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

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

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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.

Corresponding Author:

Yusak Tanoto
Department of Electrical Engineering, Faculty of Industrial Technology, Petra Christian University
St. Siwalankerto 121-131 Wonocolo, Surabaya 60236, Indonesia
Email: tanyusak@petra.ac.id

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.

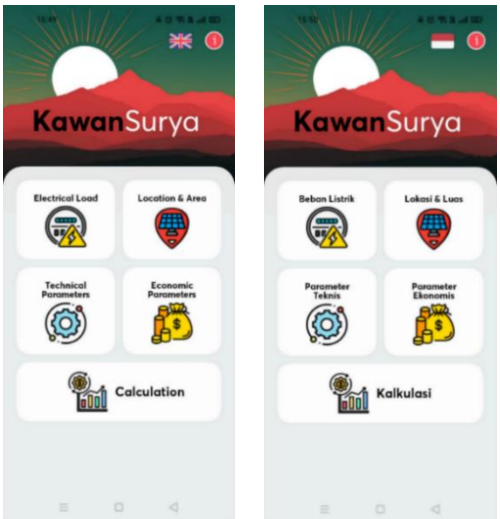
Photovoltaic geographical information system (PVGIS) [14] and PVWatts calculator [15] are web-based tools developed by the European Commission and The National Renewable Energy Laboratory to assess the performance of solar power (PV) systems in specific geographic regions. They are used in rooftop PV 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.

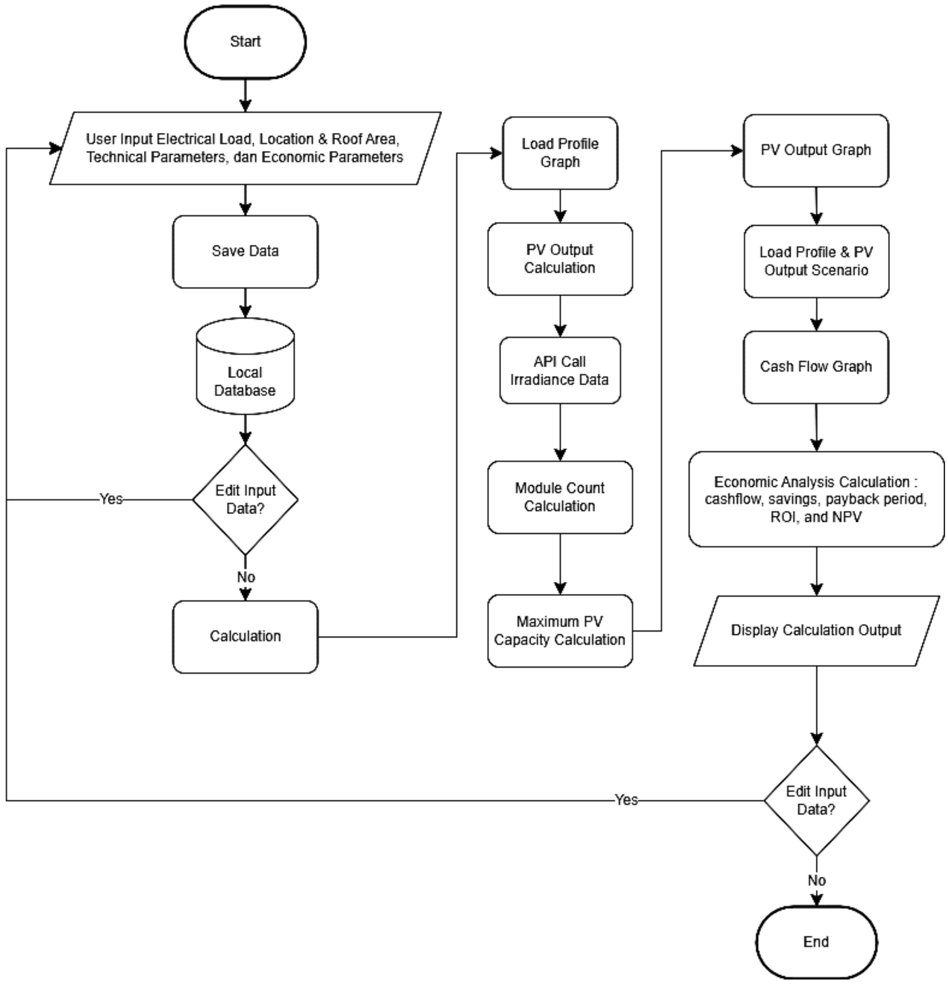


Figure 2. Flowchart of KawanSurya

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.

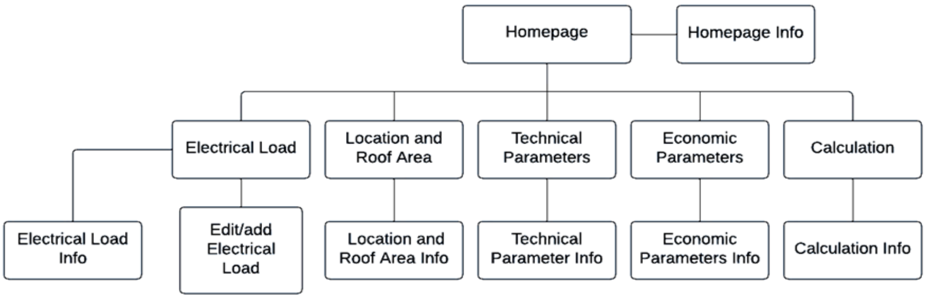


Figure 3. KawanSurya navigation diagram

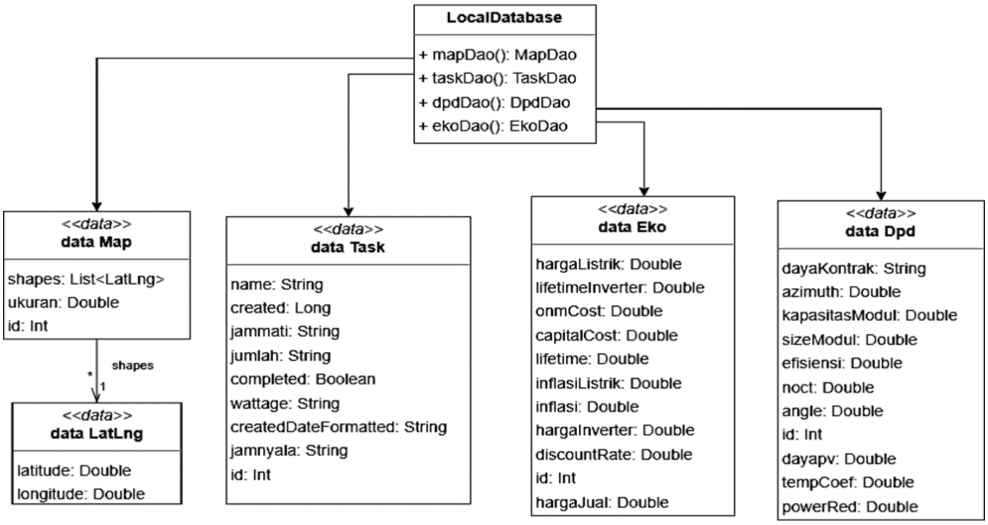


Figure 4. KawanSurya database scheme

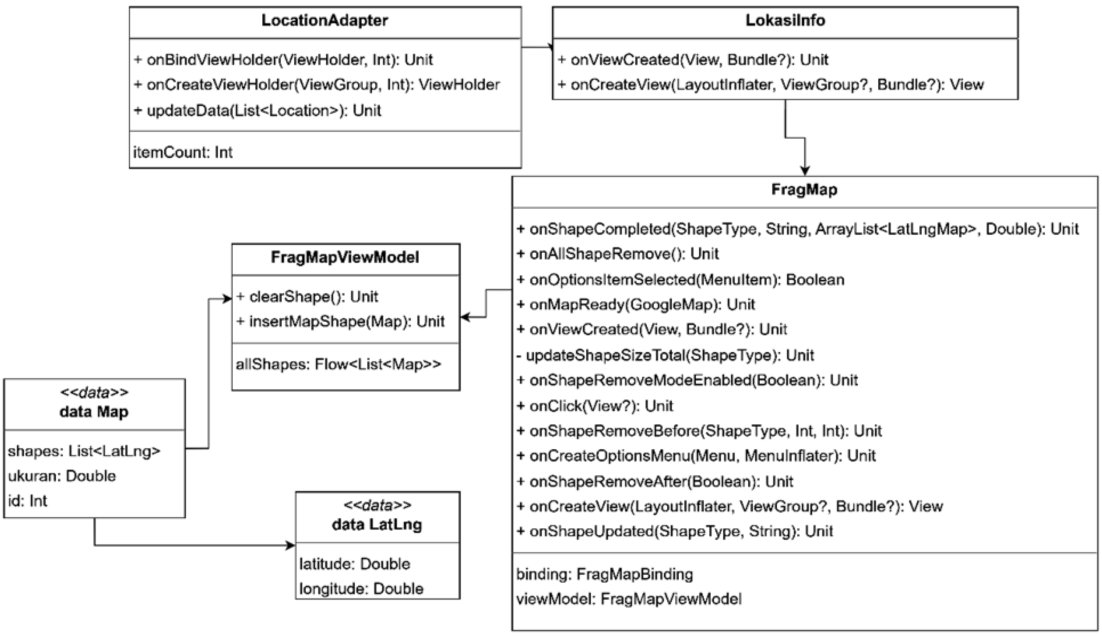


Figure 5. A class diagram of the location and area page

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 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 GI 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].

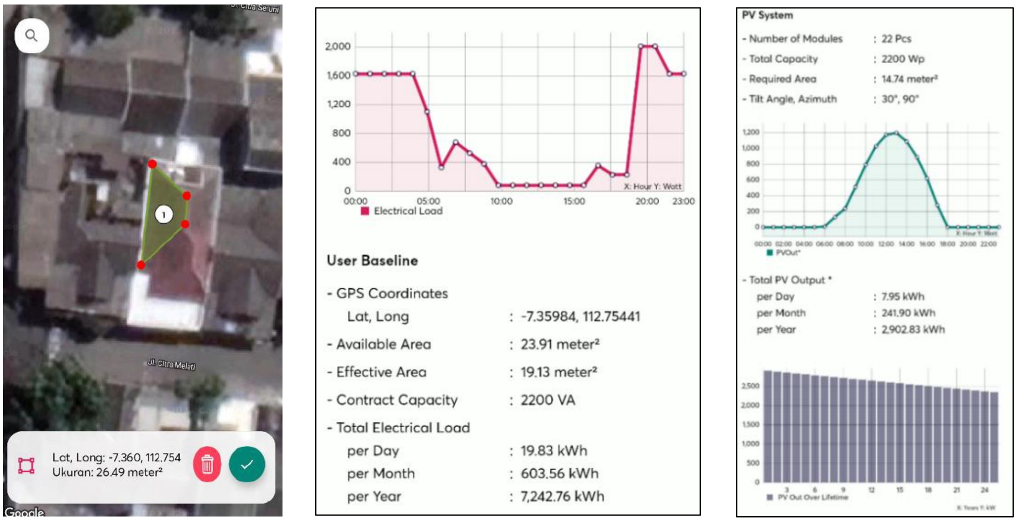
The economic parameters of a solar power system include inverter prices, system capital costs, electricity prices, export electricity prices, and O&M costs per year. The inverter costs IDR 4,290,000, 13% of the total system capital cost. The discount rate is 5%, annual growth on electricity price is 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.

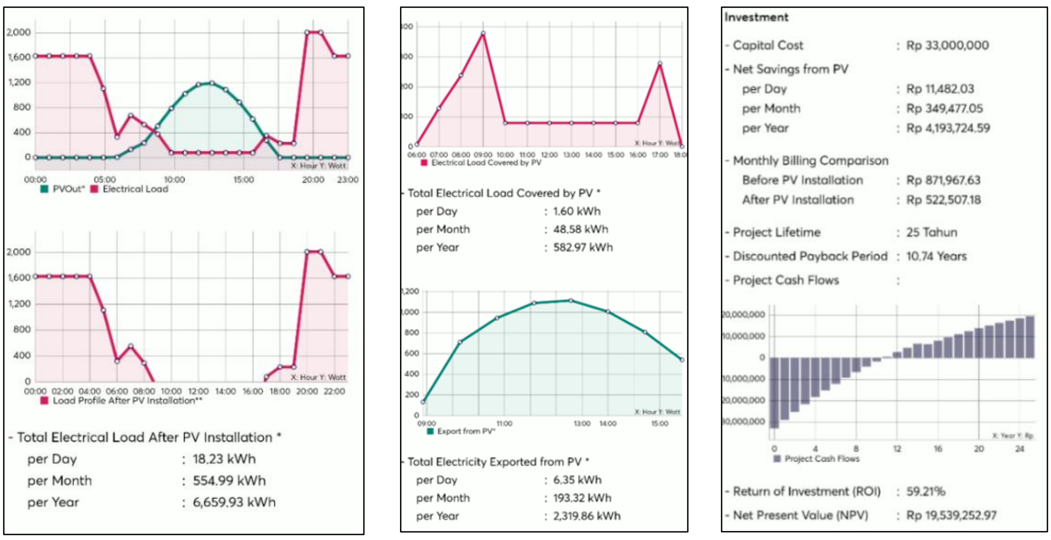
Figure 7 exhibits the S-1 results displaying user interfaces of KawanSurya; i) the screenshot of the location and roof area, ii) the user baseline, and iii) the PV system. As previously stated in section 2.5, Figure 7(a) depicts a screenshot of the house coordinates and roof area in KawanSurya. It shows 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.

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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 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.

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.

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.