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Multistakeholder collaboration in identifying rooftop solar power plant potential in Mandiri Energy Village, Kedungrong, Yogyakarta

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ABSTRACT

Background: Indonesia has significant solar energy potential due to its equatorial location, but its use remains suboptimal. This study aims to examine the installation of a pilot solar panel system in Kedungrong Village, Yogyakarta, as part of long-term plan in building an energy independent village. **Methods:** This study used a quantitative descriptive approach, with primary data in the form of field observations and system testing and secondary data in the form of solar irradiation data. The study location was in the Kedungrong Energy Independent Village, Yogyakarta, where 53 houses were identified as having the potential for rooftop PV installation. One sample was selected for system design using a 300 Wp solar panel integrated with supporting components. **Findings:** The average solar irradiation reached 4.80 kWh/m^2/day. The PV system produced a stable and reliable output voltage of 223.7 V AC for household needs. From an economic perspective, the investment cost of IDR 3,859,500 is considered affordable. Furthermore, observation results revealed that multi-stakeholder engagement involving academics, government, the community, and industry play a crucial role in supporting the program's implementation and sustainability. Each stakeholder contributed to the planning, implementation, coordination, and system use of the project to enhance its sustainability. **Conclusion:** The rooftop solar PV system is technically, economically, and socially feasible for household implementation and can support community-based sustainable energy development. **Novelty/Originality of this study:** The novelty of this research lies in the integration of technical and economic analysis with a multi-stakeholder collaborative approach can a viable and sustainable community-based rooftop solar PV system.

KEYWORDS: energy independent village; renewable energy; rooftop solar power plant; sustainable development; techno-economic analysis.

1. Introduction

Indonesia has enormous solar energy potential due tobecause of its geographical location on the equator, which allows allowing for relatively stable solar radiation intensity

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throughout the year. Based on the RUEN data, the potential for solar power plants (Pembangkit Listrik Tenaga Surya PLTS) in Indonesia isare 207,898 MW (IESR, 2017). The useUse of solar power plants (PLTS), especially rooftop PV plants, is a strategic solution because they do not require additional land, can be implemented decentralized, and directly contribute to reducing carbon emissions and the environmental impact of fossil-based power plants. In the context of developing energy-independent villages, and identifying the potential for rooftops PV is a crucial initial step to ensurein ensuring technical feasibility and optimize optimizing the use of local resources (Sakti et al., 2022; Widodo et al., 2020). Despite its considerable renewable energy potential, Indonesia continues to face significant challenges in expanding the utilization use of renewable energy, particularly in rural areas where decentralized energy. systems are needed (Sodiq et al., 2021).

Despite its considerable renewable energy potential, Indonesia continues to face significant challenges in expanding the use of renewable energy, particularly in rural areas where decentralized systems are needed. This situation further aggravated by Indonesia's heavy reliance on fossil fuels, which hinders the acceleration of the national energy transition (Putri et al., 2023). *S*olar photovoltaic (PV) technology is particularly suitable for tropical countries such as Indonesia because solar energy is abundant, renewable, and can be harnessed sustainably without producing harmful emissions (Carmen et al., 2023; Siudek et al., 2020; Wittenberg & Matthies, 2016). Rooftop PV systems provide practical solutions by using existing rooftop space without requiring additional land, making them suitable for residential buildings, public facilities, and other buildings while simultaneously supporting local energy independence (Abdullah et al., 2024; Cardenas et al., 2017; Fares & Webber, 2017).

Beyond its technical and environmental advantages, rooftop PV systems also play a crucial role in accelerating the national transition toward clean energy and renewable energy sources (Al Hakim, 2020; Al Hakim et al., 2021). Previous research by Rachmawati & Hoesein (2025) demonstrated that improving public understanding of green energy is crucial for fostering energy awareness and initiating energy-independent villages. Although rooftop PV implementation has been widely conducted in various contexts such as university buildings, urban areas, commercial facilities, and individual households, focusing on rural communities within the Energy Independent Village framework remain limited (Alatas, Styana, et al., 2025; Suriadi & Syukri, 2010; Hussein et al., 2000; Kim et al., 2021).

Table 1 shows that previous studies have primarily focused on community-based micro-hydropower development through collaboration among academia, communities, and government (A+C+G). However, these studies have given limited attention to the roles of financial perspective and information and technology adoption, which are critical for the successful solar panel implementation in target communities. Therefore, this study expands the discussion by integrating business, financial support, information dissemination, and technology development by employing the Academic, Business, Government, and Financial, and Information and Technology (ABGFIT)framework. This allows the integration of these additional dimensions to support the implementation of off-grid rooftop PV in an existing Energy Independent Village.

To address this gap, this study examines the potential for solar energy implementation using the ABGFIT framework. Kedungrong Village was chosen as the research location due to the familiarity of the community with alternative energy. Previously, they have already implemented micro-hydropower plant. The research was conducted in Kedungrong Village, Yogyakarta, a rural community of 53 households currently adopting microhydro power plants *Pembangkit Listrik Tenaga Mikrohidro*(PLTMH). The study focuses on a rural community consisting of 53 households that currently usea previously developed micro-hydropower plant *Pembangkit Listrik Tenaga Mikrohidro,* (PLTMH). Rooftop PV systems are proposed installed at the household level to complement and enhance the available energy supply for the community.

Table 1. Comparison of previous studies on community-based renewable energy development in Indonesia

No	Study	Renewable Energy System	Stakeholders	Main Contribution
	(Budiono & Susetiawan, 2023)	MHPP (Tirta Pijar Community Group)	Community members, local leaders, village government, higher education institutions, regional government, and supporting organizations A + C + G	Andung Biru Village, Probolinggo Regency, East Java The micro-hydropower plant (MHPP) has operated sustainably since 1993, improving the local economy and strengthening village institutions.
	Fauzi (2025)	Communit y based MHPP Manageme nt Group	Community members, village governments, community leaders, higher education institutions, and regional government A + C + G	Rinjing Hamlet, Gunung Lurah Village, Banyumas Regency, Central Java Strengthened community participation in the development of an Energy Independent Village.
	(Kementerian Energi dan Sumber Daya Mineral, 2010)	Communit y based MHPP Manageme nt Group	Community members, regional government, the National Program for Community Empowerment (PNPM), and the BaKTI Foundation A + C + G	Batanguru Village, Mamuju Regency, West Sulawesi Established as a National Energy Independent Village, while promoting productive economic activities and facilitating micro-hydropower (MHP) technology transfer.
	Kementerian Energi dan Sumber Daya Mineral, 2017)	Indigenous Communit y Micro-Hydropow er Manageme nt Group	Indigenous community, foundations, government agencies, Corporate Social Responsibility (CSR), and volunteers A + B + C + G + F	Kasepuhan Ciptagelar, West Java Providing electricity to remote households and strengthening indigenous community energy independence.
	Sallata et al., 2015	Village Community Group	Community members, village government, forest managers, regional government, and higher education institutions A + C + G	Several Micro-Hydropower-Based Energy Independent Villages in Indonesia's Forest Areas Supporting forest conservation while expanding access to renewable energy.
	(Alatas et al., 2022	Integrated Micro-Hydropow er Communit y of Indonesia (KMTI)	Academia (A), Business/MSM Es (B), Community (C), Government (G), CSR Support from 53 Households (F), Indonesian Journalists Association and Media (I), and Technology Development (T)	Regency, Special Region of Yogyakarta Strengthening the sustainability of KMTI through the continued operation of micro-hydropower systems and the development of off-grid rooftop PV

This study contributes to existing literature in several ways. First, it extends rooftop PV assessment to a community-scale application by identifying 53 potential residential buildings within an Energy Independent Village context. Second, a multi-stakeholder collaboration approach (ABGFIT framework) to support renewable energy planning and implementation at the village level. Third, it integrates technical feasibility analysis, economic evaluation, and stakeholder engagement into a practical and implementable model for developing community-based rooftop PV development, which may serve as a reference for similar rural energy transition initiatives.

1.1 Literature review

According to Alatas et al. (2022), sustainable development can be carried out involving ABGFIT elements: Academic (A), Business (B), Government (G), and Financial (F) and Information and Technology (IT), each of which can play a role in the eight stages of the spiral cycle, including (1) Identification of problem, (2) Initiation, (3) Deliberation, (4) Program, (5) Solution, (6) Action, (7) Monitoring, and (8) Development. Sustainable development often discuss about renewable or alternative energy, According to research by Duma et al. (2025) using solar energy is an effective way to reduce electricity consumption. Solar energy can be used as an alternative energy source that can reduce dependence on fossil-fueled power plants (Shahinzadeh et al., 2015; Tsiaras et al., 2020). Duma et al. (2025) explained that the use of solar energy not only contributes to electricity cost savings but also supports reduce carbon emissions and increasing energy efficiency. Pijoh et al. (2024) shows that this solar module can significantly reduce electricity costs and produce 23.25 kWh of independent energy over a 4-week period. Monitoring of electricity usage and production is carried out in real time via a smartphone application, thus providing energy management. The implementation of this research has great potential to reduce dependence on conventional electricity and energy sustainability (Darmawan et al., 2024; Iakovleva et al., 2022; Poullikkas, 2009). According to the Minister of Energy and Mineral Resources Regulation No. Under Law No. 31 of 2014 and No. 9 of 2015 12 groups whose electricity tariffs are adjusted. Basic electricity tariff (TDL) in PP. Nurussalam with power limits of 1,300 VA and 2,200 VA in 2019 is IDR 1,467.28 per kWh.

The profit from using solar panels is IDR 34,114.26 in four weeks. This will reduce the electricity use from PLN, thereby reducing monthly PLN electricity bills. Using solar panels convert solar energy into electrical energy (Coronas et al., 2022; Ronyastra et al., 2024). Aditama et al. (2023) showed that solar energy utilization through the Solar Energy Bank concept can be an effective and independent alternative source of electricity for the community. Results of the Community Service Program (PKM-PM) successfully provided solar energy-based lighting system for 24 houses in Batu Ampar Hamlet RT 04/RW 17 using emergency lamps that can be used at night.

Furthermore, the study revealed that the application of solar panels not only provides economic benefits in the form of electricity cost savings but also increases public knowledge and awareness regarding the environmental use of friendly renewable energy. With increased public understanding of solar energy, the use of This technology contributes to efforts toward environmental sustainability and encourages energy efficiency in daily life. Knowledge of solar energy potential at partner locations that can be used as an independent energy source (Supu et al., 2023). Pijoh et al. (2024) showed that solar energy has significant prospects for supporting energy independence, reducing electricity costs and encouraging the sustainable use of renewable energy. According to Ramadhani et al. (2023), a PLTS system is designed as a unified technology capable of converting solar energy into electrical energy that can be used directly or stored.

The main component of this system is a solar panel that functions to capture solar radiation and convert it into direct current (DC). The performance of solar panels is greatly influenced by the intensity of sunlight, tilt angle, and environmental conditions. The generated electrical energy is then channeled to a charge controller circuit that plays a crucial role in maintaining the voltage and current stability to prevent damage to other components of the system. Controlled electrical energy is stored in storage medium in the form of a maintenance-free 12-volt battery. This battery functions as an energy reserve that allows electricity to be used even when there is no sunlight, such as at night or during cloudy weather.

The use of a maintenance-free battery provides advantages in terms of operational efficiency because it does not require routine maintenance such as refilling the electrolyte water. By integrating these three components, the PLTS system can provide reliable, sustainable, and environmentally friendly energy solutions, especially for household-scale electricity needs in remote areas. The components of a PLTS system work in an integrated manner within an interconnected process flow, from the generation and regulation stages to the storage of electrical energy sourced from solar radiation. Solar energy captured by solar panels are converted into direct current (DC) electricity, which is then channeled to a charge controller for stabilization before being stored in batteries. This integration ensures that the generated energy can be optimally, safely, and efficiently used for direct use and as a backup energy source when sunlight is unavailable. Purwanto (2020) and Inayah et al. (2022) explained that solar panel modules or solar combines several photovoltaic cells arranged in series and parallel to produce voltage and electrical current according to the system requirements. The series arrangement increases the output voltage, while the parallel arrangement is used to increase the current capacity. With This configuration, solar panel modules can produce greater and more stable electrical power, thereby supporting the overall performance of the PLTS system under various operational conditions.

The series and parallel configuration of solar cells aim to produce a combination of voltage and electric current that matches the power requirements of the system. Series arrangements increase the output voltage, while the parallel arrangements increase the electric current generated, both can be optimized to achieve a specific power capacity, as explained by Pastor et al. (2020) and Sharma & Sengar (2022). With this arrangement, solar PV systems can be flexibly designed according to load specifications for small-scale needs such as households, and larger scale, such as commercial or industrial facilities. The size and composition of solar panel modules are largely determined by electrical energy requirements and the characteristics of the system to be built. The greater the power requirement, more modules must be installed with a specific configuration to meet that capacity. In addition, other factors such as the installation area, solar radiation intensity, and panel efficiency also influence system size planning. Therefore, the solar panel module design must be carefully performed to achieve optimal performance while ensuring the efficiency and long-term sustainability of solar PV system.

2. Methods

Multi-stakeholder collaborative research method was employed for identifying the rooftop potential solar power plants in the Kedungrong Energy Independent Village, Yogyakarta. The ABGFIT framework in this study comprises several stakeholders with complementary roles. The academic sector (A) contributed to project coordination, dissemination of knowledge, and, capacity building and raising awareness regarding renewable energy, as well as initiating community deliberations, identifying rooftop solar potential, and facilitating Focus Group Discussions (FGDs).

The business sector (B) supported the program through the Corporate Social Responsibility (CSR) initiatives. Community (C) played a central role in the program implementation and participation. Government support (G), represented through Universitas Gadjah Mada (UGM), was provided in the form of a rooftop solar PV installation equipment and technical assistance. The financial component (F) consisted of the funding support derived from academic research programs and community contributions. Information (I) was disseminated through various communication and outreach activities to increase public awareness and stakeholder engagement. Finally, technology (T) was represented by the deployment and adoption of rooftop photovoltaic (PV) systems as a local energy transition strategy aimed at reducing dependence on electricity supplied by the national utility company (*Perusahaan Listrik Negara,* PLN).

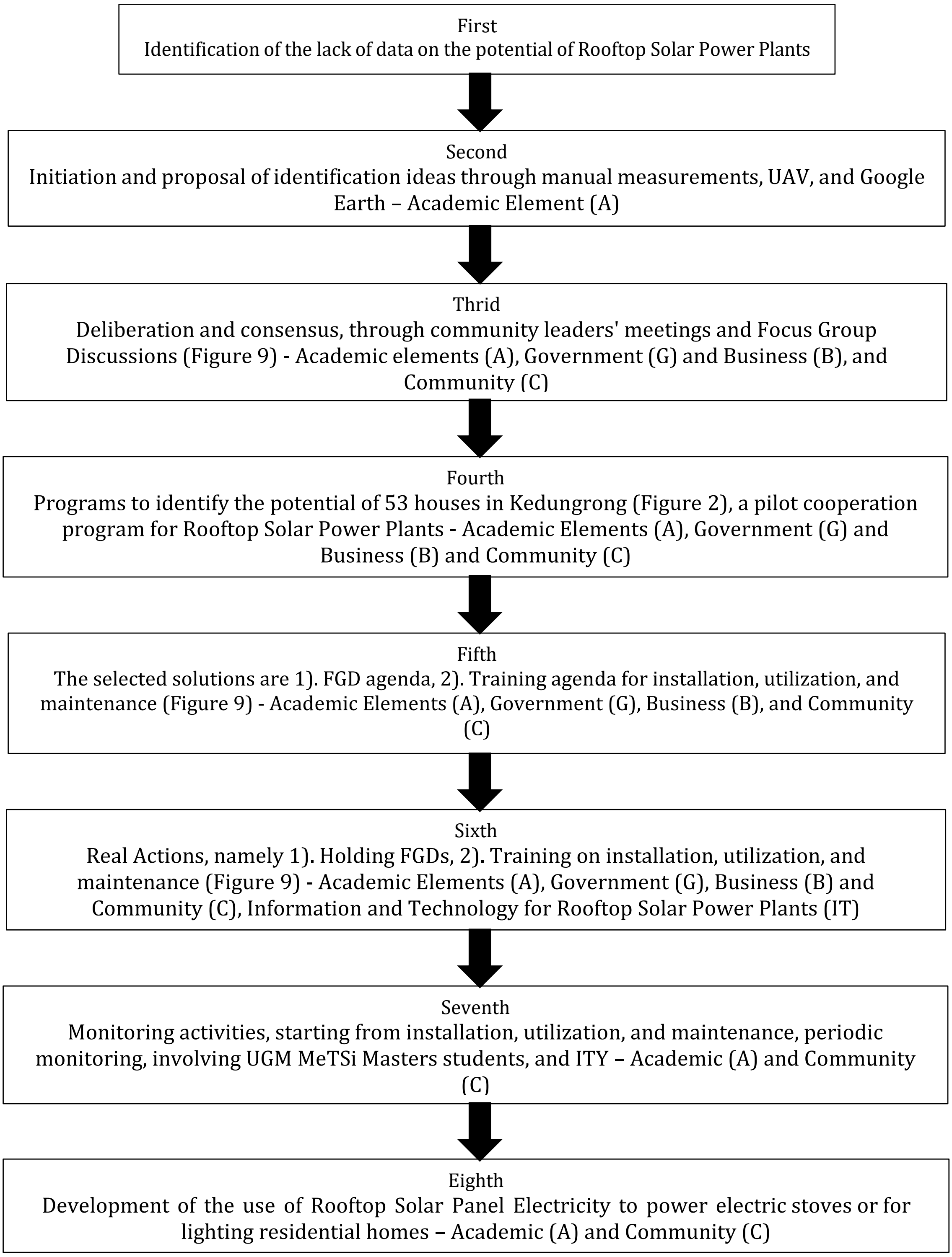
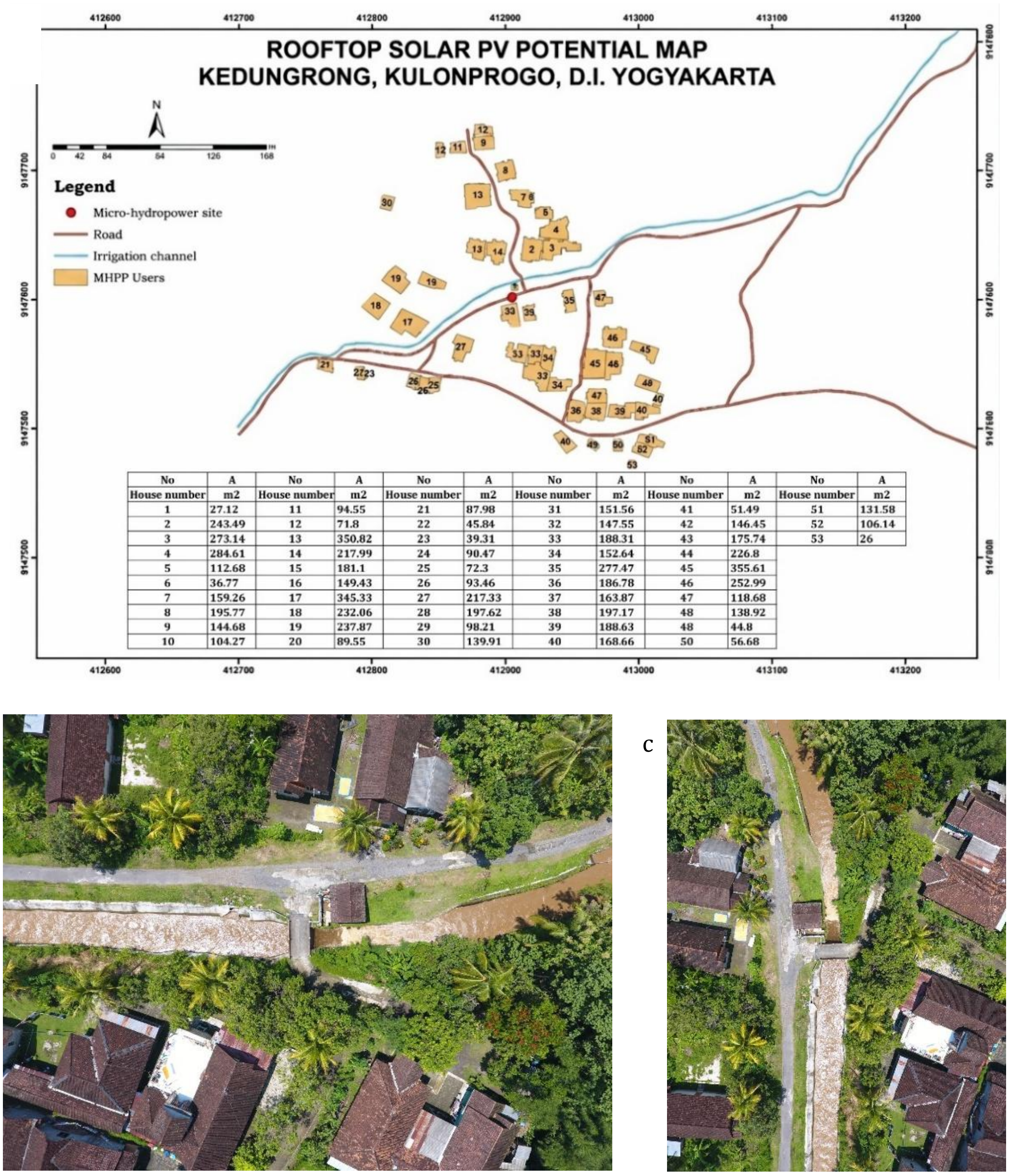


Fig. 1. The eight stages of the spiral cycle

A quantitative descriptive approach was used to analyze the potential and design of a rooftop PLTS system at the household scale. This approach is used to describe the solar energy potential, household electricity needs, and the technical and economic feasibility of installing a PLTS system. Similar to previous studies by Darmawan et al. (2024), the data used in this study consists of primary and secondary data. Primary data were obtained through direct observation at the research site, measurements of the PLTS system installation, and the system's output voltage was tested. Secondary data were obtained from scientific literature, solar radiation data, and technical references related to the PLTS systems.Focus Group Discussions (FGDs) were conducted with at least 45 selected stakeholders each: the first focused on establishing a PV management committee, while the second discussed the use of renewable energy for economic activities. Focus Group Discussions (FGDs) were conducted prior to construction, and the community was involved from the beginning, from installation to utilization, to gain knowledge and understanding of sustainable rooftop PV management. Two FGD experiments were conducted. The first FGD resulted in an agreement to establish a new management committee for KMTI Kedungrong to support the development of an off-grid rooftop PV system. The second FGD resulted in a consensus on promote the development and utilization of renewable energy to support the community economic activities.

a



No House number	A m2	No House number	A m2	No House number	A m2	No House number	A m2	No House number	A m2	No House number	A m2
1	27.12	11	94.55	21	87.98	31	151.56	41	51.49	51	131.58
2	243.49	12	71.8	22	45.84	32	147.55	42	146.45	52	106.14
3	273.14	13	350.82	23	39.31	33	188.31	43	175.74	53	26
4	284.61	14	217.99	24	90.47	34	152.64	44	226.8		
5	112.68	15	181.1	25	72.3	35	277.47	45	355.61		
6	36.77	16	149.43	26	93.46	36	186.78	46	252.99		
7	159.26	17	345.33	27	217.33	37	163.87	47	118.68		
8	195.77	18	232.06	28	197.62	38	197.17	48	138.92		
9	144.68	19	237.87	29	98.21	39	188.63	48	44.8		
10	104.27	20	89.55	30	139.91	40	168.66	50	56.68		

b

Fig. 2. (a) Potential of the 53 rooftop solar power plants in Kedungrong, Kulonprogo; (b) Aerial photo of potential sample location number 28 using UAV technology; (c) Image of rooftop solar power potential data for the 53 houses. The sample installation location is Mr. Widarto's house, with potential location number 28 and a roof area of 197.62 m^2. Potential identification can be performed using drones or UAVs
(Alatas et al., 2022)

The population in this study consisted of 53 houses located within the research location and with potential for rooftop solar power systems in Kedungrong Village, Yogyakarta. The rooftop PV potential of 53 households was identified using Google Earth satellite imagery interpretation. This method uses remote sensing techniques to estimate the rooftop area of community members affiliated with the Integrated KMTI, providing the basis for assessing rooftop PV potential. The rooftop area estimation results are presented in Figure 2(a) and Table 1.

Table 1. Estimated rooftop PV capacity for each house

No	A (m^2)	Radiation (4.8 kWh/m^2)	Coefficient (15%)	A1 10% * A (m^2)	P (Kw)
1	27.12	4.8	0.15	2.7	1.95
2	243.49	4.8	0.15	24.3	17.53
3	273.14	4.8	0.15	27.3	19.67
4	284.61	4.8	0.15	28.5	20.49
5	112.68	4.8	0.15	11.3	8.11
6	36.77	4.8	0.15	3.7	2.65
7	159.26	4.8	0.15	15.9	11.47
8	195.77	4.8	0.15	19.6	14.10
9	144.68	4.8	0.15	14.5	10.42
10	104.27	4.8	0.15	10.4	7.51
11	94.55	4.8	0.15	9.5	6.81
12	71.80	4.8	0.15	7.2	5.17
13	350.82	4.8	0.15	35.1	25.26
14	217.99	4.8	0.15	21.8	15.70
15	181.10	4.8	0.15	18.1	13.04
16	149.43	4.8	0.15	14.9	10.76
17	345.33	4.8	0.15	34.5	24.86
18	232.06	4.8	0.15	23.2	16.71
19	237.87	4.8	0.15	23.8	17.13
20	89.55	4.8	0.15	9.0	6.45
21	87.98	4.8	0.15	8.8	6.33
22	45.84	4.8	0.15	4.6	3.30
23	39.31	4.8	0.15	3.9	2.83
24	90.47	4.8	0.15	9.0	6.51
25	72.30	4.8	0.15	7.2	5.21
26	93.46	4.8	0.15	9.3	6.73
27	217.33	4.8	0.15	21.7	15.65
28	197.62	4.8	0.15	19.8	14.23
29	98.21	4.8	0.15	9.8	7.07
30	139.91	4.8	0.15	14.0	10.07
31	151.56	4.8	0.15	15.2	10.91
32	147.55	4.8	0.15	14.8	10.62
33	188.31	4.8	0.15	18.8	13.56
34	152.64	4.8	0.15	15.3	10.99
35	277.47	4.8	0.15	27.7	19.98
36	186.78	4.8	0.15	18.7	13.45
37	163.87	4.8	0.15	16.4	11.80
38	197.17	4.8	0.15	19.7	14.20
39	188.63	4.8	0.15	18.9	13.58
40	168.66	4.8	0.15	16.9	12.14
41	51.49	4.8	0.15	5.1	3.71
42	146.45	4.8	0.15	14.6	10.54
43	175.74	4.8	0.15	17.6	12.65
44	226.80	4.8	0.15	22.7	16.33
45	355.61	4.8	0.15	35.6	25.60
46	252.99	4.8	0.15	25.3	18.22
47	118.68	4.8	0.15	11.9	8.54
48	138.92	4.8	0.15	13.9	10.00
48	44.80	4.8	0.15	4.5	3.23
50	56.68	4.8	0.15	5.7	4.08
51	131.58	4.8	0.15	13.2	9.47
52	106.14	4.8	0.15	10.6	7.64

53	26.00	4.8			0.15	2.6	1.87
41	51.49	4.8			0.15	5.1	3.71
42	146.45	4.8			0.15	14.6	10.54
43	175.74	4.8			0.15	17.6	12.65
44	226.80	4.8			0.15	22.7	16.33
45	355.61	4.8			0.15	35.6	25.60
46	252.99	4.8			0.15	25.3	18.22
47	118.68	4.8			0.15	11.9	8.54
48	138.92	4.8			0.15	13.9	10.00
48	44.80	4.8			0.15	4.5	3.23
50	56.68	4.8			0.15	5.7	4.08
51	131.58	4.8			0.15	13.2	9.47
52	106.14	4.8			0.15	10.6	7.64
53	26.00	4.8			0.15	2.6	1.87
10% of roof area for solar PV							
average 10%			15,6	m^2			
average P (Kwh)			11,20	Kwh			
min			1,95	Kwh			
Power consumption							
1 unit of crystal ice machine			250	watt			

For further examination, this study used one house as the main sample, which was selected using purposive sampling. This house had a representative roof condition and was selected based on mutual agreement with the local community. The selected household was used as a case study for the detailed system design, installation, and performance evaluation. The quantitative results should therefore be interpreted as a site-specific assessment of the proposed rooftop PV system rather than a direct representation of all the 53 identified houses. Nevertheless, the findings provide an initial reference for evaluating the technical and economic feasibility of rooftop PV implementation within the community.

The roof area in the image above, using sample 1, number 28, with a roof area of 197.62 m^2, is adequate and technically feasible for installing a rooftop solar power system. The samples used as objects of analysis for the design, installation, and testing of the PLTS system to determine the system's performance in generating electricity. The research phase began with identifying the solar energy potential and roof area of a buildingarea using solar radiation data and field observations. The PLTS system was designed, including determining the capacity of the solar panels, inverter, battery, solar charge controller, and supporting installation components. After the completion of the design phase, the PLTS system was installed and assembled, and the system performance was then tested by measuring the output voltage using a multimeter to ensure that the system could generate electricity according to household voltage standards.

A technical and economic analysis was then conducted to determine the performance of the system and estimate the installation costs of the rooftop solar power plant. The economic analysis was conducted by calculating the total investment cost of the components of the solar power plant system and comparing it with the potential benefits of using solar energy as an alternative energy source. The results of this analysis were used to assess the feasibility of implementing rooftop solar power system on a household scale as a renewable energy solution. Practical benefits of implementing rooftop PV systems in supporting energy independence include reducing dependence on external electricity supplies, particularly from the national utility company (PLN). In addition, PV systems can serve as an alternative source of electricity during disruptions or outages in the grid supply, thereby enhancing household energy resilience. Households equipped with independent energy systems are also less vulnerable to fluctuations in electricity tariffs, which may contribute to long-term economic benefits. Furthermore, the usage of solar energy promotes a cleaner environment by reducing the reliance on fossil fuel-based electricity generation and supports Indonesia’s commitment to achieving its Net Zero Emissions targets. Therefore, rooftop PV systems offer not only technical and economic advantages, but also environmental and social benefits contribute to the development of sustainable communities.

3. Results and Discussion

3.1 Potential of solar energy available in Kedungrong, Yogyakarta

Solar irradiance prediction data released by the National Aeronautics and Space Administration (NASA), as also used in Darmawan et al. (2024), information regarding the solar energy potential in the Special Region of Yogyakarta Province uses the Solar Global Horizontal Irradiance (GHI) parameter. This parameter describes the total solar radiation received on a horizontal surface over a specific period, making it an important indicator for assessing the availability of solar energy sources in each region. International solar resource assessment studies, GHI is the most relevant parameter for evaluating the energy generation potential of photovoltaic (PV) systems because it directly reflects the amount of solar energy available for conversion into electricity. Therefore, GHI is widely used as the primary indicator for assessing solar energy resources and the feasibility of PLTS development in a particular region (Pravalie et al., 2019). The data presented in Table 3 shows the average GHI value, reflecting the relatively high level of solar radiation in the Yogyakarta region. This average GHI value indicates that the Yogyakarta Province has excellent potential for developing a PLTS system. Relatively stable high intensity of solar radiation throughout the year allows the PLTS system to operate optimally and efficiently. This presents a significant opportunity for households to use renewable energy needs, public facilities, and the commercial sector, while simultaneously supporting efforts to reduce dependence on fossil fuels and energy poverty at the regional level.

Table 2. Solar radiation

Month	Clearness Index	Daily Radiation (kWh/m^2/day)
January	0.396	4.280
February	0.413	4.470
March	0.437	4.590
April	0.484	4.720
May	0.533	4.730
June	0.542	4.550
July	0.559	4.800
August	0.563	5.250
September	0.545	5.540
October	0.506	5.390
November	0.438	4.710
December	0.426	4.570

Figure 3, it can be concluded that the average solar irradiance (GHI) in the Special Region of Yogyakarta Province reached its highest peak in September, with a value of 5,540 kWh/m^2/day and a brightness index (clearness index) of 0.545. Meanwhile, in February, the average solar irradiance and clearness index in the DIY Province were lower than those in other months. Overall, the annual average solar irradiance reached 4.80 kWh/m^2/day. The annual average GHI value of 4.80 kWh/m^2/day indicates a high potential for solar energy. Based on the global solar resource classification proposed by Solargis and related international studies, locations with GHI values between approximately 4.0 and 5.1 kWh/m^2/day are generally categorized as having high solar irradiation potential, making them suitable for PV electricity generation.

Monthly Average Global Horizontal Solar Irradiance (GHI) Solar irradiance or solar irradiation is the process by which solar energy is emitted and reaches the Earth's surface. It is used to measure the amount of solar radiation that falls on a certain area over a certain period of time and is usually expressed in units of power per area, namely watts per square meter (Darmawan et al., 2024). Several factors influence solar irradiance, include the position of the sun relative to the Earth, atmospheric concentration, and weather conditions. The height of the sun in the sky changes throughout the year due to the Earth's axial inclination. When the sun is directly above the equator, sunlight is more focused and provides more intense irradiation. Atmospheric conditions, such as clouds and pollution, can also affect the amount of solar radiation reaching the Earth's surface. Furthermore, there are several types of solar radiation based on their characteristics.

Fig. 3. Solar radiation and clearness

Solar radiation or solar irradiation is the process of energy emitted from the sun reaching the Earth's surface and is the primary parameter used to measure a region's solar energy potential. The amount of radiation received is usually expressed in units of power per area, namely, watts per square meter (W/m^2), which indicates the intensity of solar energy falling on a surface over a specific period. This irradiance value is an important basis for determining the feasibility and performance of a PLTS system, as it directly affects the amount of electrical energy that can be generated by solar panels. Furthermore, several key factors influence the amount of solar radiation, including the position of the sun relative to the Earth, atmospheric conditions, and weather variability such as cloud cover and rainfall. Changes in the sun's altitude throughout the year, caused by the tilt of the Earth's axis, also contribute to the intensity of radiation received at a location (Anggara et al., 2025). Therefore, understanding these factors is crucial in analyzing solar energy potential, as it will determine the energy availability pattern and the PLTS system's operational effectiveness over a specific period.

3.2 Design or planning of a household-scale rooftop solar power system

Several challenges were encountered in designing the rooftop PV system because a considerable number of roofs did not satisfy the technical requirements for PV installation due to limited effective roof area, non-optimal roof orientation and tilt, partial shading caused by surrounding trees and adjacent buildings, and structural differences that constrained module installation. Therefore, the PV system was customized for each building by optimizing the module layout, adjusting the installed capacity according to the effective roof area and household electricity demand, and selecting an appropriate system configuration to maximize energy production while ensuring installation safety and system reliability.

The design of a residential-scale rooftop *Pembangkit Listrik Tenaga Surya* (PLTS) system uses several main components, namely a solar charge controller, a power inverter, and a miniature circuit breaker (MCB) as an installation safety system. The functions of thesolar charge controller to regulate the charging process of electrical energy from the solar panels to the battery to ensure that it remains stable and does not experience overcharging or overdischarging (Adesina et al., 2023). This device is also equipped with a digital display that displays information on voltage, current, and system operating conditions, making it easier to monitor the PLTS's performance (Mehang et al., 2017).

The electrical energy stored in the battery is then converted from direct current (DC) to alternating current (AC) through a 1000 W inverter. This inverter plays an important role because most household electrical appliances use AC current with a standard voltage of around 220 V. The electrical energy generated by the solar panels can be used directly to meet household electricity needs such as lighting, charging electronic devices, and low-to-medium-power household appliances (Mehang et al., 2016).

This system is also equipped with an MCB, which functions as a protective device to protect the electrical installation from excess current or short circuits. The MCB is installed on the electrical distribution line between the inverter and the load so that the power supply can be automatically cut off if a system failure occurs. The use of this safety system is crucial for maintaining the safety of the solar power plant installation while also improving the system's long-term reliability.

(a) (b) (c)
(d) (e) (f)

Fig. 4. (a) 300 wp panel, (b) control panel installation (solar charger controller, MCB, Inverter), (c), (d), (e) Solar Panel Installation, Control Panel with Battery, (f) 223,7 Volt output result

Overall, the design of a residential-scale rooftop solar system(Figure 4), demonstrates a simple yet effective installation configuration for generating and managing electricity from renewable energy sources. The integration of solar panels, a charge controller, a battery, an inverter, and a safety system allow the system to operate optimally in providing alternative electricity for household needs. With a relatively simple and easy-to-implement design, this system has great potential to support independent solar energy utilization while reducing dependence on conventional grid electricity. Planning, design, and testing are the three important stages in research (Alatas, Arifin, et al., 2025), along with joint installation involving the community.

3.3 The process of building and implementing rooftop solar power plants

In the installation process of a residential rooftop solar system, the use of large, 6 mm black NYAF cables plays a crucial role as a medium for conducting electrical current from the solar panels to other system components, such as the solar charge controller, battery, and inverter. This cable was chosen because it has a sufficiently large current-carrying capacity and a good level of flexibility, thus facilitating the installation process in the solar power system circuit (Hasanah & Febryan, 2021). The larger cable cross-sectional size also aims to minimize power losses due to electrical resistance in the conductors, so that the electrical energy generated by the solar panels can be distributed more efficiently. By using cables that meet current capacity standards, the solar power installation system becomes safer, more stable, and able to support optimal system performance in distributing electrical energy to household loads, as shown in the image below.

Fig. 5. Federal 6mm black large NYAF cable

During the installation and assembly phase of a residential rooftop solar system, all components are integrated to ensure that the system functions properly and safely. The assembly process includes the connection of the inverter, solar charge controller, and safety components such as MCBs installed on the distribution panel. Each connecting cable is installed according to the planned installation path, considering the polarity of the electricity and the capacity of the cable conductors used. Furthermore, testing is performed using a multimeter to ensure that the voltage and current in each circuit are at the appropriate condition before the system is operated. This stage is crucial to ensure that all components are properly installed, stably connected, and capable of supporting the solar system's performance in generating and distributing electrical energy optimally for household needs, as shown in the Figure 6.

In the solar power system circuit, the inverter is connected to an energy storage source, a battery, via a DC transmission transmission cable. The battery stores the electrical energy generated by the solar panels, allowing it to be used in the absence of sunlight, such as at night or during cloudy weather (Mehang et al., 2017). The solar panels are connected to a solar charge controller to regulate the battery charging process. The power is then channeled from the battery to the inverter, which converts the DC current to alternating current (AC). The inverter's output is then channeled to an MCB, a safety device, before the electrical energy is distributed to household loads. This circuit demonstrates that each component in the solar power system is interconnected and works in an integrated manner to ensure that electrical energy conversion, storage, and distribution can take place safely (Ansori et al., 2023; Tarigan, 2018; Triana et al., 2024; Widodo et al., 2020).

Fig. 6. installation and assembly of materials

A 300 Wp (Watt-peak) solar panel is a medium-power solar energy generating module widely used in small-scale PLTS systems up to households. This panel converts solar radiation energy into electrical energy in the form of DC through the PV process. With this power capacity, a 300 Wp solar panel can produce enough electrical energy to support various independent (off-grid) applications, such as home lighting systems, public street lighting (PJU), charging 12V or 24V batteries, and operating low-power household electronic devices. In a rooftop solar power system, the solar panel is the main component that determines the amount of electrical energy that can be generated. Therefore, the performance and efficiency of the solar power generation system as a whole are greatly influenced by choosing the appropriate panel capacity.


Fig. 7. Solar cell 300wp

The image of a 300 Wp solar cell shows one of the main components of a rooftop PLTS that converts solar radiation energy into electrical energy in the form of direct current DC. These 300 Wp solar panels can produce a maximum power of up to 300 watts under optimal solar radiation conditions. In a household-scale PLTS system, the solar panel is the main source of energy which is then channeled to the solar charge controller to regulate the battery charging process. The produced electrical energy is then stored in the battery before being converted into alternating current (AC) by the inverter, which can be used to meet the electricity needs of household appliances. With a power capacity large enough for a household scale, a 300 Wp solar panel can support the PLTS system in producing electrical energy independently, efficiently, and environmentally friendly. A 300 Wp solar panel can theoretically generate approximately 1.2 kWh/day (E = 0.3 x 4.8 x 0.8) of electrical energy under the average solar irradiation conditions observed at the study site. This estimate is based on the average Global Horizontal Irradiance (GHI) of 4.8 kWh/m^2/day, which corresponds to approximately 4.8 peak sun hours per day and a performance ratio (PR) of 80%. Based on this daily energy production, the system is expected to generate approximately 438 kWh/year. Assuming a service life of 25 years, the cumulative energy production could reach approximately 10,950 kWh over the system's lifetime. This energy output is sufficient to meet basic household electricity needs. Ani reported a daily household load of approximately 0.93 kWh/day, which was used to power a television, fan, electric bulbs, and security lighting (Ani, 2015). Therefore, the proposed 300 Wp rooftop PV system's estimated energy production exceeds the daily energy demand reported in the previous study, indicating its feasibility for small-scale residential applications.

The output voltage was measured using a digital multimeter based on the system test results after the installation of the solar panels and all components of the solar power plant. The measurement results showed that the output voltage from the inverter reached approximately 223.7 volts AC, which is close to the standard household voltage of approximately 220 volts AC (Syahputra et al., 2015). This voltage value indicates that the designed and installed solar power plant system is capable of properly converting DC electrical energy generated and stored in the battery into AC through the inverter. Thus, the electrical energy generated by the solar power plant system can be used to meet the needs of household electrical appliances that require AC voltage. These measurement results also indicate that the installation circuit, cable connections, and inverter performance work optimally in distributing electrical energy from the solar power plant system.

Fig. 8. Results of 223.7-volt AC voltage

3.4 *Economic feasibility and cost aspects of installing rooftop solar power plants on a household scale*

From an economic perspective, the potential for developing rooftop PLTS shows promising prospects along with the increasing use of renewable energy globally (Hasanah & Febryan, 2021). Although the initial cost of installing a rooftop PV system is relatively high, this investment has significant potential to provide long-term economic benefits to the community, particularly through reduced monthly electricity costs. Using solar energy allows households to generate electricity independently, thereby reducing dependence on conventional grids (Samsurizal et al., 2020). This makes rooftop PV systems an alternative energy solution that is not only environmentally friendly but also has long-term economic value.

Furthermore, various projections from international energy agencies indicate that solar energy development will continue to experience significant growth in the future. This is supported by growing public awareness of the importance of clean energy use and government policies encouraging renewable energy development (Windarta et al., 2022). With increased understanding of the economic benefits of rooftop solar power plants, opportunities for their development in residential areas are expected to continue to grow. However, challenges related to the high initial investment costs remain a barrier for some communities. The impact of policies on the economic benefits and return on investment of rooftop solar power plants in the household and social sectors is reflected in the sharply varying profiles of Net Present Value, Internal Rate of Return, payback period, and Levelized Cost of Energy. This approach aligns with energy economics practices, which consider cash flows over the life of a project as the feasibility benchmark, rather than solely the initial investment cost incurred by customers.

Table 4. Costs of installing a solar power system

No	Component	Amount	Unit	Unit Price	Subtotal Price
1	300wp solar cell	1	Unit	1,350,000.00	1,350,000.00
2	Dry battery 12v/100ah	1	Unit	1,100,000.00	1,100,000.00
3	Taffware inverter 1000 watt/12v psw	1	Unit	575,000.00	575,000.00
4	Solar charger controller 3oa/12v	1	Unit	75,000.00	75,000.00
5	Red 10mm Nyaf cable	2	Meter	37,500.00	75,000.00
6	Skun sc25-8 grade a [jm25-8]	2	Pcs	3,000.00	6,000.00
7	Federal 6mm black large	8	Meter	17,000.00	136,000.00
8	National black isolation	1	Buah	8,000.00	8,000.00
9	Yans concrete cable clamps	1	Pcs	10,000.00	10,000.00
10	Mcb dc 2 pin 25 amperes	2	Pcs	72,000.00	144,000.00
11	Mcb dc 2 pin 63 amperes	1	Pcs	72,000.00	72,000.00
12	Cable ties	1	Pcs	10,000.00	10,000.00
13	Small boltbolts nutnuts	10	Pcs	300.00	3,000.00
14	10 mm jembo cable	2	Meter	33,000.00	66,000.00
15	Mc4 solar panel connector	1	Pcs	8,000.00	8,000.00
16	Bolt Tav panel box/solar panel	1	Buah	1,500.00	1,500.00
17	component panel boxboxes 30x40x15	1	Pcs	220,000.00	220,000.00
Total Expenditure on Solar Power Plants					3,859,500.00

Calculation of the installation costs for a residential-scale rooftop solar system, the total investment required to build the system is IDR 3,859,500.00. This cost includes the procurement of various key components, such as a 300 Wp solar panel, a 12 V/100 Ah dry-cell battery, a 1000 watt/12 V inverter, and a 0 A/12 V solar charge controller to regulate the charging process from the solar panel to the battery. These key components are the core of the solar system, and they play a role in converting solar energy into usable electrical energy to meet household electricity needs.

In addition to these main components, the installation cost includes several supporting components, such as electrical cables of various sizes and solar panel connectors (MC4), DC MCBs for safety, a panel box for component placement, and various installations equipment such as insulation, cable clamps, nuts, bolts, and cable ties. These supporting components ensure that the solar system is properly installed, safe, and capable of optimal long-term operation. With a relatively affordable total investment cost, this household-scale rooftop solar power system shows good potential for implementation as an alternative source of environmentally friendly and sustainable electrical energy.

Table 5. Economic assumptions

No	Parameter	Formula / Assumption	Value
1	PV System Type	-	Off-grid rooftop PV
2	Installed Capacity	-	300 Wp
3	Initial Investment Cost	-	IDR 3,859,500
4	PV Module Lifetime	-	25 years
5	Battery Lifetime	-	5 years
6	Annual Energy Production	1.2 x 365	438 kWh/year
7	Electricity tariff (off-grid equivalent)		Electricity tariff (off-grid equivalent)
8	Annual economic benefit	438 x 1,445	IDR 632,910 / year
9	O&M cost	1% x 3,859,500	IDR 38,595 / year
10	Net annual cash flow	Benefit – O&M	IDR 594,315 / year
11	Battery replacement cost (Assumed to be 30% of the initial investment as a conservative estimate based on the typical 5–10 year lifespan of batteries in off-grid PV systems)	30% x 3,859,500	IDR 1,157,850
12	Battery replacement schedule	Year 5, 10, 15, 20	4 times
13	Total battery replacement cost	4 x 1,157,850	IDR 4,631,400
14	Discount rate	-	8%
15	Payback period	3,859,500 / 594,315	~ 6.5 years (~ 8-9 years include battery)
16	Present Worth Factor (P/A, 8%, 25)	-	10.675
17	PV of benefits	594,315 x 10.675	IDR 6,344,313
18	PV of Battery Replacement	787,900 + 536,,500 + 365,000 + 248,400	1,937,800
19	NPV	PV benefit – initial investment cost – PV battery	IDR 547,013
20	IRR	Iterative calculation	~ 9.5%
21	Lifecycle cost	Initial investment + Total battery replacement cost + O&M of 25 years	IDR 9,455,775
22	LCOE	Lifecycle cost / energy	IDR 864 / kWh

Based on the economic feasibility analysis, a 300 Wp off-grid PV system with an initial investment cost of IDR 3,859,500 generates approximately 438 kWh of electricity per year. With a solar panel lifetime of 25 years and battery replacement every 5 years, the system yields a Net Present Value (NPV) of IDR 547,013. The positive NPV indicates that the project is economically feasible and financially viable for implementation . An Internal Rate of Return (IRR) of approximately 9.5%, a payback period of around 8 years, and a Levelized Cost of Energy (LCOE) of IDR 864/kWh. The IRR value, which is higher than the 8% discount rate, together with the positive NPV, indicates that the off-grid PV system is economically feasible and can be implemented as a viable solution for providing independent electricity supply at the household scale in off-grid applications.

An additional economic analysis indicates that the existing micro-hydropower community collects a monthly electricity tariff of IDR 12,000 from 53 households, generating IDR 636,000 per month (approximately IDR 7,632,000 per year). In the proposed hybrid system, the 300 Wp rooftop PV does not replace household electricity supply but provides additional energy to support crystal ice production; therefore, an increase in electricity tariffs primarily strengthen the community's financial capacity for operation and maintenance, and future component replacement rather than increasing PV energy generation. Variations in the discount rate influence economic indicators, where higher discount rates reduce the present net net value (NPV) and lengthen the payback period, while lower discount rates improve project profitability. Nevertheless, the PV capacity is relatively small, and a significant portion of the economic benefits is d erived from enhanced crystal ice production, reasonable changes in the discount rate do not alter the overall investment feasibility, provided that the NPV remains positive and IRR exceeds the discount rate. Likewise, reduced PV electricity generation due to lower solar irradiation only decreases the PV contribution to productive activities, while the micro-hydropower plant continues to provide a stable and continuous electricity supply. The proposed micro-hydropower–PV hybrid system demonstrates good economic and operational resilience, with improved financial sustainability, stable investment feasibility under varying economic assumptions, and reliable energy supply despite seasonal fluctuations in solar resources.

3.5 Community-based sustainable development

In 2020, Purwoharjo Village in Kulon Progo initiated its plan to become an energy-independent village, with Kedungrong Hamlet as the central area, and simultaneously established the KMTI Kedungrong, which focuses on micro-hydro power generation. However, several limitations were identified over time, including the inability of the micro-hydro system to generate electricity for 1–2 months during irrigation water shortages, as well as operational disruptions caused by sediment and waste blockage in the irrigation channels that require periodic turbine maintenance and temporary shutdowns. In response to these challenges in 2025, the renewable energy community initiated the development of rooftop solar PV systems in 2025 as a complementary solution to support energy reliability, particularly during micro-hydro maintenance periods, and to meet additional electricity demand for activities such as ice cube production. A pilot rooftop PV system was implemented in one household, with plans for future expansion to 53 households within the Kedungrong community.

Fig. 9. (a) Handover of the rooftop solar power plant installation system to the community, (b) solar power plant installation training, (c) Connection practice, (d), (e) FGD and delivery of materials, (f) trial of solar power plant-based electric stoves.

The implementation of the rooftop PV system originated from problems identified by the community itself, particularly electricity outages associated with the existing micro-hydropower system, both during routine maintenance activities and when waste blockage disrupted turbine operation. The community also actively participated in discussions and decision-making processes to determine development priorities and reach a consensus on implementing a rooftop PV pilot project. During the program planning stage, community members were involved alongside relevant stakeholders in developing and agreeing upon the adoption of rooftop PV as an alternative energy source. All mentoring activities, training sessions, and rooftop PV installation processes were delivered and communicated through FGDs ensuring active community participation throughout the project implementation process.

Figure 9 shows a series of community-based sustainable development activities carried out through a participatory and educational approach in the implementation of a rooftop PLTS system. The activity began with the handover of the PLTS installation system to the community as a form of technology transfer and local empowerment. This was followed by installation training to enhance the community's technical capacity to understand and independently manage solar energy systems. Furthermore, hands-on connection practice was conducted to provide practical experience, ensuring participants not only understood the theory but also were able to operate the system in practice. Furthermore, FGDs and material presentations were conducted to strengthen conceptual understanding of renewable energy, energy management, and the economic and environmental benefits of PLTS use. These discussions also served as a means to explore the aspirations, needs, and challenges faced by the community in implementing this technology. As a final step, a trial of a PLTS based electric stove was conducted, demonstrating the direct use of solar energy in everyday life. This series of activities reflects an integrative effort to promote community energy independence while supporting sustainable development at the local level.

4. Conclusions

The multi-stakeholder approach resulted in several collaborative initiatives, including community participation and support in the installation of rooftop PV systems, as well asbtechnical assistance and program development support provided by Universitas Gadjah Mada (UGM) and the Institut Teknologi Yogyakarta (ITY). Based on the results of research on the design and installation of rooftop PLTS systems on a household scale, the use of solar energy has considerable potential as an environmentally friendly and sustainable alternative energy source. Analysis of solar energy potential shows that the available solar radiation is relatively stable throughout the year with daily radiation values sufficient to support solar power generation systems. These conditions indicate that the application of rooftop PLTS in households is very possible to be developed as a solution to meet electrical energy needs while reducing dependence on conventional energy sources. The results of the PLTS system design in this study use solar panels with a capacity of 300 Wp combined with other main components, such as a solar charge controller, a 12V/100Ah battery, a 1000-watt inverter, and a safety device in the form of an MCB. All components are assembled in an integrated manner so that they are able to convert solar energy into electrical energy that can be used to meet household needs. Based on the testing results using a multimeter, the installed PLTS system is able to produce an output voltage of approximately 223.7 volts AC, which is close to the standard household voltage of 220 volts AC. This demonstrates that the designed system performs well and supports the use of electrical appliances in households. From an economic perspective, the total investment cost for installing the solar PV system in this study was IDR 3,859,500, which includes the procurement of solar panels, batteries, inverters, solar charge controllers, installation cables, and various other supporting components. This study is limited limited by the pilot project implementation in only one household among the 53 households, although the ABGCFIT approach has demonstrated sustainable management performance over the 2017–2026 period. Further research is required to conduct a more in-depth analysis of the economy. aspects of the use of rooftop PV systems in households. The study could focus on comparing monthly electricity costs before and after installation to determine the level of savings achieved. Furthermore, future research could measure the volume of household electricity consumption per month and analyze the contribution of PV-generated electricity system to the electricity demand previously supplied by the PLN grid. This analysis will provide a more comprehensive understanding of the economic benefits and energy efficiency of rooftop PV systems and serve as a basis for developing renewable energy in the household sector.

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Author Contribution

M.A., conceptualization, data curation, formal analysis, methodology, project administration, resources, software, supervision, validation, visualization, writing-original draft, writing-review and editing, A.M., conceptualization, data curation, formal analysis, methodology, project administration, resources, software, supervision, validation, visualization, writing-original draft, writing-review and editing, A.F., conceptualization, formal analysis, methodology, supervision, validation, visualization, writing-review and editing, solar panel system, solar panel roof top, E.H.M., conceptualization, formal analysis, methodology, supervision, validation, visualization, writing-review and editing, F.Z., conceptualization, formal analysis, methodology, supervision, validation, visualization, writing-review and editing, economic analysis, digital marketing and community empowerment, A, conceptualization, formal analysis, methodology, supervision, validation, visualization, writing-review and editing.

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Ethical Review Board Statement

Not available.

Informed Consent Statement

Not available. This study does not involve human subjects; the community is only considered as the beneficiary of the proposed system.

Data Availability Statement

We encourage all authors of articles published in this journal to share their research data. This section provides details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. A statement is still required when no new data is created or unavailable due to privacy or ethical restrictions.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Generative AI Use

During the preparation of this work, the authors used ChatGPT to assist in generating ideas, improving language quality, and translating the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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References

Abdullah, Putri, M., Syahruddin, M., Sitorus, N., Jumaat, A. K., Ridzuan, A. R., Cholish, Rumahorbo, P. R., Noer, Z., Masthura, & Karim, M. A. (2024). Optimization of Solar Power Plant with Variation of Solar Reflector Angles and Use of Passive Cooling Integrated Internet of Things. *Journal of Advanced Research in Fluid Mechanics and Therma ciences*, *124*(1), 233–248. https://doi.org/doi.org/10.37934/arfmts.124.1.233248

Adesina, L. M., Ogunbiyi, O., & Makinde, K. (2023). Design, implementation and performance analysis of an off-grid solar powered system for a Nigerian household. *MethodsX*, *10*, 102247. https://doi.org/10.1016/j.mex.2023.102247

Aditama, R. P., Febrian, D. D., Lestari, L. R. I., Mukaromah, S., Duri, R. D., & Rachmanita, R. E. (2023). Penerapan Bank Energi Surya sebagai Sumber Energi Mandiri untuk Penerangan Masyarakat di Dusun Batu Ampar Desa Mulyorejo. *Journal of Community Development*, *3*(3), 347–358. https://doi.org/10.47134/comdev.v3i3.124

Al Hakim, R. R. (2020). Model energi Indonesia, tinjauan potensi energi terbarukan untuk ketahanan energi di Indonesia: Sebuah ulasan. *ANDASIH Jurnal Pengabdian Kepada Masyarakat*, *1*(1). https://doi.org/10.57084/andasih.v1i1.374

Al Hakim, R. R., Ariyanto, E., & Arief, Y. Z. (2021). Techno-Economic Study of Substation Electric Power in Indonesia: A Mini-Review. *ARRUS Jpurnal of Engineering and Technology*, *1*(1). https://doi.org/10.35877/jetech540

Alatas, M., Arifin, M. S., Ridlo, D. T., & Ika, U. F. S. (2025). *Design of Fruit Fly Trap ApelB Using a Microcontroller and Sensor System Powered by Solar Photovoltaic*. *14*(6), 2194–2205. http://dx.doi.org/10.23960/jtepl.v14i6.2194-2205

Alatas, M., Budiastuti, M. T. S., Gunawan, T., & Setyono, P. (2022). Spiral Cycle Micro-Hydro Community System Model for Sustainable Development in Yogyakarta, Indonesia. *Journal of Sustainability Science and Management*, *17*(9), 44–61. https://doi.org/10.46754/jssm.2022.09.004

Alatas, M., Styana, U. I. F., Ridlo, D. T., Hindarti, F., & Kurniawan, A. (2025). Prototype Listrik Tenaga Pikohidro (PPT 1.0) untuk Alat Bantu Identifikasi Potensi dan Praktikum Mahasiswa Energi. *Jurnal Engine: Energi, Manufaktur, Dan Material*, *9*(2), 226–236. https://doi.org/10.30588/jeemm.v9i2.2422

Anggara, G. R., & Wardana, A. Y. (2025). Development of Rooftop Solar Power Plant (PLTS) on Parking Areas for EV Charging Station at Sumsel-8 Mine Mouth Power Plant. *REM (Rekayasa Energi Manufaktur) Jurnal*, *10*(1), 63-70. https://doi.org/10.21070/r.e.m.v10i1.1755

Ani, V. A. (2015). Feasibility analysis and simulation of a stand-alone photovoltaic energy system for electricity generation and environmental sustainability–equivalent to 650VA fuel-powered generator–popularly known as "I pass my neighbour". *Frontiers in Energy Research*, *3*, 38. https://doi.org/10.3389/fenrg.2015.00038

Ansori, A., Arsana, I. M., Siregar, I. H., Adiwibowo, P. H., & Haryuda, S. I. (2023). Techno-Economic Analysis Of Triangular Rooftop Solar Pv Model/Pln On-Grid Household Scale in Indonesia. *ASEAN Engineering Journal*, *13*(4). https://doi.org/10.11113/aej.V13.19858

Budiono, M. F., & Susetiawan. (2023). Pengelolaan Sumber Daya Berbasis Komunitas : Potret Penyediaan Listrik Berbasis Masyarakat di Desa Andung Biru, Kabupaten Probolinggo. *Journal of Social Development Studies*, *4*(2), 142–157. https://doi.org/10.22146/jsds.9334

Cardenas, L., Zapata, M., Franco, C. J., & Dyner, I. (2017). Assessing the combined effect of the diffusion of solar rooftop generation, energy conservation and efficient appliances in households. *Journal of cleaner production*, *162*, 491-503. https://doi.org/10.1016/j.jclepro.2017.06.068

Carmen, M., Moldovan, R., Corsiuc, G., & Chisalita, G. (2023). Improving the Energy Performance of a Household Using Solar Energy: A Case Study. *Energies*, *16*(6423). https://doi.org/10.3390/en16186423

Coronas, S., Hoz, J. de la, Alonso, À., & Martin, H. (2022). 23 Years of Development of the Solar Power Generation Sector in Spain: A Comprehensive Review of the Period 1998 – 2020 from a Regulatory Perspective. *Energies*, *15*(1593). https://doi.org/10.3390/en15041593

Darmawan, A., Nyoto, E., Setyo, D., & Raharjanto, Y. (2024). Analisis Keekonomian Pembangunan Pembangkit Listrik Tenaga Surya (PLTS) Atap pada Stasiun Yogyakarta. *AL-MIKRAJ Jurnal Studi Islam dan Humaniora*, *4*(02), 679-708. https://doi.org/10.37680/almikraj.v4i02.4867

Duma, S., Ambabunga, Y., Pawarangan, I., & Idris, L. M. J. (2025). Pemetaan Potensi Pembangkit Listrik Tenaga Surya Rooftop pada Atap Gedung Perkantoran di Kabupaten Toraja Utara. *Jurnal FisTa Fisika dan Terapannya*, *6*(1), 50-59. https://doi.org/10.67006/fista.v6i1.464

Fares, R. L., & Webber, M. E. (2017). The impacts of storing solar energy in the home to reduce reliance on the utility. *Nature Energy*, *2*(2), 17001. https://doi.org/10.1038/nenergy.2017.1

Fauzi, H. M. (2025). *Partisipasi Masyarakat dalam Mewujudkan Mandiri Energi di Desa Gunung Lurah Kecamatan Cilongok Kabupaten Banyumas.* UIN Profesor Kiai Haji Saifuddin Zuhri Purwokerto.

Hasanah, A. W., & Febryan, R. (2021). Perancangan Sistem Pembangkit Listrik Tenaga Surya Off Grid 6, 4 KWp Untuk 1 Unit Rumah Tinggal. *Energi & Kelistrikan*, *13*(1), 20-25. https://doi.org/10.33322/energi.v13i1.965

Hussein, H. M. S., Ahmad, G. E., & Mohamad, M. A. (2000). Optimization of operational and design parameters of plane reflector-tilted flat plate solar collector systems. *Energy*, *25*(6). https://doi.org/10.1016/S0360-5442(00)00003-7

Iakovleva, E., Guerra, D., Tcvetkov, P., & Shklyarskiy, Y. (2022). Technical and economic analysis of modernization of solar power plant: A case study from the Republic of Cuba. *Sustainability*, *14*(2), 822. https://doi.org/10.3390/su14020822

IESR. (2017). *ENERGI TERBARUKAN: Energi untuk Kini dan Nanti*. Institute for Essential Services Reform. http://www.iesr.or.id/wp-content/uploads/2018/11/COMS-PUB-0001_Briefing-Paper-1_Energi-Terbarukan.pdf

Inayah, I., Hayati, N., Nurcholis, A., Dimyati, A., & Prasetia, M. G. (2022). Realtime monitoring system of solar panel performance based on internet of things using blynk application. *ELINVO (Electronics, Informatics, and Vocational Education)*, *7*(2), 135-143. https://doi.org/10.21831/elinvo.v7i2.53365

Kementerian Energi dan Sumber Daya Mineral. (2010). *Warga Batanguru Berlimpah Energi karena PLTMH*. Kementerian Energi dan Sumber Daya Mineral.

Kementerian Energi dan Sumber Daya Mineral. (2017). *Geliat Pemuda Bangsa Terangi Desa dari PLTMH*. Kementerian Energi dan Sumber Daya Mineral.

Kim, M. K., Abdulkadir, K. O., Liu, J., Choi, J. H., & Wen, H. (2021). Optimal design strategy of a solar reflector combining photovoltaic panels to improve electricity output: A case study in Calgary, Canada. *Sustainability*, *13*(11), 6115. https://doi.org/10.3390/su13116115

Mehang, T. S., Santoso, M., & Tanoto, Y. (2017). Studi perencanaan pembangkit listrik tenaga surya (PLTS) Di kecamatan Ngadu Ngala, Kabupaten sumba Timur, NTT. *Jurnal Teknik Elektro*, *10*(1), 1-10. https://doi.org/10.9744/jte.10.1.1-10

Mehang, T. S., Tanoto, Y., & Santoso, M. (2016). Potential of small size hybrid diesel-photovoltaic to improve sub-district supply duration in East Sumba, Indonesia. *International Journal of Renewable Energy Research*, *6*(3), 964-969. https://doi.org/10.20508/ijrer.v6i3.4008.g6878

Pastor, R., Tobarra, L., Robles-Gómez, A., Cano, J., Hammad, B., Al-Zoubi, A., ... & Castro, M. (2020). Renewable energy remote online laboratories in Jordan universities: Tools for training students in Jordan. *Renewable Energy*, *149*, 749-759. https://doi.org/10.1016/j.renene.2019.12.100

Pijoh, F., Kusuma, B. D. P., & Purba, L. P. (2024). Pembangkit listrik tenaga surya untuk energi ramah lingkungan yang berkelanjutan. *Industrial & System Engineering Journals (ISEJOU)*, *2*(2), 197-202. https://doi.org/10.37477/isejou.v2i2.631

Poullikkas, A. (2009). Economic analysis of power generation from parabolic trough solar thermal plants for the Mediterranean region — A case study for the island of Cyprus. *Renewable and Sustainable Energy Reviews*, *13*, 2474–2484. https://doi.org/10.1016/j.rser.2009.03.014

Pravalie, R., Patriche, C., & Bandoc, G. (2019). Spatial assessment of solar energy potential at global scale. A geographical approach. *Journal of Cleaner Production*, *209*, 692–721. https://doi.org/10.1016/j.jclepro.2018.10.239

Purwanto, I. (2020). Solar cell (Photovoltaic/PV) solusi menuju pulau mandiri listrik. *Jurnal Penelitian dan Karya Ilmiah Lembaga Penelitian Universitas Trisakti*, *5*(2), 117-126. https://doi.org/10.25105/pdk.v5i2.7410

Putri, R., Asri, A., Rosdiana, R., Nasution, F. A., & Trinanda, W. P. (2023). Design and Implementation of a Solar Power System on Grid SDN 023905 BIN JAI using PVSYST Software. *Majlesi Journal of Electrical Engineering*, *17*(3), 181–189. https://doi.org/10.30486/mjee.2023.1989935.1167

Rachmawati, M., & Hoesein, Z. A. (2025). Strategi Optimalisasi Peran BUM Desa sebagai Subjek Hukum dalam Pengelolaan Energi Bersih untuk Pembangunan Berkelanjutan. *Jurnal Retentum*, *5*(1), 238-256. http://dx.doi.org/10.46930/retentum.v7i1.5286

Ramadhani, S. E. P., Ningsih, H. S. R., Rachmanita, R. E., Fuadi, M. N. W., Isnaini, E. N., Wiguna, A. A., & Wulandari, F. (2023). Insect Trap Light Berbasis Android dengan Teknologi Solar Cell sebagai Solusi Pengendalian Hama Serangga Pertanian. *Journal of Engineering Science and Technology*, *1*(2), 76-85. https://doi.org/10.47134/jesty.v1i2.8

Ronyastra, I. M., Saw, L. H., & Low, F. S. (2024). Energy for Sustainable Development Techno-economic analysis with financial risk identification for solar power plant as post-mining land use in Indonesia. *Energy for Sustainable Development*, *80*. https://doi.org/10.1016/j.esd.2024.101462

Sakti, A. D., Ihsan, K. T. N., Anggraini, T. S., Shabrina, Z., Sasongko, N. A., Fachrizal, R., Aziz, M., Aryal, J., Yuliarto, B., Hadi, P. O., & Wikantika, K. (2022). Multi-Criteria Assessment for City-Wide Rooftop Solar PV Deployment : A Case Study of Bandung, Indonesia. *Remote Sensing*, *14*(2796). https://doi.org/10.3390/rs14122796

Sallata, M. K., SHN, H. Y., & Wakka, A. (2015). Pemanfaatan mikrohidro untuk membangun desa mandiri energi. *Jurnal Penelitian Kehutanan Wallacea*, *4*(1), 71-80. https://doi.org/10.18330/jwallacea.2015.vol4iss1pp71-80

Samsurizal., Husada, H., Makkulau, A., & Christiono. (2020). Perencanaan Pembangkit Listrik Tenaga Surya (PLTS) Terpusat Di Kecamatan Embaloh Hulu. *EPSILON: Journal of Electrical Engineering and Information Technology*, *18*(2), 41-49. https://epsilon.unjani.ac.id/epsilon/article/view/20

Shahinzadeh, H., Gharehpetian, G. B., Fathi, S. H., & Nasr-Azadani, S. M. (2015). Optimal Planning of an Off-grid Electricity Generation with Renewable Energy Resources using the HOMER Software. *International Journal of Power Electronics and Drive Systems*, *6*(1), 137. http://doi.org/10.11591/ijpeds.v6.i1.pp137-147

Sharma, S., & Sengar, N. (2022). Review of solar PV training manuals and development of survey based solar PV system training formats for beginners. *Solar Energy*, *241*(January), 72–84. https://doi.org/10.1016/j.solener.2022.05.055

Siudek, A., Klepacka, A. M., Florkowski, W. J., & Gradziuk, P. (2020). Renewable Energy Utilization in Rural Residential Housing: Economic and Environmental Facets. *Energies*, *13*(6637). https://doi.org/10.3390/en13246637

Supu, I., Ahmadi, H., & Latief, M. F. (2023). Application of Solar Energy Bank as a Energy Source for Fisherman Community. *Jurnal Pemberdayaan Masyarakat Madani*, *7*(2). https://doi.org/doi.org/10.21009/JPMM.007.2.02

Suriadi, & Syukri, M. (2010). Perencanaan Pembangkit Listrik Tenaga Surya (PLTS) Terpadu Menggunakan Software PVSYST Pada Komplek Perumahan di Banda Aceh. *Jurnal Rekayasa Elektrika*, *9*(2). https://doi.org/10.17529/jre.v9i2.167

Syahputra, S., & Dalimunthe, M. E. (2025, October). DC to AC Inverter Prototype Design for Household Electronic Equipment Applications. In *Proceedings of International Conference on Islamic Community Studies* (pp. 1122-1128). https://proceeding.pancabudi.ac.id/index.php/ICIE/article/view/675

Tarigan, E. (2018). Simulation and feasibility studies of rooftop PV system for university campus buildings in Surabaya, Indonesia. *International Journal of Renewable Energy Research*, *8*(2), 895-908. https://ijrer.com/index.php/ijrer/article/view/7547

Triana, D., Garniwa, I., Rosadi, A. H. Y., & Martono, D. N. (2024). Performance Analysis Simulation of Urban Rooftop Photovoltaic Potential in Jakarta City, Indonesia. *Environmental Research, Engineering and Management*, *80*(4). https://doi.org/10.5755/j01.erem.80.4.34200

Tsiaras, E., Papadopoulos, D. N., Antonopoulos, C. N., Papadakis, V. G., & Coutelieris, F. A. (2020). Planning and assessment of an off-grid power supply system for small settlements. *Renewable Energy*, *149*, 1271-1281. https://doi.org/10.1016/j.renene.2019.10.118

Widodo, D. A., Purwanto, P., & Hermawan, H. (2020). Potential of Solar Energy in Residential Rooftop Surface Area in Semarang City, Indonesia. *Advances in Science, Technology and Engineering Systems Journal*, *5*(4), 397–404. https://dx.doi.org/10.25046/aj050446

Windarta, J., Denis, Firmansyah, A., Avinda, A. I., & Kusuma, I. A. (2022). Technical study of 1.2 KWP solar plant on Tanbihul Ghofilin Islamic Boarding School Banjarnegara. *IOP Conf. Series: Earth and Environmental Science*. https://doi.org/10.1088/1755-1315/969/1/012031

Wittenberg, I., & Matthies, E. (2016). Energy Research & Social Science Solar policy and practice in Germany: How do residential households with solar panels use electricity? *Energy Research & Social Science*, *21*, 199–211. https://doi.org/10.1016/j.erss.2016.07.008

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