200 Wp, size per module 0.67 m^2, capacity per module is 100 Wp, module efficiency (STC) is 14.92%, nominal operating cell temperature is 45°C, temperature coefficient of power is -0.39%/°C, tilt angle 30°, azimuth 90°, output power reduction per year 0.8%, inverter price is IDR 4,290,000, inverter lifetime 15 year, system capital cost (exclude inverter price) is IDR 28,710,000, electricity price is IDR 1,444.7, export electricity price is IDR 1,444.7, electricity price increase per year IDR 0, discount rate 5%, project lifetime 25 year.

KawanSurya's techno-economic analysis is divided into four sections: user baseline, PV system, load profile scenario with daily PV output, and investment. The user baseline includes the daily load curve, geographic coordinates, roof size, contracted power, and total electrical load per day, month, and year. For the case of S-1 and given the selected location, they are 19.83 kWh, 603.56 kWh, and 7246.76 kWh, respectively. The generated load curve is then used to calculate electricity export, billing, and savings from the PV system.

The PV system part includes simulation results for module number, total capacity, needed area, tilt angle, azimuth, hourly output curve, and total output over project lifetime. The output curve is generated using irradiation data from the PVGIS API and technical parameters. The calculation shows that the installed capacity is limited to a contracted power of 2,200 VA. The necessary area is smaller than the available area. An asterisk (*) indicates that the total PV output was calculated before any reduction in power output. The total PV output, calculated before any reduction in power output, is 7.95 kWh/day, 241.90 kWh/month, and 2,902.83 kWh/year in this scenario. The graph below shows the decrease in PV output power over the project's lifetime, using a technical parameter of 0.8% power output reduction per year.

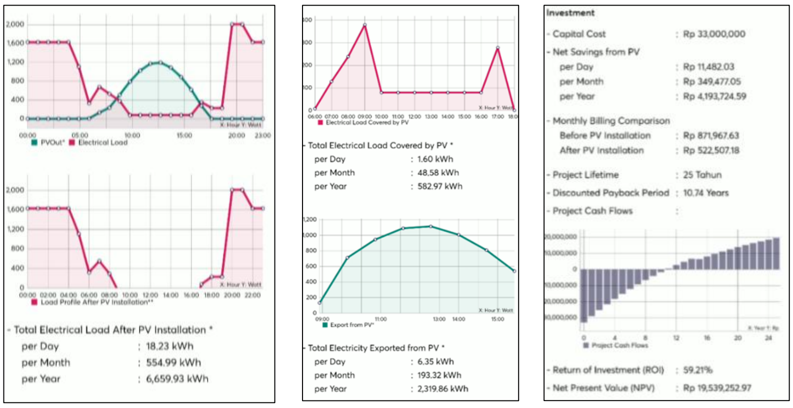
Figure 7 exhibits the S-1 results displaying user interfaces of KawanSurya; i) the screenshot of the location and roof area, ii) the user baseline, and iii) the PV system. As previously stated in section 2.5, Figure 7(a) depicts a screenshot of the house coordinates and roof area in KawanSurya. It shows the house's coordinates of -7.360° (South Latitude), 112.754° (East Longitude), and the calculated usable roof area of 26.49 m^2. The load curve scenario with daily PV output generates simulation results for the hourly electricity load after PV installation, the portion covered by PV, and the amount of electricity exported from PV to the grid.



(a) (b) (c)

Figure 7. The user interface of KawanSurya; (a) the screenshot of the location and roof area, (b) the user baseline, and (c) the PV system of S-1

Figure 8 depicts the user interface/results for the load profile scenario; Figure 8(a) showing PV output and load profiles, and Figure 8(b) investment section. As shown in Figure 8, the total electrical load after PV installation is 18.23 kWh/day, 554.99 kWh per month, and 6,659.93 kWh/year, while PV meets a total electrical load of 1.60 kWh/day, 48.58 kWh/month, and 582.97 kWh annually. The total electricity export is 6.35 kWh/day, 193.32 kWh/month, and 2,319.87 kWh annually. the investment section analyses the economic feasibility of rooftop PV, revealing net savings of IDR 11,482/day, IDR 349,477/month, and IDR 4,193,725 annually. The monthly electricity bill before and after installation is based on net savings from PV. The cash flow graph shows a discounted payback of 10.85 years at a 5% discount rate, an ROI of 59.21%, and an NPV of IDR 19,539,262.80. The S-1 scenario results in a discounted payback period of 10.74 years at a 5% discount rate and 100% bill reduction factor. However, successive scenarios, including varying inflation rates and rising electricity bills, have influenced the system's discounted payback period.



(a) (b)

Figure 8. The user interface/results of S-1 for the load profile scenario; (a) PV output and load profiles and (b) investment

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Simulation-2 (S-2) uses the same technical and economic parameters as S-1, resulting in a payback period of 19.79 years, twice the prior period. This is due to a 65% bill reduction factor, which reduces the power export price to 65% of the electricity rate per kWh. The modelled load profile shown in Figure 8 does not support maximising solar PV energy usage during the day, particularly between 09:00-15.00. Simulation-3 (S-3) adjusts the electrical load profile to a constant load while maintaining the 65% bill reduction factor from S-1. This scenario increases the energy supplied by the PV system to offset the load but reduces customer income from exporting electricity. The payback period is 11.79 years, one year longer than S-1. The overall electrical load changes, with 13.12 kWh/day, 399.35 kWh/month, and 4,792.25 kWh/year after PV installation.

Simulation-4 (S-4) assumes a 2% inflation rate while leaving all other parameters the same as S-1. The inclusion of inflation is intended to assess the impact of inflation on the payback period. Inflation can harm the economy but could benefit users by lowering the discount rate for power exported to the grid. The simulation yields a discounted payback period of 9.43 years or shorter than S-1 to S-3, allowing investors to recoup their initial investment faster. Simulation-5 (S-5) introduces a 2% annual increase in electricity tariffs while leaving all other parameters the same as S-1. This scenario benefits rooftop PV users by increasing income received, and calculating a discounted payback period of 9.66 years, assuming a 100% export rate. It should be noted that the payback period for PV users can be reduced by adjusting their daily electrical load profile between 7 a.m. and 5 p.m. and increasing daytime usage to lower the cost impact on billing caused by evening and nighttime loading. Table 5 presents possible discounted payback periods under various scenarios, including bill reduction factors, electricity load, inflation rates, increases in electricity tariffs, and minimum bill limits.

Table 5. Discounted payback periods due to different scenarios

No.	Scenario	Discounted payback period (year)
1.	Simulation-1 (S-1)	10.74
2.	S-2: with 1 65% bill reduction factor	19.79
3.	S-3: with a 65% bill reduction factor and constant electrical load	11.79
4.	S-4: with a 2% inflation rate	9.43
5.	S-5: with an annual increase of 2% in electricity tariff	9.66
6.	S-6: minimum bill limit	Exceed project lifetime

3.3. Discussions

Residential customers prefer systems with higher NPV and ROI, but decisions should also consider the ROI and NPV of different scenarios and electrical load patterns. Higher daytime energy usage is preferred for maximum electricity consumption. It should be noted that the discounted payback period of the simulated on-grid rooftop PV system is significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and the same load profile increase the discounted payback period. However, a 0% billing reduction factor or no compensation for selling back electricity to the grid can exceed the discounted payback period, making it advisable for rooftop PV system owners to increase electrical loading during the daytime. Inflation rates can help residential projects achieve shorter payback periods without significantly impacting financial cash flow, and well-compensated electricity exports are achieved regardless of daytime usage. KawanSurya reveals that a rooftop PV system's payback period can exceed the project's lifetime due to a set electricity bill limit, making the system uneconomical. Meanwhile, the accuracy and capability of the tool can be improved because it does not account for variables such as temperature, dirt, shade, and weather conditions.

4. CONCLUSION

Understanding the techno-economic potential of rooftop solar PV systems is crucial for increasing renewable energy penetration. Independent evaluation tools like KawanSurya help customers assess the potential of these systems, improving public knowledge and addressing misconceptions about costly technology tariffs. KawanSurya can be used to evaluate the techno-economic potential of installing on-grid rooftop PV under various scenarios, including daily load profiles, inflation, increased electricity tariffs, and billing reduction factors.

This study generated simulation results for a typical 2,200 VA household, resulting in a payback period of 9.44 years or longer. While the results are influenced by electrical load profiles and bill reduction factors, incorporating inflation rates in the simulations can help recover initial investment sooner. The 2% inflation rate resulted in a discounted payback period of 9.43 years, shorter than the default scenario and a

65% billing reduction factor. Adjusting the daily load profile and increasing daytime usage between 7 a.m. and 5 p.m. can reduce the payback period, while increased electricity tariffs may benefit users assuming a 100% export rate. Future work may include studies to enhance KawanSurya's capabilities and accuracy, as well as to broaden its capabilities to include off-grid and hybrid rooftop PV systems and to incorporate other factors influencing system performance.

ACKNOWLEDGEMENTS

This paper is part of the research contract no. 01010679/ELK/2023 conducted at Petra Christian University. The authors thank the reviewers for their time and effort in reading the manuscript. All comments and suggestions help to improve the manuscript's quality.

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[20] Please provide the accessed date.

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9. Email sent to BEEI as a response to the paper layout and setting
   - Email sent to BEEI (24 October 2024)
   - Final paper after layout and setting

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[BEEI Revision Required list of accepted] 8309

Yusak Tanoto <tanyusak@petra.ac.id> Thu, Oct 24, 2024 at 8:41 AM
To: beei iaes <iaesbeei@gmail.com>, Yusak Tanoto <tanyusak@petra.ac.id>

Dear Ari,

Please have a look at the attachment. I have revised the paper as well as added required information as requested, and have made some comments as needed.

Looking forward to seeing the paper published soon.

Best regards,
Yusak
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KawanSurya: an Android-based mobile app for assessing the techno-economic potential of rooftop PV

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Article Info

Article history:

Received month dd, yyyy
Revised month dd, yyyy
Accepted month dd, yyyy

Keywords:

Android application
On-grid
Rooftop PV
Solar PV
Techno-economic

ABSTRACT

Many developing countries, including Indonesia, are progressing poorly in residential rooftop PV adoption, including on-grid systems. On the customer side, the decision to implement on-grid rooftop PV or rely only on power from the utility grid has often been made without appropriate knowledge of techno-economic considerations. This includes the impression of high system costs. This paper introduces KawanSurya: PV calculator, a solar rooftop PV techno-economic application for Android mobile phones, designed to help residential customers assess the potential of installing on-grid rooftop PV systems. The tool allows users to select a specific geographic location, calculate daily load profiles, and determine available roof areas. It uses irradiance data from the PVGIS API and HOMER's solar PV output equation to determine hourly PV output power. Simulation results for a typical 2,200 VA household show a payback period of 9.44 years or beyond, significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and similar load profile prolong the payback period, while a 0% billing reduction factor or uncompensated electricity sales may exceed the project's lifetime.

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1. INTRODUCTION

The Paris Agreement aims to reduce global greenhouse gas emissions to keep global temperature rise below 2°C and 1.5°C [1]. The electricity industry is transitioning to renewable energy technology, with renewable energy accounting for over 83% of additional capacity in 2022. Wind and solar, including rooftop PV, account for 91% of additional capacity [2], [3]. Proper legislation and support are crucial for rooftop solar photovoltaics to reduce greenhouse gas emissions [4]. Indonesia, like many developing nations, is making slow progress in residential rooftop PV adoption. The Indonesian government aims to achieve a 23% renewable energy mix by 2025, including 6.5 GW of solar PV [5]. However, achieving this target is challenging due to slow installed capacity [6]. The potential for solar rooftop PV adoption is positive due to cost reductions worldwide [7]. Capacity deployment requires supportive policies, comprehensive information dissemination, and government incentives [8], [9].

Numerous studies have identified challenges to residential rooftop PV adoption, including economic, technical, and social barriers, primarily focusing on monetary costs and benefits [10], knowledge and information aspects [11], and social and regulatory aspects [12]. In Indonesia, these include high initial investment costs, lack of access to installation services, information availability, disadvantageous PV export tariffs, and policy inconsistencies [13]. Improving public knowledge and clearing up misperceptions about

costly technology tariffs and policy inconsistencies are among the important efforts to increase rooftop PV deployment [10]. Residential customers are increasingly considering solar PV energy to reduce electricity bills. However, technical and economic factors like usage compared to total electricity consumption and investment feasibility are crucial. Customers need a tool that provides an adequate system overview to assess the techno-economic potential of installing rooftop PV. Limited, independent applications and tools are available to help customers assess the potential of solar rooftop PV in their homes.

Photovoltaic geographical information system (PVGIS) [14] and PVWatts calculator [15] are web-based tools developed by the European Commission and The National Renewable Energy Laboratory to assess the performance of solar power (PV) systems in specific geographic regions. They are used in rooftop PV techno-economic studies to compare the performance of free-standing and rooftop PV systems in different climatic zones [16] and evaluate residential PV systems with tiered rates and net metering [17]. PVGIS provides simulation outputs like yearly PV energy output, variability, electricity cost, monthly PV energy output, and horizon outline, but does not consider user load profile, resulting in the system's payback period. PVWatts offers an optional analysis considering roof area but does not account for user load profile. SolarHub, an Indonesian rooftop PV calculator, estimates solar PV capacity, energy generation, system costs, roof area, CO_2 emissions, and payback period. The tool can be accessed at https://kalkulator.solarhub.id/

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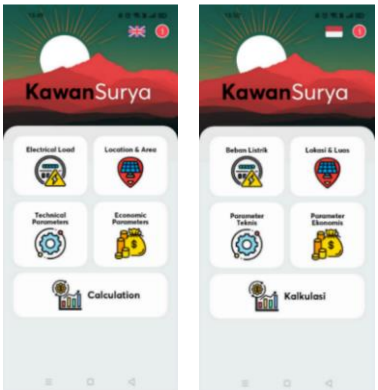
This paper introduces KawanSurya: PV calculator (which in English means 'solar friend'), a free Android tool for evaluating potential PV installations on-grid rooftops. The tool allows users to select a specific location, calculate daily load profiles, measure roof area, and calculate hourly PV output power using irradiation data from the PVGIS API [18] and HOMER's PV output equation [19], while also including the effect of shading [20] through the derating factor. The tool is designed to be a useful alternative to web-based applications for information dissemination about rooftop PV. The paper presents a methodological contribution to renewable energy literature, focusing on customer education and information dissemination on rooftop solar PV. It is intended for Indonesia's residential sector but can be used to simulate installation potential in other jurisdictions. The paper is structured into sections, including design method, results, discussions, and conclusions.

2. METHOD

2.1. Development, navigation, and database of KawanSurya

KawanSurya is an Android tool designed for data processing, calculation, and user interface components. It is built using Kotlin, the native high-level programming language for Android, and Android Studio for data processing. The tool is intended for Android versions 8 to 13. The interface is organised into five main sections: electrical load, location and area, technical parameters, economic parameters, and calculation. An Information page and user guide are also available. Figure 1 depicts the Android-based user interface of KawanSurya; Figure 1(a) in English, and Figure 1(b) in Indonesia after it has been downloaded and run.



(a) (b)

Figure 1. The Android-based user interface of KawanSurya; (a) in English and (b) in Indonesia

The KawanSurya App is available online and can be downloaded from the following link: https://play.google.com/store/apps/details?id=com.christophermarvel.pvcalc. KawanSurya is a comprehensive tool for estimating the techno-economic potential of an on-grid rooftop solar PV system, involving user input, irradiance data retrieval, energy production calculation, daily load curve generation, PV system output power computation, and outcomes presentation, based on household appliances, operation hours, technical parameters, roof area, and location. The PVGIS API retrieves irradiance data from 2005 to 2016, with a one-hour time step. The tool calculates energy production, generates a daily load curve, and determines the required area for rooftop PV installations. It calculates net present value (NPV), return on investment (ROI), payback period, and cash flow. Finally, the tool displays all the results, providing a comprehensive overview of the solar PV system's potential. Figure 2 depicts the flowchart for KawanSurya. It particularly shows stages for using the tool, which include entering the appropriate parameters, computing inputs, and presenting outcomes.

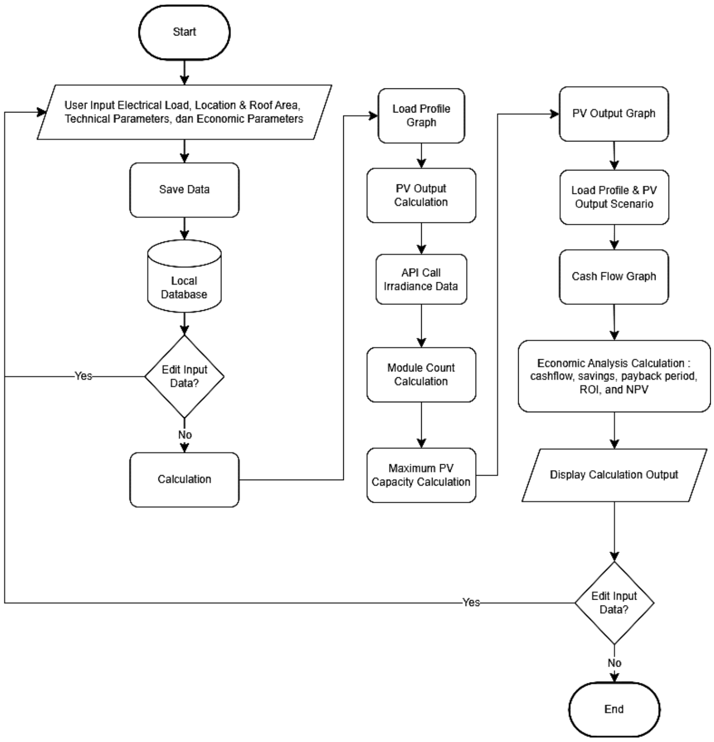


Figure 2. Flowchart of KawanSurya

KawanSurya is designed to demonstrate the techno-economic feasibility of an on-grid rooftop PV installation. It is the user interface designed with either low- or high-fidelity wireframes to merge practical and aesthetic aspects. KawanSurya uses the room database, a library provided by Android Jetpack [21], to process a local database. Room Database is built on top of SQLite [22], a database engine used in Android applications. The tool has four distinct entities: Task, Dpd, Eko, and Map. Users can specify the tables to contain data for each entity. Navigation and class diagrams depict the system structure, with a class diagram of the location and area page. Figures 3 and 4 show the navigation diagrams for KawanSurya and the developed database for the tool, respectively. Meanwhile, Figure 5 shows a class diagram of the location and area page.

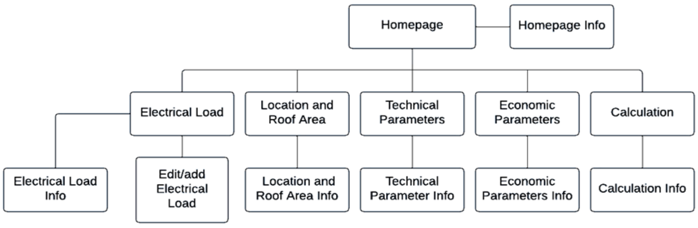


Figure 3. KawanSurya navigation diagram

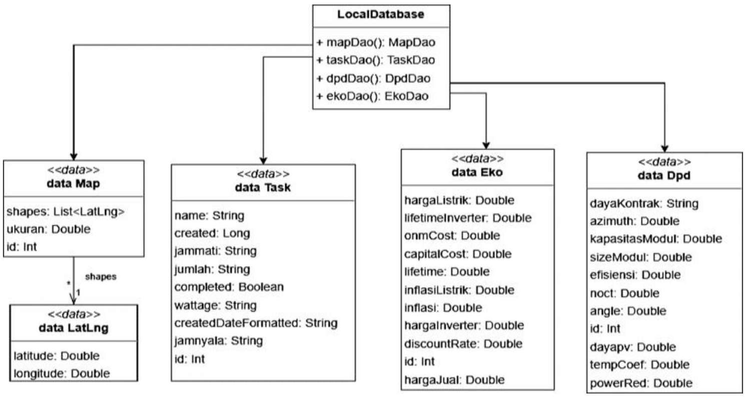


Figure 4. KawanSurya database scheme

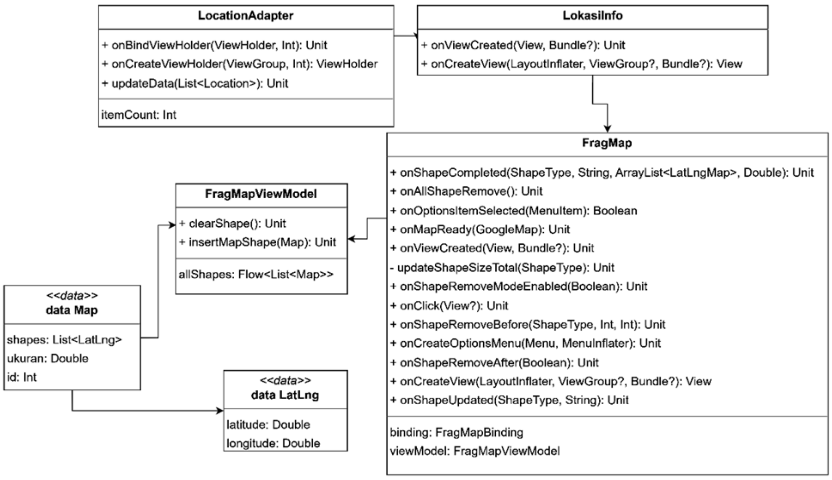


Figure 5. A class diagram of the location and area page

2.2. Electrical load page

The electrical load page allows users to add electrical loads or appliances by clicking the 'Add' button to enter their name, amount, active power, and operational hours. The tool calculates operational hours by subtracting on-time and off-time. Users can input various appliance data to gather a 24-hour electrical load on their premises. This data generates daily electrical load data and curves, estimating self-consumed PV energy and excess energy sent back to the grid.

2.3. Technical parameters page

The technical parameters page on the rooftop PV system installation tool allows users to input various technical parameters, including installed PLN contracted power capacity (VA), maximum rooftop PV capacity, (Watt-peak, Wp), module size (m^2), PV module efficiency (%), nominal operating cell temperature (°C), and temperature coefficient of power (%/°C). Other parameters include tilt angle (°), azimuth (0°=South, 90°=West, -90°=East), and annual power output reduction (%). The tool allows users to change the parameters and define settings for their installation plan but also provides default values for simulation. This helps in calculating the system's hourly power output and evaluating economic performance. Irradiance data is crucial for calculating rooftop PV system output power. KawanSurya uses the PVGIS API to obtain data from the PVGIS SARAH-2 dataset [23], which contains sun irradiance data from 2005 to 2016. Retrofit is used to create an API request with parameters like latitude, longitude, month, output format, local time, global, angle, aspect, and temperatures. Figure 6 shows a part of the code created to retrieve the solar irradiance dataset for a specific place from PVGIS.

```
interface ApiInterface {
    @GET("api/v5_2/DRcalc")

    fun getDatas(@Query("lat") lat: Double,
                 @Query("lon") lon: Double,
                 @Query("month") month: Int,
                 @Query("ouputformat") ouputFormat: String,
                 @Query("localtime") localtime: Int,
                 @Query("global") global: Int,
                 @Query("angle") angle: Double,
                 @Query("aspect") aspect: Double,
                 @Query("showtemperatures") temp: Int
    ) : Call<ResponseData>
}
object RetrofitHelper {

    val baseUrl = "https://re.jrc.ec.europa.eu/"

    fun getInstance(): Retrofit {
        return Retrofit.Builder().baseUrl(baseUrl)
            .addConverterFactory(GsonConverterFactory.create())
            .build()
    }
}
private fun getDatas() {
    val api = RetrofitHelper.getInstance().create(ApiInterface::class.java)
    val viewModel2 = ViewModelProvider(this)[FragMapViewModel::class.java]
    lifecycleScope.launch {
        var lat: Double
        var lon: Double
        viewModel2.getAllShapes().collect {
            if (it.isNotEmpty()) {

                lat = it[it.size - 1].shapes[0].latitude
                lon = it[it.size - 1].shapes[0].longitude

                binding.tvLatlon.text = "%.5f, %.5f".format(lat, lon)
```

Figure 6. A screenshot of coding for retrieving the solar irradiance dataset

2.4. PV output power, solar PV capacity and module quantity

KawanSurya calculates rooftop PV output power using the HOMER software's equation, considering factors like derating factor and solar absorptivity and transmittance. The derating factor considers panel dirt, wire loss, shadowing, snow coverage, and aging. The tool calculates an estimated value of 0.77 [24] to determine the impact of these parameters on the performance of the rooftop PV system. Solar absorptivity and transmittance are calculated using the product of 0.9 or 90% [25]. The equations used to determine rooftop PV output power and PV cell temperature are as (1):

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}}\right) [1 + \alpha_p (T_c - T_{C,STC})] \quad (1)$$

where P_{PV} is PV output (kW); Y_{PV} is rated capacity solar PV array in standard test conditions (kW); f_{PV} is a derating factor (%); $\overline{G_T}$ is the solar radiation incident on the PV array in the current time step (kW/m^2); $\overline{G_{T,STC}}$ is the incident radiation at standard test conditions (1 kW/m^2); α_p is the temperature coefficient of power (%/°C); T_c is the PV cell temperature in the current time step (°C); and $T_{C,STC}$ is the PV cell temperature under standard test conditions (25°C).

$$T_c = \frac{T_a + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(1 - \frac{\eta_{mp,STC}(1 - \alpha_p T_{c,STC})}{\tau\alpha}\right)}{1 + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_p \eta_{mp,STC}}{\tau\alpha}\right)} \quad (2)$$

where T_c is the PV cell temperature (°C); T_a is the ambient temperature (°C); $T_{c,NOCT}$ is the nominal operating cell temperature (°C); $T_{a,NOCT}$ is the ambient temperature at which the NOCT is defined (20°C); G_T is the solar radiation striking the PV array (kW/m^2); $G_{T,NOCT}$ is the solar radiation at which the NOCT is defined (0.8 kW/m^2); $\eta_{mp,STC}$ is the maximum power point efficiency under standard test conditions (%); α_p is temperature coefficient of power (%); $T_{C,STC}$ is the cell temperature under standard test conditions (25°C); τ is the solar transmittance of any cover over the PV array (%); and α is the solar absorptance of the PV array (%). The tool predicts solar PV's electricity output power over multiple years, considering yearly power loss using (3):

$$PV_{out\ year\ n} = PV_{out\ yearly} \times (1 - yearly\ rate\ of\ PV_{out} degradation\ (\%)) \times (n - 1) \quad (3)$$

The tool is designed to limit solar PV module capacity to 100% of a household's contracted electricity. The tool determines the number of modules and PV capacity by comparing the maximum power generated by all solar modules with the user's maximum power (Watt-peak) or a 100% permitted capacity equal to the household contracted power.

2.5. Location and area page

The location and area page allows users to estimate the available roof area for solar PV modules by drawing a polygon and clicking on the areas on the house's roof. The program uses the MapDrawingManager library to compute the area, which is an effective area considering 80% of the true size of the measured polygon. This usable roof space shows 80% of the total area within the polygon for installation and maintenance purposes. The program uses the site's coordinates and the roof area to provide accurate information.

2.6. Economic parameters page

The economic parameters page allows users to define the economic parameters of a rooftop PV system, including inverter price, lifetime, capital cost, electricity price, feed-in tariff, annual O&M cost, annual electricity price increase, inflation rate, discount rate, and project lifetime, for economic analysis purposes. KawanSurya uses payback period analysis to evaluate the economic feasibility of monocrystalline silicon-based PV module systems [26], [27], in addition to return on investment (ROI) and NPV.

The study includes simple and discounted payback periods, with the present value (PV) calculated using an assumed interest rate [28]. The discount factor (DF) is based on the assumed discount rate. ROI measures the profitability of the system, defined as the ratio of net benefits (NPV) to the initial investment. A negative ROI indicates the investment is not profitable. The equations for calculating the simple or discounted payback period, ROI, and NPV are as (4) and (5):

$$PP = Nb + \frac{ccNb}{ncNa};\ PV = S \times F_{PW};\ DF = \left(1 + \frac{d}{100}\right)^{-n};\ IF = (1 + i)^n \quad (4)$$

$$F_{PW} = \frac{(1 + i)^n}{(1+d)^n};\ NPV = \sum PV_{income} - \sum PV_{cost};\ ROI = \frac{NPV}{Capital\ Cost} \quad (5)$$

where PP is payback period; Nb is the year before recovery; $ccNb$ is cumulative cash flow in the year before recovery; and $ncNa$ is net cash flow in the year after recovery; PV is the present value of S in year n; S is cash flow in the year n; F_{PW} is a present worth factor in the year n; i is inflation rate; d is the discount rate; and n is year.

3. RESULTS AND DISCUSSION

This section presents the simulation results conducted on KawanSurya, focusing on testing features and obtaining techno-economic results. Initial tests were performed to verify and validate the application's functionality, including processing electrical load data and retrieving solar irradiance data using an API. The findings and implications of these tests are discussed in detail.

3.1. Preliminary tests on electrical loading and solar irradiance data retrieval

The electrical loading test evaluates the data gathering and processing for all appliances in a tool. The information is recorded in a local database and used during computation. The testing ensures accurate retrieval and processing of the data by adjusting the debug log level on the calculation page. The testing uses database-based electrical load data, listing appliances, power, on-time, and off-time. The tool calculates operating hours based on these values, resulting in 2 hours of operation for an on-time value of 1 and an off-time value of 3.

Solar irradiance data retrieval through API is tested to determine whether the geographical location entered the tool and the retrieval of solar irradiance data. The tool considers solar irradiation in terms of the average monthly sum of global irradiation (GI) per square meter received by the modules (W/m^2/month). It is conducted by carrying out the debug log level. The testing site is at latitude 3.589 and longitude 114.893, with a tilt angle of 30° and azimuth of 0° (South facing).

Tables 1 and 2 provide examples of data submitted for processing electrical load data, including the outcome of each appliance's operational period, and an example of the testing results for hourly temporal-based electrical load data processing, respectively. Meanwhile, Table 3 shows the locations debug log results, along with the corresponding irradiance data. The GI data originates from PVGIS's default solar dataset for the region, the PVGIS-SARAH dataset, which spans 2005 to 2016 and is available on an hourly temporal basis.

Table 1. Examples of data entered for processing the electrical load data

Electrical load	Quantity	Wattage (W)	Operational hours	Duration
a	4	99	05:00-07:00	2.25 hours
b	5	100	10:00-02:00	16 hours

Table 2. Testing results of electrical load data processing

Time	Wattage (W)	Time	Wattage (W)	Time	Wattage (W)
00:00	500	08:00	0	16:00	500
01:00	500	09:00	0	17:00	500
02:00	0	10:00	500	18:00	500
03:00	0	11:00	500	19:00	500
04:00	0	12:00	500	20:00	500
05:00	396	13:00	500	21:00	500
06:00	396	14:00	500	22:00	500
07:00	99	15:00	500	23:00	500

Table 3. Testing results of the average monthly sum of global irradiation data retrieval

Time	GI (W/m^2)	Time	GI (W/m^2)	Time	GI (W/m^2)
00:00	0	08:00	1,519.71	16:00	3,582.74
01:00	0	09:00	2,898.66	17:00	1,968.99
02:00	0	10:00	5,058.98	18:00	533.57
03:00	0	11:00	6,803.24	19:00	0
04:00	0	12:00	7,669.45	20:00	0
05:00	0	13:00	7,561.26	21:00	0
06:00	0	14:00	6,626.56	22:00	0
07:00	83.92	15:00	5,193.40	23:00	0

3.2. Simulation settings and results

The study explores the techno-economic implications of on-grid rooftop PV systems in households, considering low maximum power capacity scenarios and six policy-setting scenarios. It considers bill reduction, inflation, increased electricity tariffs, and load profile. Table 4 shows electrical loads in the household, including quantity, wattage, and on-time-off-time.

Table 4. Electrical loads in a household with a 2,200VA power contract

Electrical load	Quantity	Wattage	On-time	Off-time
Refrigerator	1	80	24 hours	-
Rice cooker	1	300	17:00	17:40
Iron	1	300	09:00	10:00
Water pump	1	600	07:00	08:30
Washing machine	1	150	08:00	09:00
Laptop	2	100	20:00	22:00
Water heater	1	500	05:30	06:30
AC ½ hp	2	375	20:00	05:30
AC 1 hp	1	750	20:00	05:30
TV	1	80	20:00	22:00
Lamp	15	10	17:30	22:00
Lamp	5	10	22:00	05:30

Simulation-1 (S-1) is a case study of a household with a 2,200 VA power contract in Tropodo, Sidoarjo Regency, East Java, with standard household appliances. The study examines the use of a solar power (PV) system on the roof, focusing on the polygon drawn on the West-facing area. The user interface shows the house's latitude and longitude (-7.360 and 112.754, respectively), and it is usable roof area (26.49 m^2). The simulation is based on a 100 Wp monocrystalline solar PV module [30], with specifications including size, capacity, efficiency, NOCT, and annual output power reduction. The economic parameters include inverter prices, system capital cost, electricity prices, export electricity prices, and annual operation and maintenance costs, with a 30° roof tilt angle and 90° azimuth, with the azimuth facing west, as provided by the PVGIS input API [20].

The economic parameters of a solar power system include inverter prices, system capital costs, electricity prices, export electricity prices, and O&M costs per year. The inverter costs IDR 4,290,000, 13% of the total system capital cost. The discount rate is 5%, annual growth on electricity price is 0%, and inflation is 0%. The O&M cost for a PV system is IDR 0, and the electricity price is based on a 2,200 VA power contract with a 100% sellback rate for exporting to the grid. The tool can support a 0% sellback rate if a policy change prevents rooftop PV owners from exporting electricity to the network. The investment cost for installing 1 kWp of rooftop PV is IDR 15 million, totalling IDR 33 million.

The technical and economic parameters for S-1 are as follows: contracted power capacity is 2,200 VA, maximum rooftop PV capacity is 2,200 Wp, size per module 0.67 m^2, capacity per module is 100 Wp, module efficiency (STC) is 14.92%, nominal operating cell temperature is 45°C, temperature coefficient of power is -0.39%/°C, tilt angle 30°, azimuth 90°, output power reduction per year 0.8%, inverter price is IDR 4,290,000, inverter lifetime 15 year, system capital cost (exclude inverter price) is IDR 28,710,000, electricity price is IDR 1,444.7, export electricity price is IDR 1,444.7, electricity price increase per year IDR 0, discount rate 5%, project lifetime 25 year.

KawanSurya's techno-economic analysis is divided into four sections: user baseline, PV system, load profile scenario with daily PV output, and investment. The user baseline includes the daily load curve, geographic coordinates, roof size, contracted power, and total electrical load per day, month, and year. For the case of S-1 and given the selected location, they are 19.83 kWh, 603.56 kWh, and 7246.76 kWh, respectively. The generated load curve is then used to calculate electricity export, billing, and savings from the PV system.

The PV system part includes simulation results for module number, total capacity, needed area, tilt angle, azimuth, hourly output curve, and total output over project lifetime. The output curve is generated using irradiation data from the PVGIS API and technical parameters. The calculation shows that the installed capacity is limited to a contracted power of 2,200 VA. The necessary area is smaller than the available area. An asterisk (*) indicates that the total PV output was calculated before any reduction in power output. The total PV output, calculated before any reduction in power output, is 7.95 kWh/day, 241.90 kWh/month, and 2,902.83 kWh/year in this scenario. The graph below shows the decrease in PV output power over the project's lifetime, using a technical parameter of 0.8% power output reduction per year.

Figure 7 exhibits the S-1 results displaying user interfaces of KawanSurya; i) the screenshot of the location and roof area, ii) the user baseline, and iii) the PV system. As previously stated in section 2.5, Figure 7(a) depicts a screenshot of the house coordinates and roof area in KawanSurya. It shows the house's coordinates of -7.360° (South Latitude), 112.754° (East Longitude), and the calculated usable roof area of 26.49 m^2. Meanwhile, Figure 7(b) depicts the load curve scenario with information on total electrical load, while Figure 7(c) depicts a simulated curve of daily PV output and total PV output per day, month, and year. Figure 7(c) also shows how PV output degrades over time.

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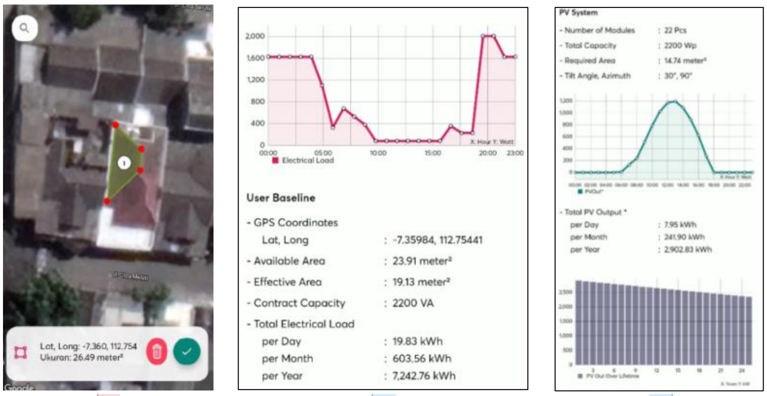
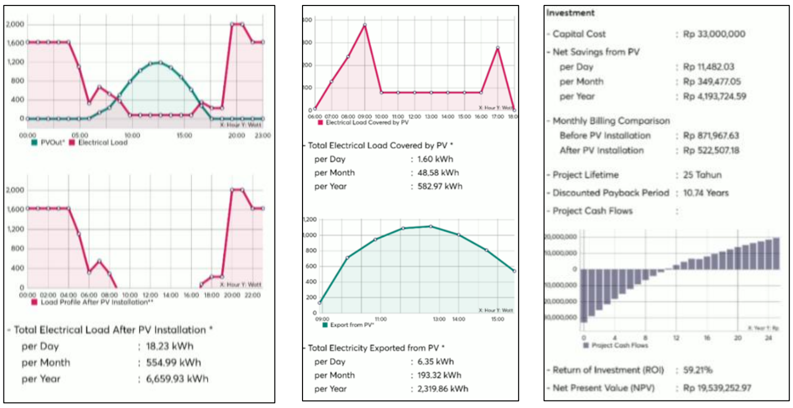


(a) (b) (c)

Figure 7. The user interface of KawanSurya; (a) the screenshot of the location and roof area, (b) the user baseline, and (c) the PV system of S-1

Figure 8 depicts the user interface/results for the load profile scenario; Figure 8(a) shows PV output and load profiles, hourly electricity load after PV installation, the portion covered by PV, and the amount of electricity exported from PV to the grid, and Figure 8(b) investment section. As shown in Figure 8, the total electrical load after PV installation is 18.23 kWh/day, 554.99 kWh per month, and 6,659.93 kWh/year, while PV meets a total electrical load of 1.60 kWh/day, 48.58 kWh/month, and 582.97 kWh annually. The total electricity export is 6.35 kWh/day, 193.32 kWh/month, and 2,319.87 kWh annually. the investment section analyses the economic feasibility of rooftop PV, revealing net savings of IDR 11,482/day, IDR 349,477/month, and IDR 4,193,725 annually. The monthly electricity bill before and after installation is based on net savings from PV. The cash flow graph shows a discounted payback of 10.85 years at a 5% discount rate, an ROI of 59.21%, and an NPV of IDR 19,539,262.80. The S-1 scenario results in a discounted payback period of 10.74 years at a 5% discount rate and 100% bill reduction factor. However, successive scenarios, including varying inflation rates and rising electricity bills, have influenced the system's discounted payback period.



(a) (b)

Figure 8. The user interface/results of S-1 for the load profile scenario; (a) PV output and load profiles and (b) investment

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Commented [YT4R3]: Done. I added: Meanwhile, Figure 7(b) depicts the load curve scenario with information on total electrical load, while Figure 7(c) depicts a simulated curve of daily PV output and total PV output per day, month, and year. Figure 7(c) also shows how PV output degrades over time.

Simulation-2 (S-2) uses the same technical and economic parameters as S-1, resulting in a payback period of 19.79 years, twice the prior period. This is due to a 65% bill reduction factor, which reduces the power export price to 65% of the electricity rate per kWh. The modelled load profile shown in Figure 8 does not support maximising solar PV energy usage during the day, particularly between 09:00-15.00. Simulation-3 (S-3) adjusts the electrical load profile to a constant load while maintaining the 65% bill reduction factor from S-1. This scenario increases the energy supplied by the PV system to offset the load but reduces customer income from exporting electricity. The payback period is 11.79 years, one year longer than S-1. The overall electrical load changes, with 13.12 kWh/day, 399.35 kWh/month, and 4,792.25 kWh/year after PV installation.

Simulation-4 (S-4) assumes a 2% inflation rate while leaving all other parameters the same as S-1. The inclusion of inflation is intended to assess the impact of inflation on the payback period. Inflation can harm the economy but could benefit users by lowering the discount rate for power exported to the grid. The simulation yields a discounted payback period of 9.43 years or shorter than S-1 to S-3, allowing investors to recoup their initial investment faster. Simulation-5 (S-5) introduces a 2% annual increase in electricity tariffs while leaving all other parameters the same as S-1. This scenario benefits rooftop PV users by increasing income received, and calculating a discounted payback period of 9.66 years, assuming a 100% export rate. It should be noted that the payback period for PV users can be reduced by adjusting their daily electrical load profile between 7 a.m. and 5 p.m. and increasing daytime usage to lower the cost impact on billing caused by evening and nighttime loading. Table 5 presents possible discounted payback periods under various scenarios, including bill reduction factors, electricity load, inflation rates, increases in electricity tariffs, and minimum bill limits.

Table 5. Discounted payback periods due to different scenarios

No.	Scenario	Discounted payback period (year)
1.	Simulation-1 (S-1)	10.74
2.	S-2: with 1 65% bill reduction factor	19.79
3.	S-3: with a 65% bill reduction factor and constant electrical load	11.79
4.	S-4: with a 2% inflation rate	9.43
5.	S-5: with an annual increase of 2% in electricity tariff	9.66
6.	S-6: minimum bill limit	Exceed project lifetime

3.3. Discussions

Residential customers prefer systems with higher NPV and ROI, but decisions should also consider the ROI and NPV of different scenarios and electrical load patterns. Higher daytime energy usage is preferred for maximum electricity consumption. It should be noted that the discounted payback period of the simulated on-grid rooftop PV system is significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and the same load profile increase the discounted payback period. However, a 0% billing reduction factor or no compensation for selling back electricity to the grid can exceed the discounted payback period, making it advisable for rooftop PV system owners to increase electrical loading during the daytime. Inflation rates can help residential projects achieve shorter payback periods without significantly impacting financial cash flow, and well-compensated electricity exports are achieved regardless of daytime usage. KawanSurya reveals that a rooftop PV system's payback period can exceed the project's lifetime due to a set electricity bill limit, making the system uneconomical. Meanwhile, the accuracy and capability of the tool can be improved because it does not account for variables such as temperature, dirt, shade, and weather conditions.

4. CONCLUSION

Understanding the techno-economic potential of rooftop solar PV systems is crucial for increasing renewable energy penetration. Independent evaluation tools like KawanSurya help customers assess the potential of these systems, improving public knowledge and addressing misconceptions about costly technology tariffs. KawanSurya can be used to evaluate the techno-economic potential of installing on-grid rooftop PV under various scenarios, including daily load profiles, inflation, increased electricity tariffs, and billing reduction factors.

This study generated simulation results for a typical 2,200 VA household, resulting in a payback period of 9.44 years or longer. While the results are influenced by electrical load profiles and bill reduction factors, incorporating inflation rates in the simulations can help recover initial investment sooner. The 2%

inflation rate resulted in a discounted payback period of 9.43 years, shorter than the default scenario and a 65% billing reduction factor. Adjusting the daily load profile and increasing daytime usage between 7 a.m. and 5 p.m. can reduce the payback period, while increased electricity tariffs may benefit users assuming a 100% export rate. Future work may include studies to enhance KawanSurya's capabilities and accuracy, as well as to broaden its capabilities to include off-grid and hybrid rooftop PV systems and to incorporate other factors influencing system performance.

ACKNOWLEDGEMENTS

This paper is part of the research contract no. 01010679/ELK/2023 conducted at Petra Christian University. The authors thank the reviewers for their time and effort in reading the manuscript. All comments and suggestions help to improve the manuscript's quality.

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Christopher Marvel received a Bachelor of Engineering in Electrical Engineering (Power System) from Petra Christian University, Indonesia, in 2023. His research interest is around the deployment of solar PV and other renewable energy technologies. He is currently working at SEDAYUSolar, one of the leading solar PV companies in Indonesia with the role of Business Development. He can be contacted at email: christopher.marvel19@gmail.com.

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Hanny H. Tumbelaka received a Bachelor of Engineering in Electrical Engineering from Petra Christian University, Indonesia in 1988, a Master of Science in Electric Power Engineering from Rensselaer Polytechnic Institute, New York, USA in 1993, and a Ph.D. in Electrical Engineering from Curtin University of Technology in 2006. Since 1989, he has been a certified lecturer in The Electrical Engineering Department, at Petra Christian University, Indonesia. Currently, he is the Professor in this department. He was a research fellow at Sophia University, Japan (2008) and NREL, Colorado, USA (2016). His research interests are power electronics, power quality, and renewable energy. He is a certified engineer (Insinyur-IPM) and a member of PII and IEEE. He can be contacted at email: tumbeh@petra.ac.id.

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KawanSurya: an Android-based mobile app for assessing the techno-economic potential of rooftop photovoltaic

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Article Info

Article history:

Received Feb 13, 2024
Revised Aug 30, 2024
Accepted Sep 28, 2024

Keywords:

Android application
On-grid
Rooftop photovoltaic
Solar photovoltaic
Techno-economic

ABSTRACT

Many developing countries, including Indonesia, are progressing poorly in residential rooftop photovoltaic (PV) adoption, including on-grid systems. On the customer side, the decision to implement on-grid rooftop PV or rely only on power from the utility grid has often been made without appropriate knowledge of techno-economic considerations. This includes the impression of high system costs. This paper introduces KawanSurya: PV calculator, a solar rooftop PV techno-economic application for Android mobile phones, designed to help residential customers assess the potential of installing on-grid rooftop PV systems. The tool allows users to select a specific geographic location, calculate daily load profiles, and determine available roof areas. It uses irradiance data from the PVGIS API and HOMER's solar PV output equation to determine hourly PV output power. Simulation results for a typical 2,200 VA household show a payback period of 9.44 years or beyond, significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and similar load profile prolong the payback period, while a 0% billing reduction factor or uncompensated electricity sales may exceed the project's lifetime.

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1. INTRODUCTION

The Paris Agreement aims to reduce global greenhouse gas emissions to keep global temperature rise below 2°C and 1.5°C [1]. The electricity industry is transitioning to renewable energy technology, with renewable energy accounting for over 83% of additional capacity in 2022. Wind and solar, including rooftop photovoltaic (PV), account for 91% of additional capacity [2], [3]. Proper legislation and support are crucial for rooftop solar photovoltaics to reduce greenhouse gas emissions [4]. Indonesia, like many developing nations, is making slow progress in residential rooftop PV adoption. The Indonesian government aims to achieve a 23% renewable energy mix by 2025, including 6.5 GW of solar PV [5]. However, achieving this target is challenging due to slow installed capacity [6]. The potential for solar rooftop PV adoption is positive due to cost reductions worldwide [7]. Capacity deployment requires supportive policies, comprehensive information dissemination, and government incentives [8], [9].

Numerous studies have identified challenges to residential rooftop PV adoption, including economic, technical, and social barriers, primarily focusing on monetary costs and benefits [10], knowledge and information aspects [11], and social and regulatory aspects [12]. In Indonesia, these include high initial investment costs, lack of access to installation services, information availability, disadvantageous PV export tariffs, and policy inconsistencies [13]. Improving public knowledge and clearing up misperceptions about

costly technology tariffs and policy inconsistencies are among the important efforts to increase rooftop PV deployment [10]. Residential customers are increasingly considering solar PV energy to reduce electricity bills. However, technical and economic factors like usage compared to total electricity consumption and investment feasibility are crucial. Customers need a tool that provides an adequate system overview to assess the techno-economic potential of installing rooftop PV. Limited, independent applications and tools are available to help customers assess the potential of solar rooftop PV in their homes.

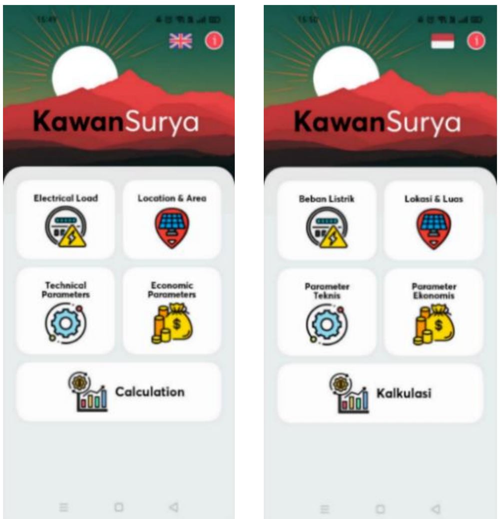
Photovoltaic geographical information system (PVGIS) [14] and PVWatts calculator [15] are web-based tools developed by the European Commission and The National Renewable Energy Laboratory to assess the performance of solar power (PV) systems in specific geographic regions. They are used in rooftop PV techno-economic studies to compare the performance of free-standing and rooftop PV systems in different climatic zones [16] and evaluate residential PV systems with tiered rates and net metering [17]. PVGIS provides simulation outputs like yearly PV energy output, variability, electricity cost, monthly PV energy output, and horizon outline, but does not consider user load profile, resulting in the system's payback period. PVWatts offers an optional analysis considering roof area but does not account for user load profile. SolarHub, an Indonesian rooftop PV calculator, estimates solar PV capacity, energy generation, system costs, roof area, CO_2 emissions, and payback period. The tool can be accessed at https://kalkulator.solarhub.id/.

This paper introduces KawanSurya: PV calculator (which in English means 'solar friend'), a free Android tool for evaluating potential PV installations on-grid rooftops. The tool allows users to select a specific location, calculate daily load profiles, measure roof area, and calculate hourly PV output power using irradiation data from the PVGIS API [18] and HOMER's PV output equation [19], while also including the effect of shading [20] through the derating factor. The tool is designed to be a useful alternative to web-based applications for information dissemination about rooftop PV. The paper presents a methodological contribution to renewable energy literature, focusing on customer education and information dissemination on rooftop solar PV. It is intended for Indonesia's residential sector but can be used to simulate installation potential in other jurisdictions. The paper is structured into sections, including design method, results, discussions, and conclusions.

2. METHOD

2.1. Development, navigation, and database of KawanSurya

KawanSurya is an Android tool designed for data processing, calculation, and user interface components. It is built using Kotlin, the native high-level programming language for Android, and Android Studio for data processing. The tool is intended for Android versions 8 to 13. The interface is organised into five main sections: electrical load, location and area, technical parameters, economic parameters, and calculation. An Information page and user guide are also available. Figure 1 depicts the Android-based user interface of KawanSurya; Figure 1(a) in English, and Figure 1(b) in Indonesia after it has been downloaded and run.



(a) (b)

Figure 1. The Android-based user interface of KawanSurya; (a) in English and (b) in Indonesia

The KawanSurya App is available online and can be downloaded from the following link: https://play.google.com/store/apps/details?id=com.christophermarvel.pvcalc. KawanSurya is a comprehensive tool for estimating the techno-economic potential of an on-grid rooftop solar PV system, involving user input, irradiance data retrieval, energy production calculation, daily load curve generation, PV system output power computation, and outcomes presentation, based on household appliances, operation hours, technical parameters, roof area, and location. The PVGIS API retrieves irradiance data from 2005 to 2016, with a one-hour time step. The tool calculates energy production, generates a daily load curve, and determines the required area for rooftop PV installations. It calculates net present value (NPV), return on investment (ROI), payback period, and cash flow. Finally, the tool displays all the results, providing a comprehensive overview of the solar PV system's potential. Figure 2 depicts the flowchart for KawanSurya. It particularly shows stages for using the tool, which include entering the appropriate parameters, computing inputs, and presenting outcomes.

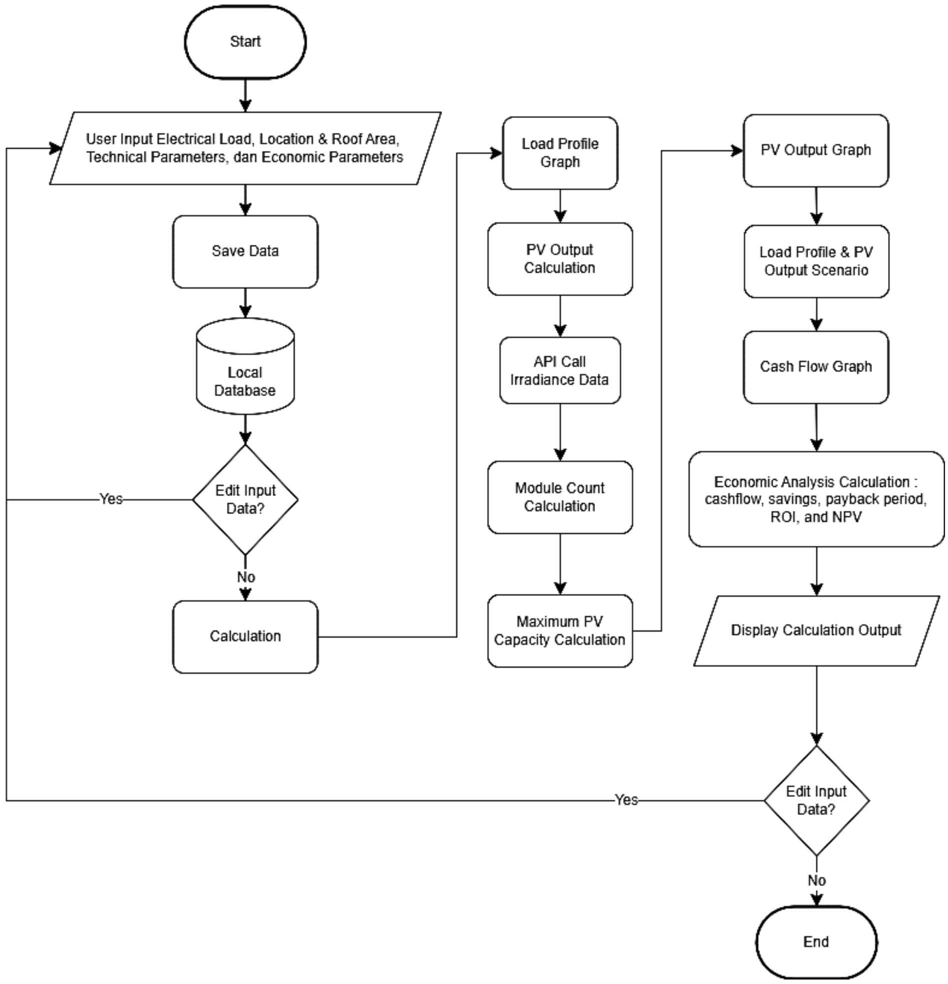


Figure 2. Flowchart of KawanSurya

KawanSurya is designed to demonstrate the techno-economic feasibility of an on-grid rooftop PV installation. It is the user interface designed with either low- or high-fidelity wireframes to merge practical and aesthetic aspects. KawanSurya uses the room database, a library provided by Android Jetpack [21], to process a local database. Room Database is built on top of SQLite [22], a database engine used in Android applications. The tool has four distinct entities: Task, Dpd, Eko, and Map. Users can specify the tables to contain data for each entity. Navigation and class diagrams depict the system structure, with a class diagram of the location and area page. Figures 3 and 4 show the navigation diagrams for KawanSurya and the developed database for the tool, respectively. Meanwhile, Figure 5 shows a class diagram of the location and area page.

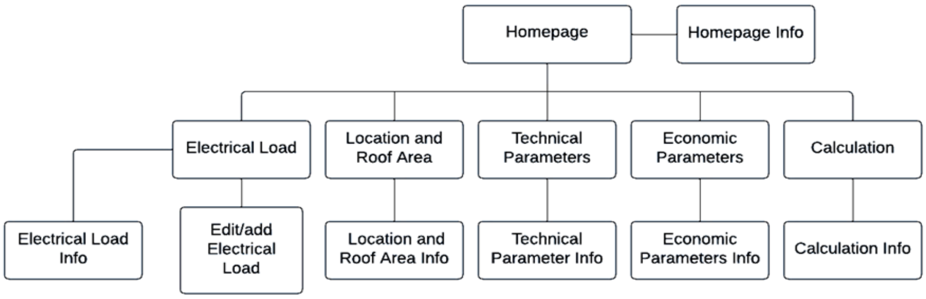


Figure 3. KawanSurya navigation diagram

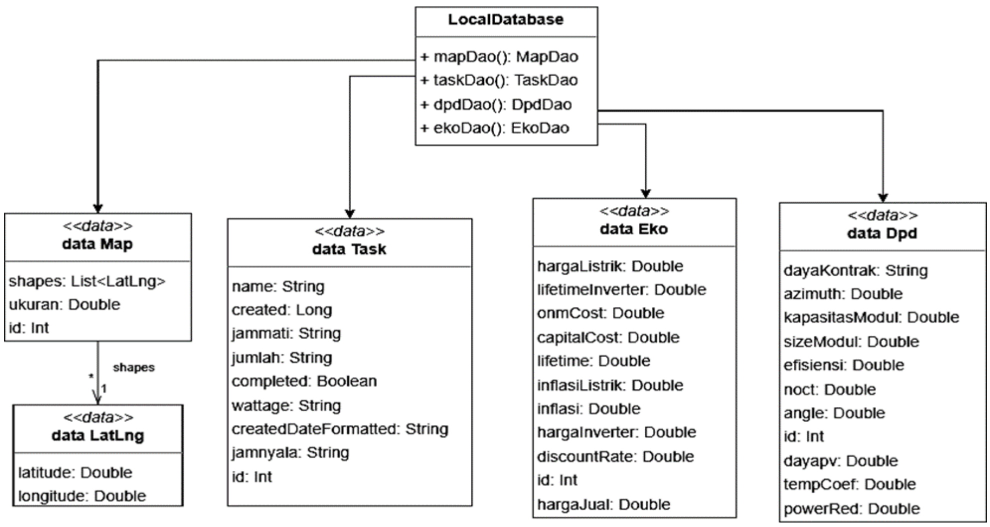


Figure 4. KawanSurya database scheme

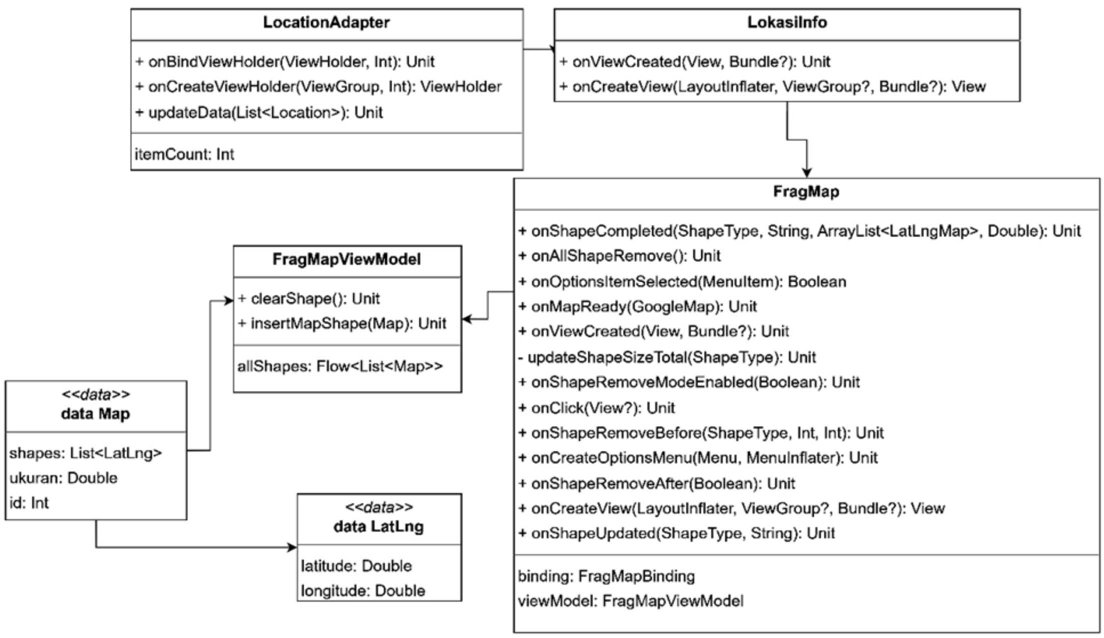


Figure 5. A class diagram of the location and area page

2.2. Electrical load page

The electrical load page allows users to add electrical loads or appliances by clicking the 'Add' button to enter their name, amount, active power, and operational hours. The tool calculates operational hours by subtracting on-time and off-time. Users can input various appliance data to gather a 24-hour electrical load on their premises. This data generates daily electrical load data and curves, estimating self-consumed PV energy and excess energy sent back to the grid.

2.3. Technical parameters page

The technical parameters page on the rooftop PV system installation tool allows users to input various technical parameters, including installed PLN contracted power capacity (VA), maximum rooftop PV capacity, (Watt-peak, Wp), module size (m^2), PV module efficiency (%), nominal operating cell temperature (°C), and temperature coefficient of power (%/°C). Other parameters include tilt angle (°), azimuth (0°=South, 90°=West, -90°=East), and annual power output reduction (%). The tool allows users to change the parameters and define settings for their installation plan but also provides default values for simulation. This helps in calculating the system's hourly power output and evaluating economic performance. Irradiance data is crucial for calculating rooftop PV system output power. KawanSurya uses the PVGIS API to obtain data from the PVGIS SARAH-2 dataset [23], which contains sun irradiance data from 2005 to 2016. Retrofit is used to create an API request with parameters like latitude, longitude, month, output format, local time, global, angle, aspect, and temperatures. Figure 6 shows a part of the code created to retrieve the solar irradiance dataset for a specific place from PVGIS.

```
interface ApiInterface {
    @GET("api/v5_2/DRcalc")

    fun getDatas(@Query("lat") lat: Double,
                 @Query("lon") lon: Double,
                 @Query("month") month: Int,
                 @Query("ouputformat") ouputFormat: String,
                 @Query("localtime") localtime: Int,
                 @Query("global") global: Int,
                 @Query("angle") angle: Double,
                 @Query("aspect") aspect: Double,
                 @Query("showtemperatures") temp: Int
    ) : Call<ResponseData>
}
object RetrofitHelper {

    val baseUrl = "https://re.jrc.ec.europa.eu/"

    fun getInstance(): Retrofit {
        return Retrofit.Builder().baseUrl(baseUrl)
            .addConverterFactory(GsonConverterFactory.create())
            .build()
    }
}
private fun getDatas() {
    val api = RetrofitHelper.getInstance().create(ApiInterface::class.java)
    val viewModel2 = ViewModelProvider(this)[FragMapViewModel::class.java]
    lifecycleScope.launch {
        var lat: Double
        var lon: Double
        viewModel2.getAllShapes().collect {
            if (it.isNotEmpty()) {

                lat = it[it.size - 1].shapes[0].latitude
                lon = it[it.size - 1].shapes[0].longitude

                binding.tvLatlon.text = "%.5f, %.5f".format(lat, lon)
```

Figure 6. A screenshot of coding for retrieving the solar irradiance dataset

2.4. PV output power, solar PV capacity and module quantity

KawanSurya calculates rooftop PV output power using the HOMER software's equation, considering factors like derating factor and solar absorptivity and transmittance. The derating factor considers panel dirt, wire loss, shadowing, snow coverage, and aging. The tool calculates an estimated value of 0.77 [24] to determine the impact of these parameters on the performance of the rooftop PV system. Solar absorptivity and transmittance are calculated using the product of 0.9 or 90% [25]. The equations used to determine rooftop PV output power and PV cell temperature are as (1):

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}}\right) [1 + \alpha_p (T_c - T_{C,STC})] \quad (1)$$

where P_{PV} is PV output (kW); Y_{PV} is rated capacity solar PV array in standard test conditions (kW); f_{PV} is a derating factor (%); $\overline{G_T}$ is the solar radiation incident on the PV array in the current time step (kW/m^2); $\overline{G_{T,STC}}$ is the incident radiation at standard test conditions (1 kW/m^2); α_p is the temperature coefficient of power (%/°C); T_c is the PV cell temperature in the current time step (°C); and $T_{C,STC}$ is the PV cell temperature under standard test conditions (25°C).

$$T_c = \frac{T_a + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(1 - \frac{\eta_{mp,STC}(1-\alpha_p T_{c,STC})}{\tau\alpha}\right)}{1 + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_p \eta_{mp,STC}}{\tau\alpha}\right)} \quad (2)$$

where T_c is the PV cell temperature (°C); T_a is the ambient temperature (°C); $T_{c,NOCT}$ is the nominal operating cell temperature (°C); $T_{a,NOCT}$ is the ambient temperature at which the NOCT is defined (20°C); G_T is the solar radiation striking the PV array (kW/m^2); $G_{T,NOCT}$ is the solar radiation at which the NOCT is defined (0.8 kW/m^2); $\eta_{mp,STC}$ is the maximum power point efficiency under standard test conditions (%); α_p is temperature coefficient of power (%); $T_{C,STC}$ is the cell temperature under standard test conditions (25°C); τ is the solar transmittance of any cover over the PV array (%); and α is the solar absorptance of the PV array (%). The tool predicts solar PV's electricity output power over multiple years, considering yearly power loss using (3):

$$PV_{out\ year\ n} = PV_{out\ yearly} \times (1 - yearly\ rate\ of\ PV_{out} degradation\ (\%)) \times (n-1) \quad (3)$$

The tool is designed to limit solar PV module capacity to 100% of a household's contracted electricity. The tool determines the number of modules and PV capacity by comparing the maximum power generated by all solar modules with the user's maximum power (Watt-peak) or a 100% permitted capacity equal to the household contracted power.

2.5. Location and area page

The location and area page allows users to estimate the available roof area for solar PV modules by drawing a polygon and clicking on the areas on the house's roof. The program uses the MapDrawingManager library to compute the area, which is an effective area considering 80% of the true size of the measured polygon. This usable roof space shows 80% of the total area within the polygon for installation and maintenance purposes. The program uses the site's coordinates and the roof area to provide accurate information.

2.6. Economic parameters page

The economic parameters page allows users to define the economic parameters of a rooftop PV system, including inverter price, lifetime, capital cost, electricity price, feed-in tariff, annual O&M cost, annual electricity price increase, inflation rate, discount rate, and project lifetime, for economic analysis purposes. KawanSurya uses payback period analysis to evaluate the economic feasibility of monocrystalline silicon-based PV module systems [26], [27], in addition to return on investment (ROI) and NPV.

The study includes simple and discounted payback periods, with the present value (PV) calculated using an assumed interest rate [28]. The discount factor (DF) is based on the assumed discount rate. ROI measures the profitability of the system, defined as the ratio of net benefits (NPV) to the initial investment. A negative ROI indicates the investment is not profitable. The equations for calculating the simple or discounted payback period, ROI, and NPV are as (4) and (5):

$$PP = Nb + \frac{ccNb}{ncNa};\ PV = S \times F_{PW};\ DF = \left(1 + \frac{d}{100}\right)^{-n};\ IF = (1 + i)^n \quad (4)$$

$$F_{PW} = \frac{(1+i)^n}{(1+d)^n};\ NPV = \sum PV_{income} - \sum PV_{cost};\ ROI = \frac{NPV}{Capital\ Cost} \quad (5)$$

where PP is payback period; Nb is the year before recovery; $ccNb$ is cumulative cash flow in the year before recovery; and $ncNa$ is net cash flow in the year after recovery; PV is the present value of S in year n; S is cash flow in the year n; F_{PW} is a present worth factor in the year n; i is inflation rate; d is the discount rate; and n is year.

3. RESULTS AND DISCUSSION

This section presents the simulation results conducted on KawanSurya, focusing on testing features and obtaining techno-economic results. Initial tests were performed to verify and validate the application's functionality, including processing electrical load data and retrieving solar irradiance data using an API. The findings and implications of these tests are discussed in detail.

3.1. Preliminary tests on electrical loading and solar irradiance data retrieval

The electrical loading test evaluates the data gathering and processing for all appliances in a tool. The information is recorded in a local database and used during computation. The testing ensures accurate retrieval and processing of the data by adjusting the debug log level on the calculation page. The testing uses database-based electrical load data, listing appliances, power, on-time, and off-time. The tool calculates operating hours based on these values, resulting in 2 hours of operation for an on-time value of 1 and an off-time value of 3.

Solar irradiance data retrieval through API is tested to determine whether the geographical location entered the tool and the retrieval of solar irradiance data. The tool considers solar irradiation in terms of the average monthly sum of global irradiation (GI) per square meter received by the modules (W/m^2/month). It is conducted by carrying out the debug log level. The testing site is at latitude 3.589 and longitude 114.893, with a tilt angle of 30° and azimuth of 0° (South facing).

Tables 1 and 2 provide examples of data submitted for processing electrical load data, including the outcome of each appliance’s operational period, and an example of the testing results for hourly temporal-based electrical load data processing, respectively. Meanwhile, Table 3 shows the locations debug log results, along with the corresponding irradiance data. The GI data originates from PVGIS’s default solar dataset for the region, the PVGIS-SARAH dataset, which spans 2005 to 2016 and is available on an hourly temporal basis.

Table 1. Examples of data entered for processing the electrical load data

Electrical load	Quantity	Wattage (W)	Operational hours	Duration (hours)
a	4	99	05:00-07:00	2
b	5	100	10:00-02:00	16

Table 2. Testing results of electrical load data processing

Time	Wattage (W)	Time	Wattage (W)	Time	Wattage (W)
00:00	500	08:00	0	16:00	500
01:00	500	09:00	0	17:00	500
02:00	0	10:00	500	18:00	500
03:00	0	11:00	500	19:00	500
04:00	0	12:00	500	20:00	500
05:00	396	13:00	500	21:00	500
06:00	396	14:00	500	22:00	500
07:00	99	15:00	500	23:00	500

Table 3. Testing results of the average monthly sum of global irradiation data retrieval

Time	GI (W/m^2)	Time	GI (W/m^2)	Time	GI (W/m^2)
00:00	0	08:00	1,519.71	16:00	3,582.74
01:00	0	09:00	2,898.66	17:00	1,968.99
02:00	0	10:00	5,058.98	18:00	533.57
03:00	0	11:00	6,803.24	19:00	0
04:00	0	12:00	7,669.45	20:00	0
05:00	0	13:00	7,561.26	21:00	0
06:00	0	14:00	6,626.56	22:00	0
07:00	83.92	15:00	5,193.40	23:00	0

3.2. Simulation settings and results

The study explores the techno-economic implications of on-grid rooftop PV systems in households, considering low maximum power capacity scenarios and six policy-setting scenarios. It considers bill reduction, inflation, increased electricity tariffs, and load profile. Table 4 shows electrical loads in the household, including quantity, wattage, and on-time-off-time.

Table 4. Electrical loads in a household with a 2,200VA power contract

Electrical load	Quantity	Wattage	On-time	Off-time
Refrigerator	1	80	24 hours	-
Rice cooker	1	300	17:00	17:40
Iron	1	300	09:00	10:00
Water pump	1	600	07:00	08:30
Washing machine	1	150	08:00	09:00
Laptop	2	100	20:00	22:00
Water heater	1	500	05:30	06:30
AC ½ hp	2	375	20:00	05:30
AC 1 hp	1	750	20:00	05:30
TV	1	80	20:00	22:00
Lamp	15	10	17:30	22:00
Lamp	5	10	22:00	05:30

Simulation-1 (S-1) is a case study of a household with a 2,200 VA power contract in Tropodo, Sidoarjo Regency, East Java, with standard household appliances. The study examines the use of a solar power (PV) system on the roof, focusing on the polygon drawn on the West-facing area. The user interface shows the house's latitude and longitude (-7.360 and 112.754, respectively), and it is usable roof area (26.49 m^2). The simulation is based on a 100 Wp monocrystalline solar PV module [30], with specifications including size, capacity, efficiency, NOCT, and annual output power reduction. The economic parameters include inverter prices, system capital cost, electricity prices, export electricity prices, and annual operation and maintenance costs, with a 30° roof tilt angle and 90° azimuth, with the azimuth facing west, as provided by the PVGIS input API [20].

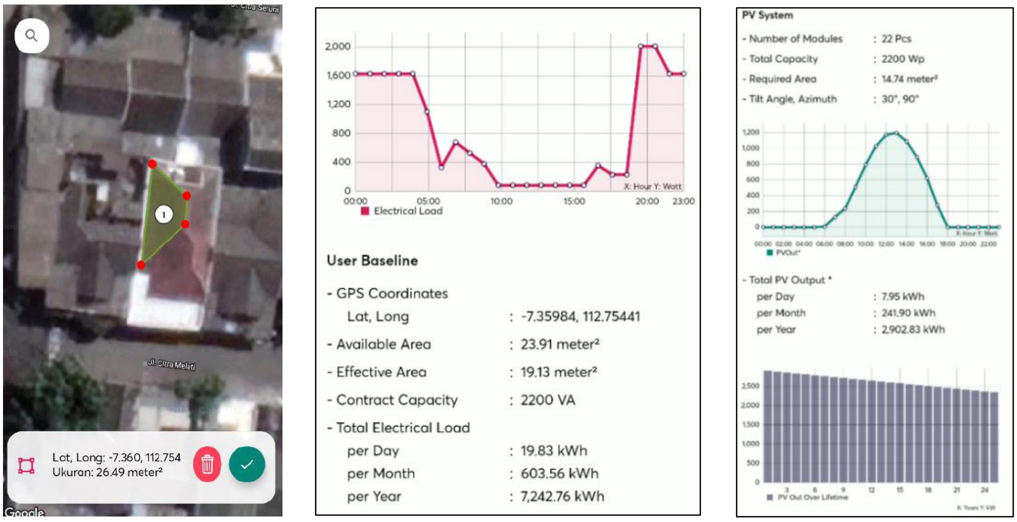
The economic parameters of a solar power system include inverter prices, system capital costs, electricity prices, export electricity prices, and O&M costs per year. The inverter costs IDR 4,290,000, 13% of the total system capital cost. The discount rate is 5%, annual growth on electricity price is 0%, and inflation is 0%. The O&M cost for a PV system is IDR 0, and the electricity price is based on a 2,200 VA power contract with a 100% sellback rate for exporting to the grid. The tool can support a 0% sellback rate if a policy change prevents rooftop PV owners from exporting electricity to the network. The investment cost for installing 1 kWp of rooftop PV is IDR 15 million, totalling IDR 33 million.

The technical and economic parameters for S-1 are as follows: contracted power capacity is 2,200 VA, maximum rooftop PV capacity is 2,200 Wp, size per module 0.67 m^2, capacity per module is 100 Wp, module efficiency (STC) is 14.92%, nominal operating cell temperature is 45°C, temperature coefficient of power is -0.39%/°C, tilt angle 30°, azimuth 90°, output power reduction per year 0.8%, inverter price is IDR 4,290,000, inverter lifetime 15 year, system capital cost (exclude inverter price) is IDR 28,710,000, electricity price is IDR 1,444.7, export electricity price is IDR 1,444.7, electricity price increase per year IDR 0, discount rate 5%, project lifetime 25 year.

KawanSurya's techno-economic analysis is divided into four sections: user baseline, PV system, load profile scenario with daily PV output, and investment. The user baseline includes the daily load curve, geographic coordinates, roof size, contracted power, and total electrical load per day, month, and year. For the case of S-1 and given the selected location, they are 19.83 kWh, 603.56 kWh, and 7246.76 kWh, respectively. The generated load curve is then used to calculate electricity export, billing, and savings from the PV system.

The PV system part includes simulation results for module number, total capacity, needed area, tilt angle, azimuth, hourly output curve, and total output over project lifetime. The output curve is generated using irradiation data from the PVGIS API and technical parameters. The calculation shows that the installed capacity is limited to a contracted power of 2,200 VA. The necessary area is smaller than the available area. An asterisk (*) indicates that the total PV output was calculated before any reduction in power output. The total PV output, calculated before any reduction in power output, is 7.95 kWh/day, 241.90 kWh/month, and 2,902.83 kWh/year in this scenario. The graph below shows the decrease in PV output power over the project's lifetime, using a technical parameter of 0.8% power output reduction per year.

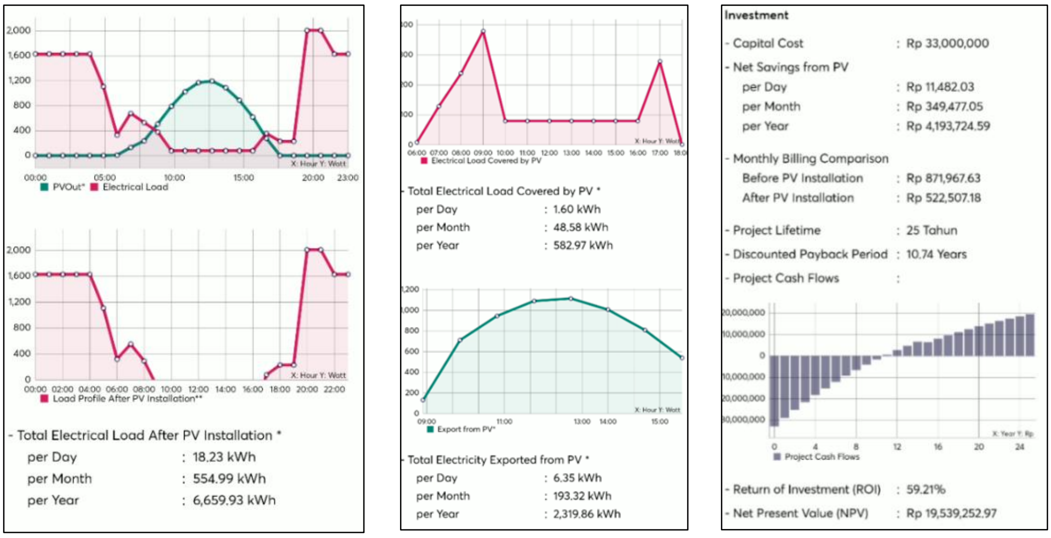
Figure 7 exhibits the S-1 results displaying user interfaces of KawanSurya; i) the screenshot of the location and roof area, ii) the user baseline, and iii) the PV system. As previously stated in section 2.5, Figure 7(a) depicts a screenshot of the house coordinates and roof area in KawanSurya. It shows the house's coordinates of -7.360° (South Latitude), 112.754° (East Longitude), and the calculated usable roof area of 26.49 m^2. Meanwhile, Figure 7(b) depicts the load curve scenario with information on total electrical load, while Figure 7(c) depicts a simulated curve of daily PV output and total PV output per day, month, and year. Figure 7(c) also shows how PV output degrades over time.



(a) (b) (c)

Figure 7. The user interface of KawanSurya; (a) the screenshot of the location and roof area, (b) the user baseline, and (c) the PV system of S-1

Figure 8 depicts the user interface/results for the load profile scenario; Figure 8(a) shows PV output and load profiles, hourly electricity load after PV installation, the portion covered by PV, and the amount of electricity exported from PV to the grid, and Figure 8(b) investment section. As shown in Figure 8, the total electrical load after PV installation is 18.23 kWh/day, 554.99 kWh per month, and 6,659.93 kWh/year, while PV meets a total electrical load of 1.60 kWh/day, 48.58 kWh/month, and 582.97 kWh annually. The total electricity export is 6.35 kWh/day, 193.32 kWh/month, and 2,319.87 kWh annually. the investment section analyses the economic feasibility of rooftop PV, revealing net savings of IDR 11,482/day, IDR 349,477/month, and IDR 4,193,725 annually. The monthly electricity bill before and after installation is based on net savings from PV. The cash flow graph shows a discounted payback of 10.85 years at a 5% discount rate, an ROI of 59.21%, and an NPV of IDR 19,539,262.80. The S-1 scenario results in a discounted payback period of 10.74 years at a 5% discount rate and 100% bill reduction factor. However, successive scenarios, including varying inflation rates and rising electricity bills, have influenced the system's discounted payback period.



(a) (b)

Figure 8. The user interface/results of S-1 for the load profile scenario; (a) PV output and load profiles and (b) investment

Simulation-2 (S-2) uses the same technical and economic parameters as S-1, resulting in a payback period of 19.79 years, twice the prior period. This is due to a 65% bill reduction factor, which reduces the power export price to 65% of the electricity rate per kWh. The modelled load profile shown in Figure 8 does not support maximising solar PV energy usage during the day, particularly between 09:00-15.00. Simulation-3 (S-3) adjusts the electrical load profile to a constant load while maintaining the 65% bill reduction factor from S-1. This scenario increases the energy supplied by the PV system to offset the load but reduces customer income from exporting electricity. The payback period is 11.79 years, one year longer than S-1. The overall electrical load changes, with 13.12 kWh/day, 399.35 kWh/month, and 4,792.25 kWh/year after PV installation.

Simulation-4 (S-4) assumes a 2% inflation rate while leaving all other parameters the same as S-1. The inclusion of inflation is intended to assess the impact of inflation on the payback period. Inflation can harm the economy but could benefit users by lowering the discount rate for power exported to the grid. The simulation yields a discounted payback period of 9.43 years or shorter than S-1 to S-3, allowing investors to recoup their initial investment faster. Simulation-5 (S-5) introduces a 2% annual increase in electricity tariffs while leaving all other parameters the same as S-1. This scenario benefits rooftop PV users by increasing income received, and calculating a discounted payback period of 9.66 years, assuming a 100% export rate. It should be noted that the payback period for PV users can be reduced by adjusting their daily electrical load profile between 7 a.m. and 5 p.m. and increasing daytime usage to lower the cost impact on billing caused by evening and nighttime loading. Table 5 presents possible discounted payback periods under various scenarios, including bill reduction factors, electricity load, inflation rates, increases in electricity tariffs, and minimum bill limits.

Table 5. Discounted payback periods due to different scenarios

No.	Scenario	Discounted payback period (year)
1.	Simulation-1 (S-1)	10.74
2.	S-2: with 1 65% bill reduction factor	19.79
3.	S-3: with a 65% bill reduction factor and constant electrical load	11.79
4.	S-4: with a 2% inflation rate	9.43
5.	S-5: with an annual increase of 2% in electricity tariff	9.66
6.	S-6: minimum bill limit	Exceed project lifetime

3.3. Discussions

Residential customers prefer systems with higher NPV and ROI, but decisions should also consider the ROI and NPV of different scenarios and electrical load patterns. Higher daytime energy usage is preferred for maximum electricity consumption. It should be noted that the discounted payback period of the simulated on-grid rooftop PV system is significantly influenced by electrical load profiles and bill reduction factors. A 65% bill reduction factor and the same load profile increase the discounted payback period. However, a 0% billing reduction factor or no compensation for selling back electricity to the grid can exceed the discounted payback period, making it advisable for rooftop PV system owners to increase electrical loading during the daytime. Inflation rates can help residential projects achieve shorter payback periods without significantly impacting financial cash flow, and well-compensated electricity exports are achieved regardless of daytime usage. KawanSurya reveals that a rooftop PV system's payback period can exceed the project's lifetime due to a set electricity bill limit, making the system uneconomical. Meanwhile, the accuracy and capability of the tool can be improved because it does not account for variables such as temperature, dirt, shade, and weather conditions.

4. CONCLUSION

Understanding the techno-economic potential of rooftop solar PV systems is crucial for increasing renewable energy penetration. Independent evaluation tools like KawanSurya help customers assess the potential of these systems, improving public knowledge and addressing misconceptions about costly technology tariffs. KawanSurya can be used to evaluate the techno-economic potential of installing on-grid rooftop PV under various scenarios, including daily load profiles, inflation, increased electricity tariffs, and billing reduction factors.

This study generated simulation results for a typical 2,200 VA household, resulting in a payback period of 9.44 years or longer. While the results are influenced by electrical load profiles and bill reduction factors, incorporating inflation rates in the simulations can help recover initial investment sooner. The 2% inflation rate resulted in a discounted payback period of 9.43 years, shorter than the default scenario and a

65% billing reduction factor. Adjusting the daily load profile and increasing daytime usage between 7 a.m. and 5 p.m. can reduce the payback period, while increased electricity tariffs may benefit users assuming a 100% export rate. Future work may include studies to enhance KawanSurya's capabilities and accuracy, as well as to broaden its capabilities to include off-grid and hybrid rooftop PV systems and to incorporate other factors influencing system performance.

ACKNOWLEDGEMENTS

This paper is part of the research contract no. 01010679/ELK/2023 conducted at Petra Christian University. The authors thank the reviewers for their time and effort in reading the manuscript. All comments and suggestions help to improve the manuscript's quality.

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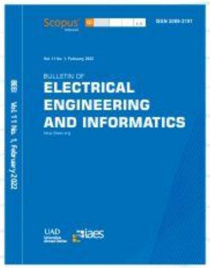

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