



Socio-techno-economic assessment to design an appropriate renewable energy system for remote agricultural communities in developing countries

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ABSTRACT

Access to clean energy for communities living in remote areas where grid extension is considered unfeasible can be provided by off-grid electrification systems using renewable energy (RE). Especially in developing countries, ensuring the appropriateness of such systems is crucial because it will determine the system's sustainability despite its limited resources. This study demonstrates the design process of an appropriate system by assessing the potential of three RE sources: solar, wind, and biomass in an oil palm and rubber-tree plantation village in South Kalimantan Province, Indonesia. A social assessment is done to avoid sustainability issues of the previously introduced technology intervention by identifying correlations between residents' attributes and satisfaction levels on a selection of social values through multiple correspondence analysis (MCA) and nonparametric methods. The techno-economic assessment and sensitivity analysis uses local data processed with the Hybrid Optimization of Multiple Energy Resources (HOMER) software. Results identified the need for a more appropriate clean energy supply for cooking, the potential role of modern technology, and access to information and communication in income generation, among other needs and opportunities that can be linked with the energy system design. The technical assessment showed that a centralized solar power plant paired with a diesel engine could provide power to the village. However, the cost of electricity (COE) is much higher than the price cap introduced by the national electricity company. This study urges a clear mechanism and a guarantee for the delivery of feed-in-tariffs (FIT) and a price cap exemption for off-grid RE systems. Furthermore, a people-centered public-private partnership business model and a remote capacity-building intervention are also needed. An appropriate energy system design must be supported by an enabling environment and supporting policies to be feasible.

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1. Introduction

Access to electricity is known to support the improvement of the well-being of humankind (Mandelli et al., 2016) and is a crucial instrument to alleviate poverty (Kanagawa and Nakata, 2008). A recent study showed that villages with new access to electricity show a significant increase in the number of small-scale industries, suggesting that the potential of small-scale industries may become an intermediate mechanism where electricity has a positive effect on poverty alleviation (Wirawan and Gultom, 2021). However, populations living in remote rural areas, characterized by low literacy rates, poor access to health care, and clean water supply (Sahn and Stifel, 2004), are facing

challenges in obtaining access to modern energy (Pandyaswargo et al., 2020). The world has pledged to “leave no one behind” by the sustainable development goals (SDGs) (United Nations Statistics Division (UNStats), 2016). Goal number 7, representing the energy sector, stated that it is crucial to ensure that every individual has access to affordable and clean energy. Goal 7 is also central to other important nexuses, including decent work and economic growth (goal no. 8), industry, innovation, and infrastructure (goal no. 9), reduced inequalities (goal no. 10), and responsible production and consumption (goal no. 12) (United Nations (UN), 2016), and can provide access and delivery to basic needs such as clean water, food, and livelihoods. The COVID-19 pandemic has bolded the importance and urgency of the energy-healthcare nexus where without electricity to power refrigeration, the delivery of vaccines becomes extremely challenging (UNICEF, 2021; Seforall, 2021). However, attempts to provide energy to people living in such communities often face system sustainability issues. Common

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causes of challenges are inappropriate energy system design, technology gaps, operational challenges (Julius et al., 2014), financial unfeasibility (Bertheau et al., 2020; Chmiel and Bhattacharyya, 2015; Ahlborg and Hammar, 2014), poor communication between stakeholders (Bertheau et al., 2020), and cultural incompatibility (Urme and Md, 2016).

Techno-economic assessment for RE designs in the remote areas is widely practiced (Chambon et al., 2020; Ghasemi et al., 2013; Shahzad et al., 2017; Veilleux, 2020; Vendoti et al., 2021) because of its highly accessible methodologies to produce tangible outputs and its immediate use for investment's financial consideration. However, studies that suggest methodologies to perform social assessment for RE design purposes are limited (Come Zebra et al., 2021). The present study demonstrates the social, technology, and economic assessment to design an appropriate off-grid RE system and identifies key challenges to anticipate implementation and sustainability problems. The aim is achieved by (1) understanding the rural energy users' social needs through correlation assessment of their attributes, and perceived social value satisfaction levels, (2) assessing local renewable energy (RE) potentials to design a system that is technically and economically optimal for villages, and (3) conducting a sensitivity analysis of the designed system to anticipate price and resource fluctuations.

2. Literature Review

2.1. Appropriate RE System Design for Remote Communities in Developing Countries

Off-grid RE systems have become the mainstream solution to expand access to clean energy for communities living in remote areas. In recent years, the world has witnessed tremendous growth in RE systems mainly because technology prices have plummeted, while innovative adaptation and business models to sustain the system financially have peaked (IRENA, 2018). Lessons can be learned from case practices reporting the success of various innovative approaches that are sustainable for the community. Some examples are the renting and pay-as-you-go business model for solar lanterns in India (Singh, 2016) and the Philippines (Hong and Abe, 2013), the solar bread-making machine in India (Selco Foundation, 2017), and a solar mobile phone charging station business in Kenya (Louie et al., 2018). The common aspect that may be the factor of sustainability among these cases is the appropriateness of the design. Here, appropriateness refers to designs that respond to the needs of the people and make people the central focus when establishing the system. The solar bread-maker (Selco Foundation, 2017) example in particular is not only focused on income generation and cash flow but also allows mechanization of food production, resulting in improved efficiency, productivity, and saved time that can be used for other productive activities, especially among women.

2.2. Access to Finance v.s. Financial Independency

An appropriate design is necessary in developing countries where financial resources are limited (Gabriel et al., 2016). Access to financing the upfront cost, market development barriers, and financing replacement of technology replacement has been reported as common economic challenges of off-grid RE systems (Come Zebra et al., 2021). The high upfront cost of a centralized community-scale RE system is often not compatible with the economic power of the people living in remote areas, who are often categorized as the bottom billion (Scott, 2017). However, projects that are solely dependent on external funding from grants, international donors, and philanthropies are vulnerable to financial breakdowns when the project duration is completed (Hong et al., 2015). Logically, the more sustainable approach would be to focus on cash flow and income generation from the RE system. However, communities living in remote areas are often very isolated, and they face poor access to the market outside of the village so that cash flow only

circulates within the village community. Such situations pose a high risk of financial return, causing unattractiveness to private investment and bank loans (Come Zebra et al., 2021). This situation emphasizes more on the importance of an appropriate design to build confidence among investors.

2.3. Role of Policies and Regulations

The lack of clarity and transparency of policies regulating the implementation of off-grid RE systems have been identified by international reports as a main obstacle for integration (Manetsgruber et al., 2015; IRENA, 2017; Chessin et al., 2017). While there are countries where policies have shown effectiveness in accelerating the integration of off-grid RE systems appropriate to local conditions, such as India (Tenenbaum et al., 2018) and Tanzania (Energy Sector Management Assistance Program (ESMAP), 2017), the common situation in many developing countries is the absence or insufficiency of specific regulations that support such systems (Come Zebra et al., 2021). Prohibitive policies are also observable in some countries, such as inappropriate price caps (Asian Development Bank (ADB), 2020) and subsidies. Subsidies for the fossil based fuel for grid electricity supply have been practiced for a long time in many Southeast Asian countries (International Energy Agency (IEA), 2019), making RE less competitive in the region. While governments may act in the interest of service to the public by enforcing price caps and subsidies for fossil fuel, the exorbitant cost of grid extension to remote areas has prevented the private sector from offering supports when the off-grid RE systems are necessary. Quite recently, Vietnam has pioneered a policy reform and has shown a tremendous growth of solar and wind share in the electricity mix between year 2018 and 2020 much faster than that achieved in the broader Asia-Pacific region and the world (Do et al., 2021). Some of the policies deemed to have contributed to the success are: 1) generous feed-in tariffs, 2) income tax and land lease payment exemptions, 3) political and social support, 4) a supportive investment environment, and 5) fossil fuel subsidy reform (Do et al., 2021).

3. Methods

This study analyses an off-grid oil palm plantation village, Karya Jadi, located in South Kalimantan Province, Indonesia (Fig. 1), as a case study to demonstrate a design process of an appropriate RE system. In 2014, Indonesia, the largest archipelago country with vast agricultural areas, declared a universal electrification target by 2020 (Central Government of Indonesia, 2014). In the first quarter of 2021, the country achieved a 98.28% total electrification rate and a 99.59% village electrification rate. These percentages are equivalent to 542,124 of the population and 346 villages still with no access to electricity (Ministry of Energy and Mineral Resources (MEMR/Kementerian Energi dan Sumber Daya Mineral Republik Indonesia), 2021). Some known challenges faced by Indonesia in achieving a 100% electrification rate are (1) challenging geographical characteristics (Nagpal and Hawila, 2018), (2) inadequate planning capacity, and (3) the enforcement of caps on power purchase prices set below RE project costs (Asian Development Bank (ADB), 2020). The archipelagic country is made up of approximately 17,500 islands (Wolters et al., 2021). Grid extension to some remote islands is not economically feasible, especially where the population is small and sparse with limited economic activities (Surroop et al., 2018). Additionally, some mountainous areas can make grid extension technically impossible or extremely costly (Nguyen, 2007). The country is also home to large plantation areas, mainly oil palm plantations expanding from Sumatera Island in western Indonesia, Borneo Island in central Indonesia, and West Papua Province in eastern Indonesia along the equator line (Moreno-Peñaranda et al., 2015).

Pandyaswargo et al. (2020) estimated the energy demand and growth of Karya Jadi village's population that is not connected to the



Fig. 1. Location and satellite view of Karya Jadi Village in Central Kalimantan. (Source: captured from Google map and Google earth.)

grid using a time-use survey. Sixty households in the village received a photovoltaic (PV) panel each from the Indonesian government in 2014. The distributed PV capacity was an 80-W peak (Wp) per household, enough to power approximately four lightbulbs. However, approximately three years after installation, the batteries were entirely deteriorated, making them practically useless for nighttime lighting. Because the price of kerosene was relatively high after the Indonesian government lifted the kerosene subsidy in 2016, only a few have shifted back to kerosene lamps to overcome this situation. The PV panels are still functional, as the expected lifespan of a PV panel is approximately 20 years (The Renewable Energy Hub UK, 2020). However, only several households in the village reported attempting to reinvest in the inverter and battery to continue using the panel for nighttime lighting. In 2019, electric appliance ownerships were identified among the village residents, indicating an existing demand for electricity. The appliance ownership rates have been reported to be 54.7%, 41.5%, and 32.1% for lighting appliances, cellphones, and radio, respectively (Pandyaswargo et al., 2020). Furthermore, it is expected that there will be significant growth of electricity demand in the village in the coming years (Pandyaswargo et al., 2020). Anticipating the demand growth, the present study demonstrates a socio-techno-economic assessment to appropriately design a new energy system.

The data, methodologies, and expected outcomes from the analysis of the three sustainability factors (1) social, (2) technical, and (3) economic to design the off-grid RE system for the village in this study are presented in Fig. 2. Data are taken through field surveys, interviews with the head of the village, and questionnaires to the village residents collected through door-to-door interviews by trained facilitators who assisted in filling out the questionnaire [SI 1] in 2021. The door-to-door interview approach is employed to ensure that literacy problems do not interfere with the data collection and to avoid gathering many people in one place as a measure for COVID-19 infection prevention. Despite resident houses located quite far from one another (approximately 500 m to 1 km between houses), random sampling was successfully performed for 88% of the household population (50 out of 60 registered households). Respondents consist of a balanced representation of adult females and males (25 persons each gender) to have a fair view from both gender groups.

The main methodologies in this study are the multiple correspondence analysis (MCA) and the nonparametric tests for the social assessment and verification, and the Hybrid Optimization Model for Electric Renewable (HOMER) for the technology and economic assessment. The use of MCA to assess the social sustainability of an RE system in a remote area has been demonstrated in a previous study by Hong and Abe

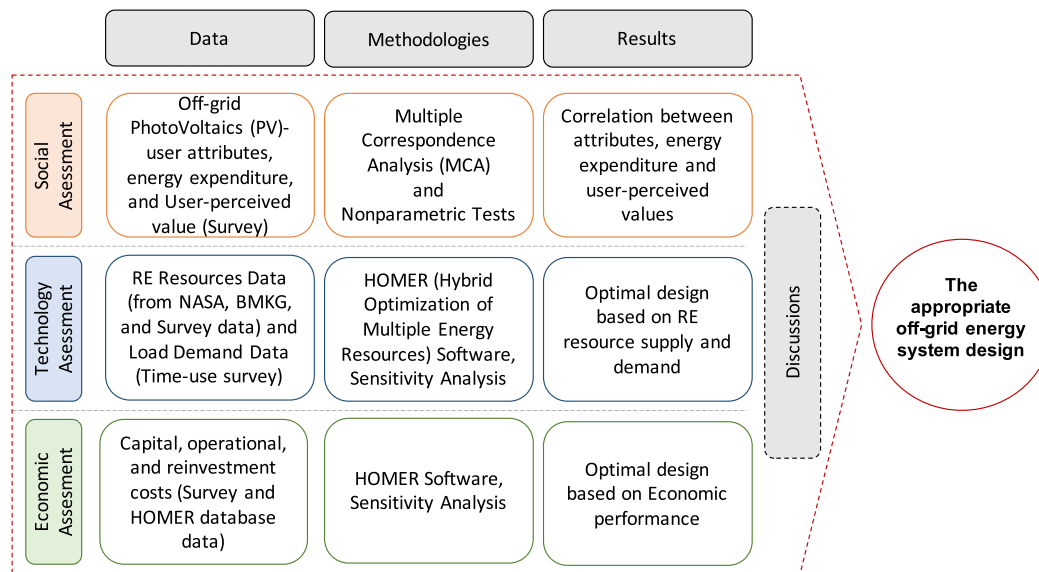


Fig. 2. Research methodological framework.

(2012), and the use of HOMER to assess the techno-economic sustainability of off-grid RE systems has been exercised by many studies in the developed and developing countries (Shahzad et al., 2017; Vendoti et al., 2021; Chambon et al., 2020; Veilleux et al., 2020; Sen and Bhattacharyya, 2014; El Zein and Gebresenbet, 2021; Nag and Sarkar, 2018; Xu et al., 2019; Islam et al., 2018). To the best of our knowledge, the present study demonstrates for the first time the combination of both methodologies to capture the social, technology, and economic aspects with the aim of developing an appropriate system design.

3.1. Rationale for Methodology Selection

3.1.1. The Hirmer's Wheel

An extensive review study on off-grid electrification in developing countries by Come Zebra et al. (2021) has identified the importance of social value as one determining aspect of the viability of an energy system throughout its life cycle (Come Zebra et al., 2021). However, the study reported that only two studies have explored the topic of "user-perceived value", both of which were performed by Hirmer's research groups (Hirmer and Guthrie, 2016; Hirmer and Cruickshank, 2014). The group developed a user-value framework for village electrification based on the understanding that user value is a determining factor for product acceptance in product design using a circular chart called Hirmer's wheel (Fig. 3). The Hirmer wheel was developed with a focus of electrification in the rural developing countries (Hirmer and Cruickshank, 2014) and has been tested in seven villages across rural Uganda (Hirmer and Guthrie, 2016). Many studies have mentioned the importance of addressing the social aspect in order to build a robust approach to energy system design and referred to the Hirmer's wheel in their arguments (Kumar et al., 2018; Murugaperumal and Vimal Raj, 2019; Madriz-Vargas et al., 2018; Chatterjee and Kar, 2018; Riva et al., 2018). However, demonstration of how to apply it in practice is limited to the one proposed by the Hirmer group themselves in the form of the "User-Perceived Value Game", where all of the 46 items in the wheel are used (Hirmer and Guthrie, 2016). Our experience working with communities with low literacy showed that simplicity is key to maintaining focus respondents' engagement in data collection (Pandyaswargo et al., 2014). The present study shortlisted the values by direct observation and discussions with the community prior to the survey and only uses relevant values for the village.

3.1.2. Multiple Correspondence Analysis

The social assessment in this study identifies relationships between energy users' attributes, and their perceived social values by the MCA methodology. Due to its powerful ability to show relationships among a large data matrix with homogenous and unknown structure (Ayele et al., 2014), MCA has been used in various fields such as public health (Ayele et al., 2014), neuroscience (Rodriguez-Sabate et al., 2017), and literature and art informatics (Paling, 2007). Facilitated by the joint graphical displays generated, the multivariate treatment of the data through multiple categorical variables can reveal relationships that usually occur during a series of pairwise comparisons of variables (Tian et al., 1993). The proximity of spaces shown in the produced MCA diagram indicates how similar or dissimilar individuals or objects in each category are (Pandyaswargo and Abe, 2014; Roux and Rouanet, 2010) and can present some insights into the correlations between them (Pandyaswargo and Abe, 2014).

The observed relationships from the MCA results in this study are then verified for their statistical significance by employing the Chi-Square test. The Chi-square test is a nonparametric tool that is as robust as its parametric counterpart, but it does not require equality of variances among the study groups in the data to provide considerable information about how each of the groups performed in the study (Mchugh, 2013). If a significant Chi-square result is obtained, it is followed by a strength statistic to identify the degree of significance (Mchugh, 2013). This study uses the Cramer's V as the strength statistic for this purpose. A limitation of Chi-square test is that it requires a minimum of 5 values in each observed parameter. We perform the Fisher's exact test for parameters that do not meet this requirement (McDonald, 2014).

3.1.3. Hybrid Optimization Model for Electric Renewable Software (HOMER)

Many commercial computational tools are available in the market to conduct a techno-economic assessment for an off-grid RE system design. A review study (Guelleh et al., 2020) comparing various computational tools indicated that HOMER is the most commonly used software for the following reasons: 1) it's ability to run simulation and optimization of hybrid energy systems, 2) it's availability for the general market, and 3) it can be used for free for a limited trial time frame. Such accessibility factors are important for the least developed countries where most communities without access to electricity are located in. Therefore, the present study adopted HOMER for the techno-economic analysis.

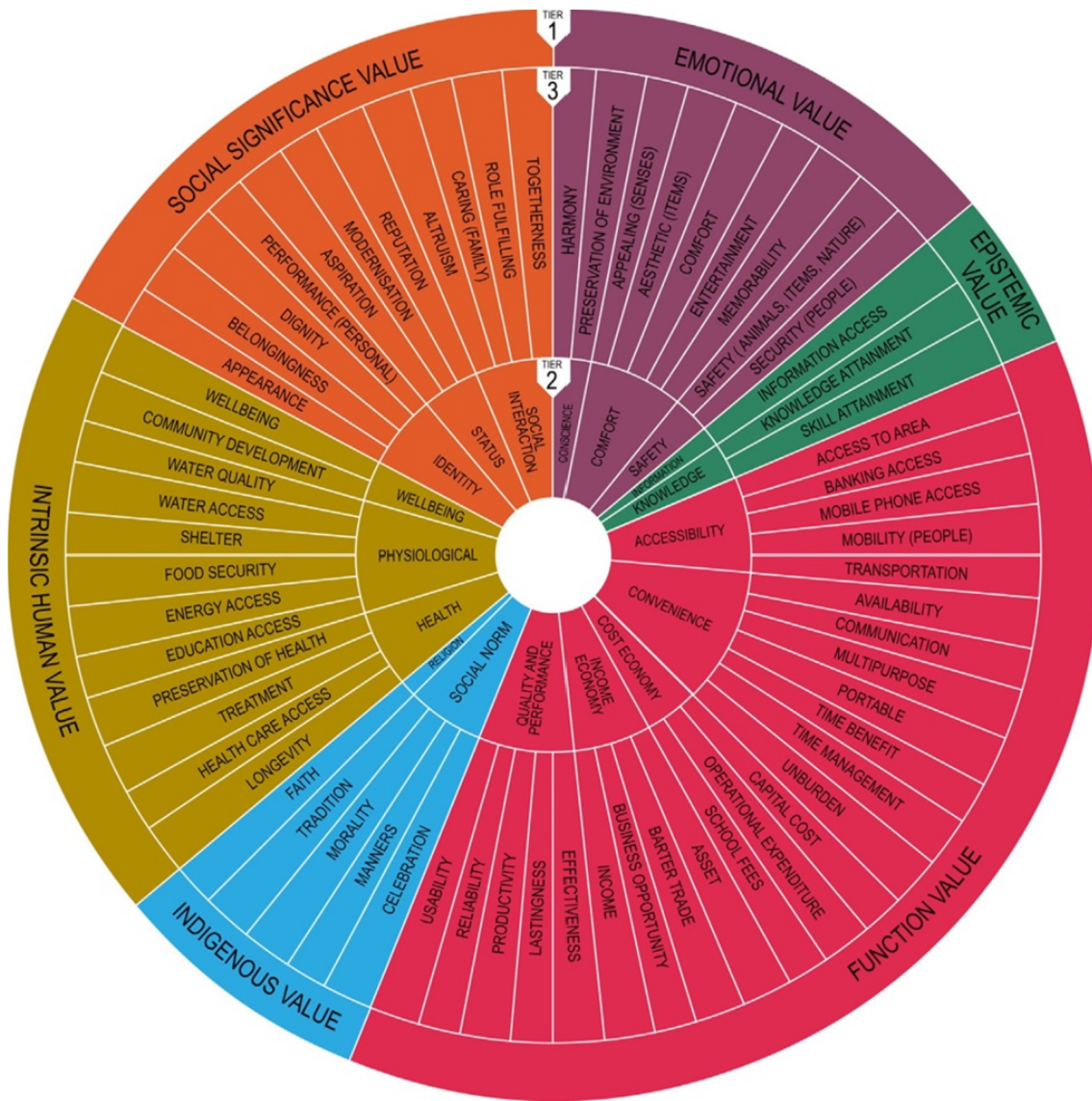


Fig. 3. The Hirmer's wheel social values (Hirmer and Guthrie, 2016).

Table 1

Selected values and the corresponding tier 1 in the Hirmer's wheel.

Tier 1	Emotional value	Epistemic value	Functional value	Indigenous value	Intrinsic human value	Social significance value
Selected values (Terminology in Hirmer's wheel)	Safety (security) Relationship between residents (harmony) Leadership (role fulfilling)		Family income Ease of transportation (transportation) Cost of transportation (transportation) Access to information and communication (mobile phone access/communication)	Religious activities (faith) Cultural preservation (tradition)	Energy quality (energy access) Energy price (energy access) Education access Environmental cleanliness Healthcare access Water access and quality Overall life quality (well-being)	Working condition

3.2. Social Assessment

Social values from the Hirmer's wheel are selected based on the authors' field observations of the village and discussions with the village's manager in 2019 and 2021. Considering the low literacy level of the village residents, questionnaires are presented in a 5-scale Likert multiple choice on their satisfaction level of the selected values with 1 as "not satisfied" and 5 as "very satisfied." Table 1 summarizes the selected values in this study and their corresponding tier 1 in Hirmer's wheel. The correlation between the residents' satisfaction levels on these selected social values and the user's attributes is analysed by performing MCA.

3.2.1. Survey Respondents' Attributes and Social Value Satisfaction

Residents of Karya Jadi Village mainly work in oil palm or rubber tree plantations as farmers. A few also maintain their own rice fields for local consumption. Because there is only an elementary school established within the village proximity, most of the population did not have access to higher education. To pursue education beyond the elementary level, one must leave the village and stay with a relative outside of the village (if they have any). This situation poses a barrier to pursuing a higher level of education for most children in the village. The mean value of a year of living in the village is relatively high (29.92 years) considering the mean age of the interviewed respondents (41.52 years). The house areas range quite diversely between 6 m² and 125 m², and many have a large land area (up to 50,000 m²). These lands are usually leased to the oil palm plantation companies (Moreno-Peñaranda et al., 2015).

The average household income is 1,641,200 IDR, equivalent to 114 USD using the December 2021 conversion rate. Approximately one-quarter of the family has female family members contributing to the family's financial income by working as farmers, running a small shop, or as a schoolteacher. Table 2 summarizes the attributes and ownership of energy-related items of the survey respondents in Karya Jadi village in 2021. Here, energy-related items refer to appliances, devices, or other assets that directly or indirectly require energy to operate or are used to generate energy to support daily life activities.

The survey respondents were asked to rate their satisfaction levels using a 5-level Likert scale on the selected social values from Hirmer's wheel (Table 1). Answers are summarized in Fig. 4. It can be observed that there is a higher satisfaction level in the emotional and indigenous value categories and a lower satisfaction level in the intrinsic and functional value categories. In other words, respondents are generally satisfied with the harmony between residents, village leadership, access to religious facilities and activities, and cultural preservation situations in the village. The lowest satisfaction levels are identified in the energy quality, ease of transportation, access for communication, energy price, environmental cleanliness, and cost of transportation. The remoteness of the village and unpaved roads toward the city have contributed to transportation difficulty. As a plantation irrigation system, the village is condensed with canals. Temporary bridges built above the canals often collapse during the rainy season, making 4-wheeler motored vehicles difficult to pass. Gasoline to fuel motorbikes and diesel engines must be transported from the city; therefore, the price must be

Table 2

Survey respondents' attributes and ownership of energy-related items from the 2021 survey.

	Mean or %	Std.	Min	Max	n
Age	41.52	16.67	17	86	50
Education level					50
No formal education	20%				
Elementary School	56%				
Middle high school	10%				
High school	12%				
University level	2%				
Gender					50
Male	50%				
Female	50%				
Year of living in the village	29.92	19.42	1	86	50
Number of a household member	3.2	1.32	1	6	50
Number of minors	1.14	1.09	0	4	50
House area (m ²)	43.16	22.75	6	125	50
Owned land area (m ²)	10,282	10,871	0	50,000	50
Occupation					50
Housewife	2%				
Farmer (oil palm, rubber tree, and rice)	88%				
Business (small stores and goods trading)	4%				
Family income (IDR)	1,641,200	864,385	200,000	3,050,000	50
Total energy expenditure (IDR)	261,340	174,706	0	700,000	50
Gas (for cooking)	45,320	36,693	0	120,000	50
Gasoline (for transportation)	213,460	157,866	0	600,000	50
Kerosene (for cooking or lighting)	2560	11,335	0	68,000	50
Ownership of energy-related items (%)	No	Yes (1)	Yes (multiple)		50
Electric lamp	36	44	20		
Kerosene lamp	88	6	6		
Cellphone (household)	32	40	28		
TV	88	12	0		
Radio	80	20	0		
Water pump (hand handled)	88	12	0		
Diesel engine	78	22	0		
Solar panel	6	88	6		
Liquified petroleum gas (LPG) tank	28	52	20		
Gas stove	28	68	74		
Firewood stove	24	74	2		
Motorbike	22	40	38		
Bicycle	30	58	12		
Loudspeaker	64	28	8		

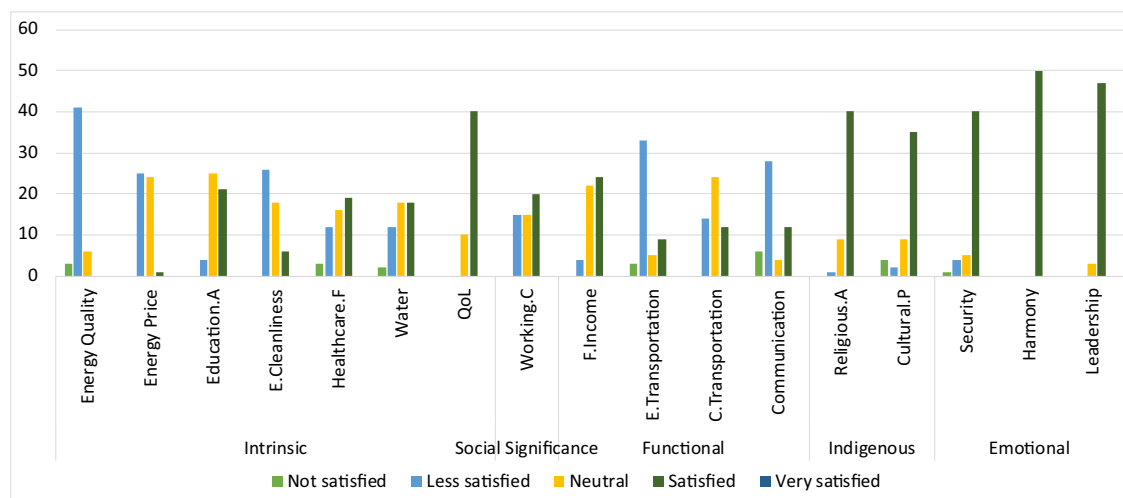


Fig. 4. Satisfaction levels of the selected social values from the 2021 survey.

Table 3

Attributes and ownership of energy-related items with categorical frequencies.

Attributes and item ownership	Obs	Categories, ranges, and frequencies		
		1st category	2nd category	3rd category
Household income (IDR)	50	Low ($\leq 1000,000$), 16	Medium ($> 1000,000 - 1,800,000$), 10	High ($> 1,800,000$), 24
Education	50	Low (No School), 10	Medium (Elementary School), 28	High (Junior High School, High School, and University), 12
Household member	50	Low (1–2), 17	Medium (3), 11	High (≥ 4), 22
Number of minors	50	Low (0), 18	Medium (1), 13	High (≥ 2), 19
Total energy expenditure (IDR)	50	Low (0 – $< 200,000$), 18	Medium (200,000–350,000), 18	High ($> 350,000$), 14
Gas Expenditure (IDR)	50	Low (0), 14	Medium ($> 0 - 50,000$), 14	High ($> 50,000 - 150,000$), 22
Gasoline Expenditure (IDR)	50	Low (0–80,000), 14	Medium ($> 80,000 - 220,000$), 12	High ($> 220,000 - 600,000$), 24
Kerosene Expenditure (IDR)	50	Low (0), 47	Medium (20,000), 1	High ($> 20,000$), 2
House area	50	Low ($\leq 24 \text{ m}^2$), 15	Medium ($> 24 \text{ m}^2 - 40 \text{ m}^2$), 11	High ($> 40 \text{ m}^2$), 24
Owned land area	50	Low ($< 1 \text{ ha}$), 20	Medium (1 ha), 16	High ($> 1 \text{ ha}$), 14
Electric lamp	50	No (0), 18	Yes (1), 22	Multiple (> 1), 10
Kerosene lamp	50	No (0), 44	Yes (1), 3	Multiple (> 1), 3
Cellphone (household)	50	No (0), 16	Yes (1), 20	Multiple (> 1), 14
TV	50	No (0), 44	Yes (1), 6	Multiple (> 1), 0
Radio	50	No (0), 40	Yes (1), 10	Multiple (> 1), 0
Water pump	50	No (0), 44	Yes (1), 6	Multiple (> 1), 0
Diesel engine	50	No (0), 39	Yes (1), 11	Multiple (> 1), 0
Solar panel	50	No (0), 3	Yes (1), 44	Multiple (> 1), 3
LPG tank	50	No (0), 14	Yes (1), 26	Multiple (> 1), 10
Gas stove	50	No (0), 14	Yes (1), 34	Multiple (> 1), 2
Firewood stove	50	No (0), 12	Yes (1), 37	Multiple (> 1), 1
Motorbike	50	No (0), 11	Yes (1), 20	Multiple (> 1), 19
Bicycle	50	No (0), 15	Yes (1), 29	Multiple (> 1), 6
Loudspeaker	50	No (0), 32	Yes (1), 14	Multiple (> 1), 4
Social value (initial) ^a		Satisfaction levels		
		Low = 1 and 2	Medium = 3	High = 4 and 5
Energy quality (H1)	50	Low (44)	Medium (24)	High (0)
Energy price (H2)	50	Low (25)	Medium (24)	High (1)
Education.A (H3)	50	Low (4)	Medium (25)	High (21)
E.cleanness (H4)	50	Low (26)	Medium (18)	High (6)
Healthcare.F (H5)	50	Low (15)	Medium (16)	High (19)
Water (H6)	50	Low (14)	Medium (18)	High (18)
QoL (H7)	50	Low (0)	Medium (10)	High (40)
Working.C (S1)	50	Low (15)	Medium (15)	High (20)
F.income (F1)	50	Low (4)	Medium (22)	High (24)
E.transportation (F2)	50	Low (36)	Medium (5)	High (9)
C.transportation (F3)	50	Low (14)	Medium (24)	High (12)
Communication (F4)	50	Low (34)	Medium (4)	High (12)
Religious.A (I1)	50	Low (1)	Medium (9)	High (40)
Cultural.P (I2)	50	Low (6)	Medium (9)	High (35)
Security (E1)	50	Low (5)	Medium (5)	High (40)
Harmony (E2)	50	Low (0)	Medium (0)	High (50)
Leadership (E3)	50	Low (0)	Medium (3)	High (47)

^a The initial is based on a letter and number combination from the corresponding tier group in Hirmer's wheel (Table 1).

Table 4
Sample cross table.

Respondents (n = 50)	1	2	3...50
Income	High	High	High
Education	Medium	Medium	Low
Minors	High	Medium	Medium
Energy Expenditure	High	High	High
H1	High	High	High
H2	Low	Low	Low
H3	Low	Medium	Medium
H4	High	Medium	High
H5	Medium	High	Medium
H6	Medium	Medium	Medium
H7	High	Medium	Medium
H8	High	High	High
S1	High	High	High
F1	High	High	High
F2	Medium	Low	Low
F3	Medium	Low	Medium
F4	Low	Low	Low
I1	High	High	High
I2	High	High	High
E1	High	High	High
E2	High	High	High
E3	High	High	High

increased significantly. A landline telephone is not available, and mobile phones have limited connectivity because satellite signals are poor.

3.2.2. Multiple Correspondence Analysis Preparation

To prepare data for MCA, a cross-section table that consists of the qualitative variables to be observed, is constructed. For this purpose, the variables are categorized into groups (low, medium, high). In this way, the variations in data could be simplified for more straightforward observation and fulfilled the qualitative data requirement for MCA. It should be noted that the way variables are categorized into groups will affect the results derived. In this particular study, the first quartile, the mean, and the third quartile of each variable were used as guides to categorize the data. For the satisfaction level, responses 1 and 2 are considered as “low”, response 3 is considered “medium”, and responses 4 and 5 are considered as “high”. Table 3 lists the variables and defines the ranges of each subgrouping category and the frequency of occurrence in detail. The majority of respondents earn a monthly income below 2,000,000 IDR (or about 140 USD using February 2022 conversion rate), only complete elementary school, have two children or more, and spend below 350,000 IDR (or about 24 USD using February 2022

conversion rate) monthly for their energy consumption. Each respondents' attributes and satisfaction levels are then arranged in a cross table (Table 4 presents the sample cross table) to be processed with R programming software. The *FactoMineR* and *ggplot2* packages are employed to run the MCA algorithms.

3.3. Techno-economic Assessments

This study's techno-economic and sensitivity assessments are performed by inputting data derived from fieldwork, such as the electricity load and local prices, into HOMER software. The output of the techno-economic analysis is the total net present cost (NPC) and cost of electricity (COE). Furthermore, the software simulates the system configurations by producing information about the energy balance in each hour and the system's supply of electric load per hour (Ghasemi et al., 2013).

3.3.1. User Load Assessment

Daily load data were collected in August 2019 using the time-use questionnaire [SI 2]. The load chart produced from the questionnaire shows two peaks in a day: a lower peak at approximately 6 in the morning when people started their activities and a higher peak at 6 in the evening when people returned from work and were ready to rest (Fig. 5). During the day, most of the residents are out in the field where they work as palm oil trees and rubber tree farmers; therefore, there is no energy demand in households during the weekday. The electricity generated from PV is mainly used for lighting, cooling, and entertainment purposes. To accommodate the peak loads, we set the daily load configuration in the HOMER software to 10.5 kWh per day.

3.3.2. Resource Assessment

The location of Karya Jadi village is in South Kalimantan Province in Indonesia. Because the equator line crosses this island, the climate is very warm with significant sunlight throughout the year. We observed sunlight data from the Banjarbaru climatology station, operated by the Indonesian Meteorology, Climatology, and Geophysical Agency (BMKG) (2021). The data show that the duration of sunlight averages approximately 5 h a day, with the most extended daylight between May and August. The BMKG, however, does not provide data for solar radiation. Therefore, we use the National Aeronautics and Space Administration (NASA) Prediction of Worldwide Energy Resource (POWER) database downloadable via HOMER (Fig. 6). The employed data are specific to the longitude and latitude of the village location.

We also observed the wind speed for wind power potential. Approximately 3.5 m/s speed is required for the smallest wind turbine to

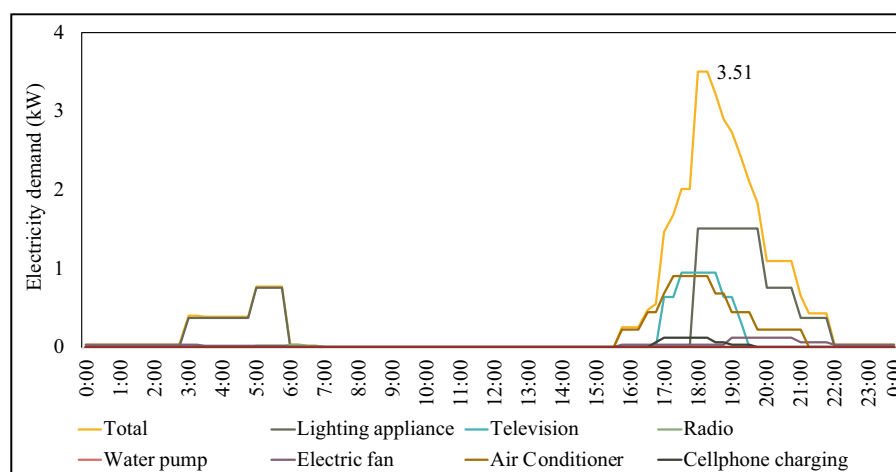


Fig. 5. Electricity demand daily load pattern in Karya Jadi Village (Pandyaswargo et al., 2020).

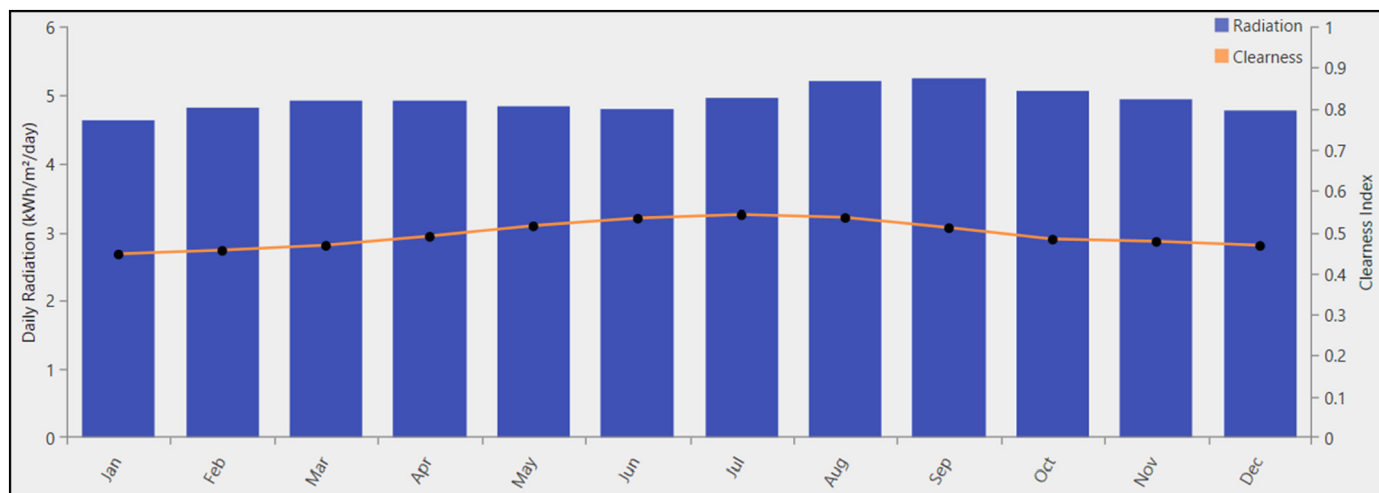


Fig. 6. Monthly average solar irradiance in Karya Jadi village.

generate power (BRANZ Ltd, 2021). The BMKG data in 2020 show that the average daily wind speed is 1.6 m/s, and the average daily maximum wind speed is 3.9 m/s. The NASA data (Fig. 6), on the other hand, showed that the wind speed at the village ranged from approximately 4 to 7 m/s. A factor that may explain the discrepancies between BMKG data and NASA data is the measurement duration. The NASA data provided a measurement over 30 years at 50 m above the Earth's surface. On the other hand, we only observed 1-year data from BMKG. Furthermore, there is no information about the height of the measurement in the BMKG data. Considering these aspects, we decided to use the NASA data for analysis.

3.3.3. Solar Radiation and Wind Speed Data

The monthly averages for global horizontal solar radiation over 22 years (Jul 1983 – Jun 2005) are taken from the NASA POWER database and downloaded through HOMER software in August 2021 (Fig. 6). The wind speed data are taken from the same database. We utilize the monthly average wind speed at 50 m above the Earth's surface over 30 years (Jan 1984 – Dec 2018) (Fig. 7).

3.3.4. Biomass Resource Assessment

Based on interviews with the head of Karya Jadi village and field observations, there are three potential biomass sources from agricultural residue. The first one is rice husk. The village head estimated that the

production volume was 100 kg/farmer/year. Rice husks are currently disposed of in undetermined open dumping areas, and regular direct combustion is practiced. The second biomass potential is the palm fronds from the oil palm plantation, and the third is rubber tree branches. Currently, palm fronds are used as soil-enriching material by leaving them to decompose between oil palm trees. Based on the waste management hierarchy, this practice is considered a material recovery. Material recovery has a higher priority in the hierarchy than energy recovery (European Commission, 2012). It usually means a lower or even negative environmental load; therefore, the practice should be continued instead of trying to converse palm fronds as a biomass boiler feedstock. Moreover, while the land ownership where these agricultural activities are taking place belongs to the residents, the land planted with oil palm trees is under leased with palm oil milling companies. This situation implies that products from these leased lands, including residues, are the company's property. In terms of the rubber tree, trimming activities are not done collectively or on any determined schedule. Therefore, the number of trimmed rubber tree branches is considered insignificant and insufficient to meet the demand of a biomass energy generation plant that often requires a constant feedstock (Pandyaswargo et al., 2019). Considering these situations, only rice husks remained a candidate for biomass energy generation plants in this study. The daily rice husk residue is calculated with Eq. (1), where RD is rice husk production in the village per day, R_i is the estimated amount of rice husk produced/

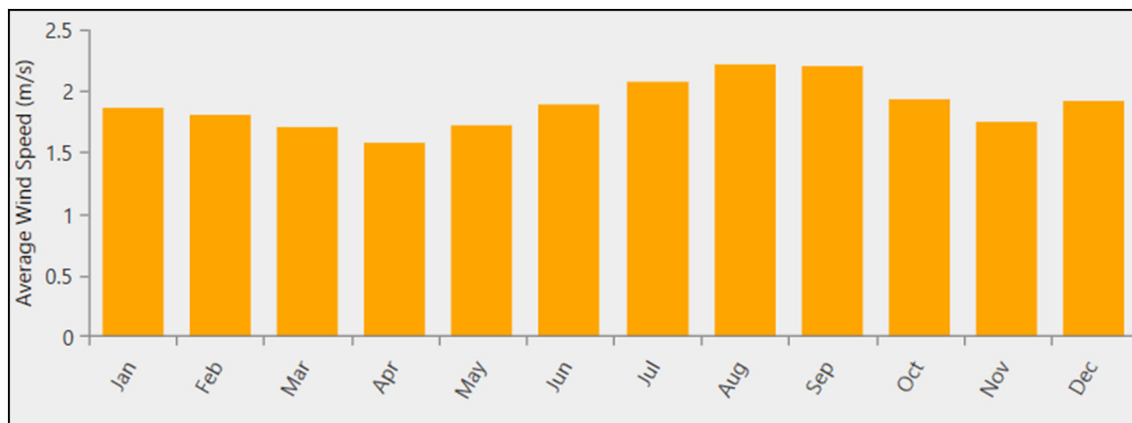


Fig. 7. Monthly average wind speed in Karya Jadi village.

farmer/year, and F is the number of farmers in the village. The assumed number of days of rice mill operation is 100.

$$RD = \frac{R_i * F}{100} \quad (1)$$

With an estimated rice husk production volume of 100 kg/farmer/year and 53 farmers in the village, the daily rice husk production is 53 kg/day. Existing studies have examined the feasibility and potential of using rice husk as a biomass energy generation feedstock to electrify villages in emerging Asian countries (Mitsubishi Research Institute and Fujita Corporation, 2015; Rao and Yadav, 2015; Akgün and Luukkanen, 2012; Ejiofor et al., 2020; Cheng et al., 2020). Some of the identified technologies that can take rice husks as energy generation feedstocks are direct combustion, hydrothermal gasification, and torrefaction.

However, there is a minimum feedstock amount requirement for a biomass gasification boiler. Several studies have presented various feasible capacities of rice husk feedstock to a biomass boiler. A Thailand case study reported the utilization of 1448 ton/day rice husk to feed a 3 MW capacity biomass boiler (Industrial Decisions, 2010). Nazar et al. (2021) reported that to produce 1 MWh of power, 1 ton of rice husk is required. The study also reported that the commercially feasible capacity for rice husk combustion, pyrolysis, and gasification is approximately 10 MW to 20 MW. A study exercising the potential of using rice husk for off-grid electrification in South Asia reported that a small-scale (Bhattacharyya, 2014) rice husk boiler (20 kW capacity) could supply off-peak household demand (30 W) but would be very costly. The study suggested that costs can be reduced if electricity is used for rice milling. However, the minimum feedstock capacity per day example exercised in the study is 2 ton, which is still much larger than the production capacity in Karya Jadi village. Therefore, it would not be technically feasible to electrify the village using rice husk boilers.

3.3.5. System Configuration

The village households' peak load demand information from the time-use survey (Section 3.3.1) and other collected parameters from the field (Table 5) are inputted into the HOMER software to configure the solar and wind hybrid system. Actual parameter data are taken with direct communication with village residents and village heads in 2021. The system configuration of the hybrid PV and wind system is shown in Fig. 8.

4. Results

4.1. Social Aspects

4.1.1. Multiple Correspondence Analysis Results

Fig. 9a–e shows the results of the MCA for the intrinsic, social significance, function, indigenous, and emotional values, respectively. A

rough observation indicates that most of the results are concentrated in one cluster, implying a high level of homogeneity of satisfaction perception among the village residents against the social values inquired. However, a closer observation to the intrinsic figure (Fig. 9a) indicates the following insights: 1) Respondents reporting a high satisfaction level with energy price are in closer correlation with those owning multiple liquefied petroleum gas (LPG) tanks, multiple gas stoves, multiple solar panels, owning hand handled water pumps, owning multiple electric lamps, owning multiple bicycles, have higher LPG expenditure and medium household members; 2) Respondents reporting a low satisfaction level with energy price are in closer correlation with those who do not own electric lamps, owning multiple kerosene lamps, do not own LPG tanks, do not own gas stoves, and own smaller land areas, 3) Respondents reporting a low satisfaction level with education access are in closer correlation with those who do not own electric lamps, LPG tanks, or gas stoves.

Observation of the social significance value figure (Fig. 9b) indicates the following insights: 1) Respondents reporting low satisfaction levels with working condition are in closer correlation with those owning firewood stoves and kerosene lamps, are with low education and income levels, and do not own solar panels, radio, or loudspeakers. 2) Respondents with high income are more closely correlated with those who own multiple cellphones and multiple motorbikes and do not own kerosene lamps and bicycles.

The functional value figure (Fig. 9c) indicates the following insights: 1) respondents reporting low satisfaction levels with ease of transportation are more closely correlated with those who spend high expenditures on gasoline and LPG, owning cellphones, LPG tanks, and gas stoves; 2) respondents reporting high satisfaction levels with the cost of transportation are more closely correlated with those who do not own LPG tanks and gas stoves, 3) respondents reporting low satisfaction levels with access to information and communication are more closely correlated with those who have higher household income and spend higher expenditures on LPG, owning cellphones, electric lamps, LPG tanks, and gas stoves.

The indigenous value figure (Fig. 9d) indicates respondents reporting high satisfaction levels with cultural preservation are in closer correlation with those who do not own electric lamp, diesel engine, gas stove, and LPG tank, but has firewood stove, and multiple kerosene lamps.

Finally, respondents reporting a medium satisfaction level in safety are more closely correlated with owning hand-handled water pumps, TVs, multiple electric lamps, multiple LPG tanks, and do not own firewood stoves (Fig. 9e).

Table 5
Configured parameters in the HOMER software from the 2021 survey.

No	Parameters	Value	Unit
1	Average daily load	10.30	kWh/day
2	Generator cost	140	USD/kW
3	Fuel cost	0.7	USD/l
4	PV capital cost	783	USD/kW
5	Wind turbine capital cost	783	USD/kW
6	PV & wind turbine lifetime	20	Years
7	Battery type	12 V, 83.4 Ah, 1 kWh Lead Acid	
8	Battery cost	229	USD/battery
9	Battery lifetime	3	Years
10	Discount rate	8	%
11	Village location latitude	−2.54	
12	Village location longitude	114.35	

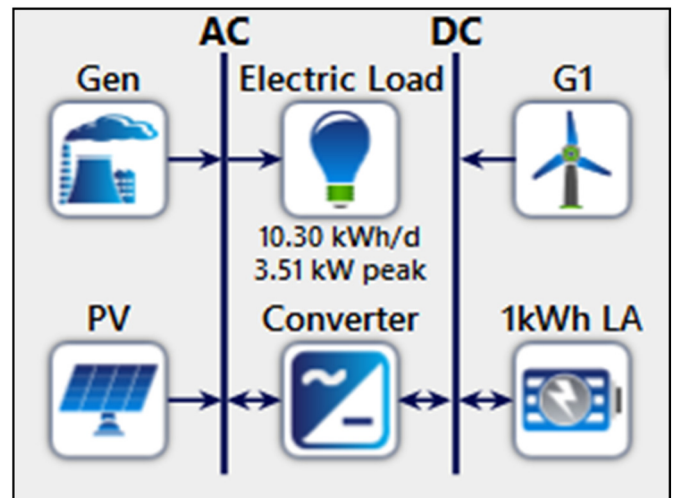
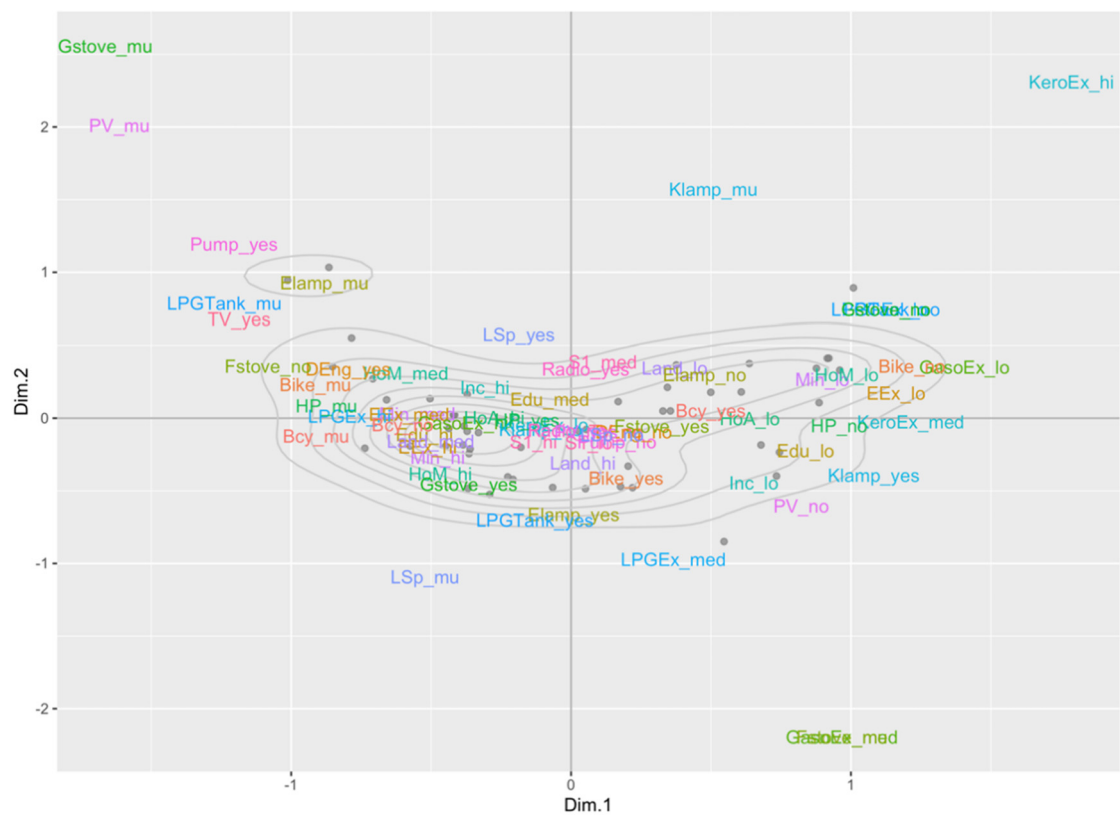
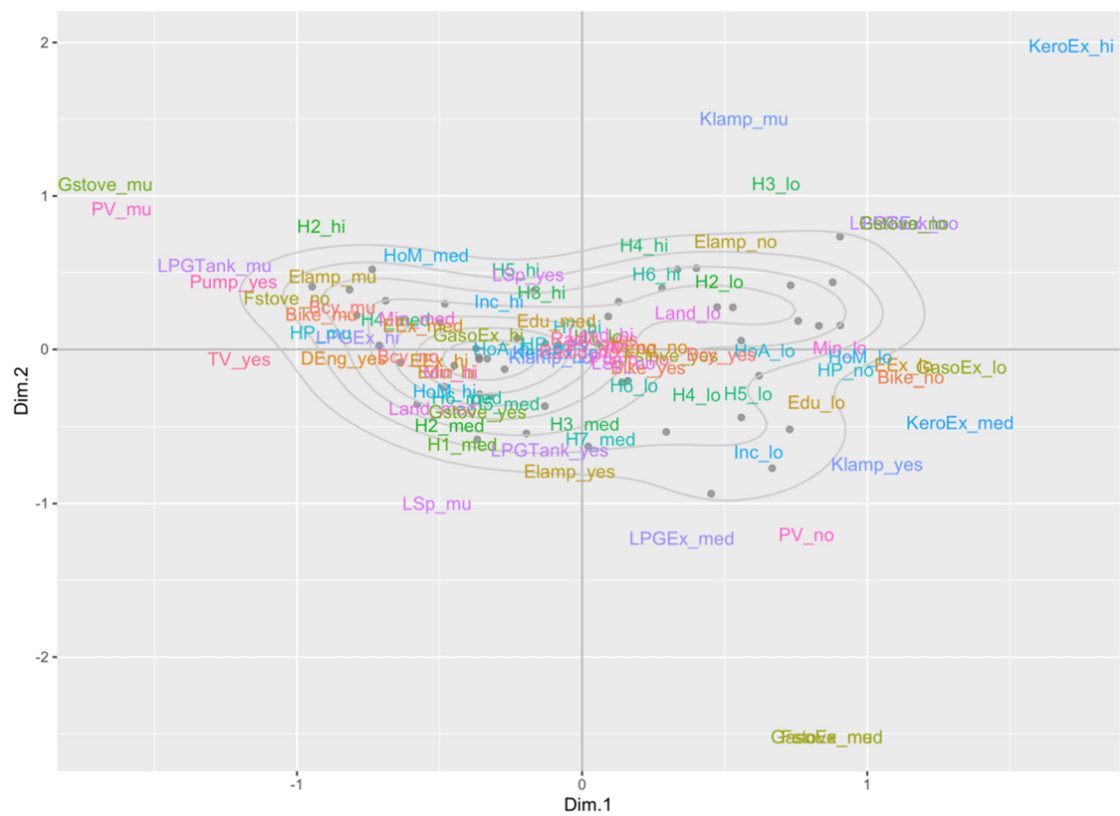
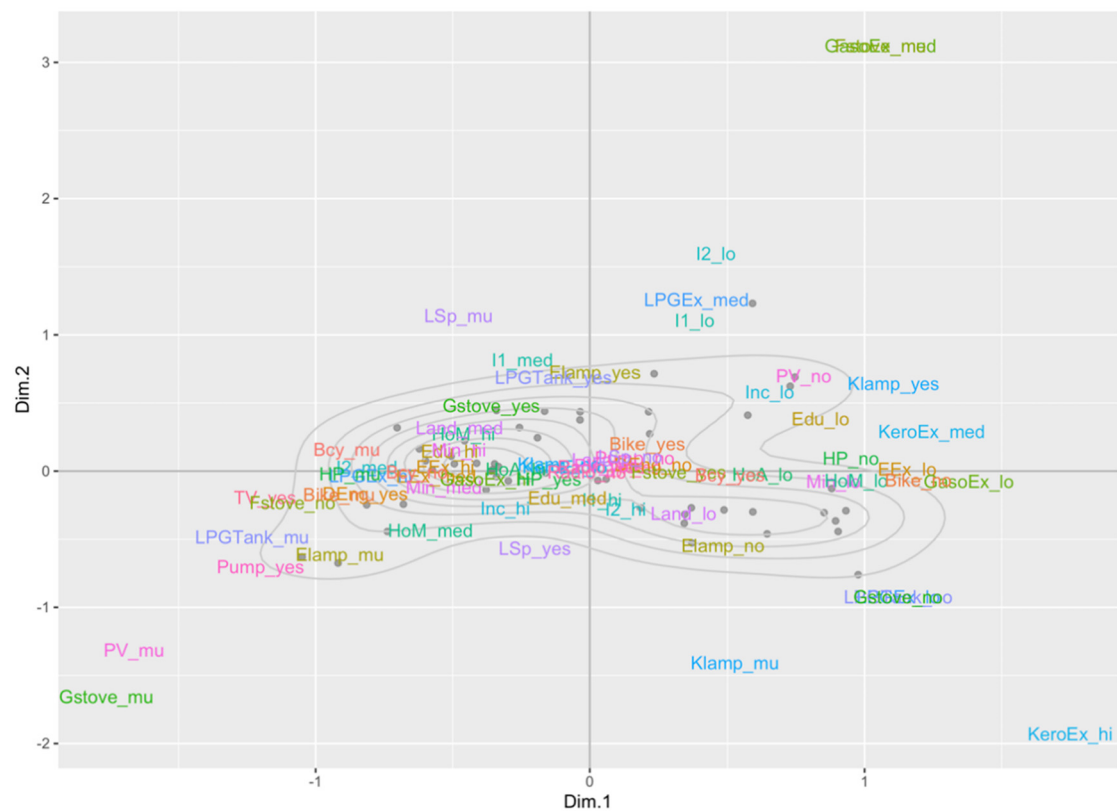
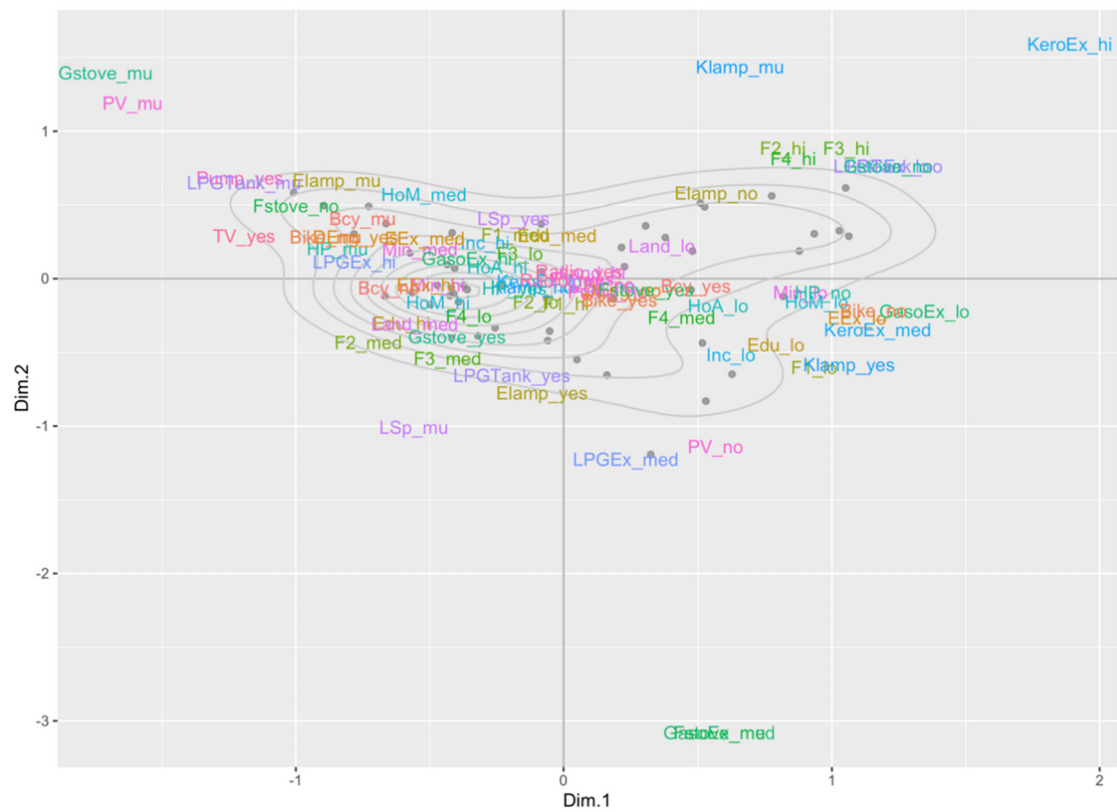


Fig. 8. Configuration of PV/wind hybrid system.







Inc.: Household Income, Edu: Education, Min: Minors, EEx: Energy expenditure, LPGEx: Gas expenditure, GasOEx: Gasoline expenditure, KeroEx: Kerosene expenditure, HoM: Number of household member, HoA: House area, Land: Land area, Elamp: Electric lamp, Klamp: Kerosene lamp, HP: Cellphone, TV: TV, Radio: Radio, Pump: Water pump, DEng: Diesel Engine, PV: Solar panel, LPGTank: LPG Tank, Gstove: Gas stove, Fstove: Firewood stove, Bike: Motorbike, Bcy: Bicycle, LSp: Loud speaker, H1: Energy Quality, H2: Energy Price, H3: Education Access, H4: Environmental Cleanliness, H5: Healthcare Facility, H6: Water, H7: Quality of Life, S1: Working Condition, F1: Household Income, F2: Ease of Transportation, F3: Cost of Transportation, F4: Access to Information/Communication, I1: Religious Activities, I2: Cultural Preservation, E1: Safety, E2: Harmon, E3: Leadership, hi: high, med: medium, lo: low, mu: multiple.

To test whether the correlations identified from the MCA results can be considered as statistically significant, we conducted a Chi-square test. When the Chi-square test showed a significant p value (less than 0.05), we derived the Cramer's V value to show the strength of the significance. When there were cells that did not meet the minimum content requirement for a Chi-square test (5 per cell), we performed Fisher exact test. Additionally, as the literature has mentioned the importance of opportunities enabled by clean energy access to women (Selco Foundation, 2017; Summers et al., 2020; Hilbert, 2011), the test is also conducted to identify whether there is any difference in response between the male and female respondents in this study. Table 6 summarizes the results of the tests of the correlations identified from MCA and Table 7 summarizes the significant results for the gender-based responses.

two filled 3 kg LPG tanks on a monthly basis (Pandeyaswargo et al., 2020; Thoday et al., 2018; Bruce et al., 2017). The price of 3 kgs LPG tank and refill has been heavily subsidized such that it did not change for over 14 years (Putri, 2021). However, recent developments have shown that this subsidy is being lifted gradually (Ministry of Energy and Mineral Resources, 2020).

On the other hand, relationships between low satisfaction level on energy price with respondents without electric lamp, LPG tank, and gas stove might imply that they do not belong to documented households and therefore did not qualify for the conversion program, nor to the 2014 PV panel distribution program. It is also significantly verified that these respondents have a low satisfaction level regarding access to education and low job satisfaction levels.

It is also found that higher income correlates significantly with multiple ownership of motorbikes and cellphones, and non-ownership of bicycles and kerosene lamps. This finding may indicate the role of modern technology adoption and access to information and communication with income generation. Furthermore, it may also indicate the willingness of higher income households to adopt modern technologies and leave the traditional ones.

Among the identified relationships in the functional value MCA figure, all are verified to be relevant. Respondents reporting a low satisfaction level with ease of transportation and access to information and communication are those who own cellphones and spend more on LPG. With the LPG assistance program being lifted, they need to

Table 6

Test results of the correlations identified from MCA.

Cross table parameters	Results value			
	Chi-square test p value	Cramer's V	Number of cells with expected count less than 5	Fisher's exact test p value
Energy price * LPG tank	0.006	0.381	4 cells (44.4%)	0.002
Energy price * gas stove	0.024	0.335	5 cells (55.6%)	0.43
Energy price * solar panel	0.392			
Energy price * water pump	0.025	0.384	4 cells (66.7%)	0.128
Energy price * electric lamp	0.000	0.466	4 cells (44.4%)	0.000
Energy price * bicycle	0.729			
Energy price * number of household member	0.512			
Energy price * kerosene lamp	0.936			
Energy price * LPG expenditure	0.027	0.331	3 cells (33.3%)	0.01
Energy price * owned land area	0.124			
Education * electric lamp	0.049	0.309	4 cells (44.4%)	0.045
Education * LPG tank	0.017	0.347	4 cells (44.4%)	0.015
Education * gas stove	0.092			
Working condition * firewood stove	0.669			
Working condition * kerosene lamp	0.072			
Working condition * education	0.681			
Working condition * household income	0.345			
Working condition * PV	0.034	0.323	6 cells (66.7%)	0.022
Working condition * radio	0.302			
Working condition * loudspeaker	0.559			
Income * cellphones	0.000	0.552	1 cell (16.7%)	0.000
Income * motorbike	0.010	0.428	1 cell (16.6%)	0.009
Income * kerosene lamp	0.019	0.398	4 cells (66.7%)	0.031
Income * bicycle	0.014	0.415	3 cells (50%)	0.008
Cost of transportation * LPG tank	0.000	0.509	5 cells (55.6%)	0.000
Cost of transportation * gas stove	0.000	0.516	5 cells (55.6%)	0.000
Access to information/communication * household income	0.004	0.470	3 cells (50%)	0.003
Access to information/communication * LPG expenditure	0.042	0.315	5 cells (55.6%)	0.037
Access to information/communication * cellphone	0.021	0.340	6 cells (66.7%)	0.017
Access to information/communication * electric lamp	0.013	0.357	5 cells (55.6%)	0.009
Access to information/communication * LPG tank	0.043	0.314	5 cells (55.6%)	0.039
Access to information/communication * gas stove	0.044	0.313	6 cells (66.7%)	0.035
Cultural preservation * electric lamp	0.006	0.378	6 cells (66.7%)	0.005
Cultural preservation * diesel engine	0.027	0.380	3 cells (50%)	0.037
Cultural preservation * gas stove	0.002	0.406	6 cells (66.7%)	0.008
Cultural preservation * LPG tank	0.060			
Cultural preservation * firewood stove	0.028	0.330	6 cells (66.7%)	0.037
Cultural preservation * kerosene lamp	0.533			
Safety * pump	0.010	0.010	5 cells (83.3%)	0.023
Safety * TV	0.092			
Safety * electric lamp	0.027	0.331	6 cells (66.7%)	0.23
Safety * LPG tank	0.164			
Safety * firewood stove	0.004	0.393	7 cells (77.8%)	0.007

transport their own LPG tank to the nearest city to get it refilled. It is very challenging to transport these heavy tanks with motorbikes or bicycles, which are the main transportation modes used by the village residents. Respondent owning cellphones reported frustration when using the device because the signal is poor, causing as text messages and calls cannot always be made when needed. Consequently, those reporting a high satisfaction level with the cost of transportation are those who do not own LPG tanks as they do not have the need to transport any.

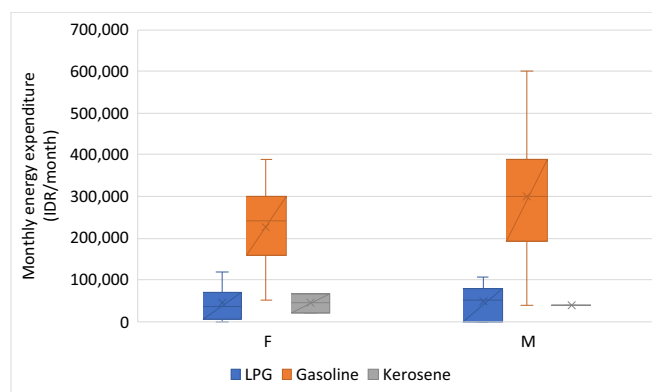
Significant correlations are also observed for respondents who reported high satisfaction levels with cultural preservation with

non-ownership of electric lamps, diesel engines, and gas stoves. This finding suggests that respondents with traditional lifestyles and technologies may associate it with cultural preservation.

Table 7

Significant test results of the gender responses.

Cross table parameters	Results value			
	Chi-square test p value	Cramer's V	Number of cells with expected count less than 5 ^a	Fisher's Exact Test p value
Gender * energy expenditure	0.010	0.430	0	
Gender * solar panel	0.033	0.369	4 cells (66.7%)	0.022

**Fig. 10.** Household energy expenditure reported by gender

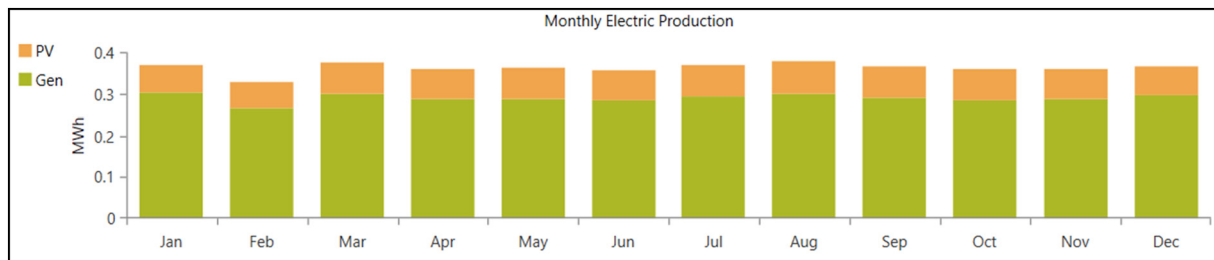


Fig. 11. Monthly average electricity production of the PV system (fuel = 0.7 USD/l, Wind = 3 m/s).

Finally, a medium satisfaction level in safety has a significant correlation with ownership of hand-handled water pumps and multiple electric lamps, and non-ownership of firewood stoves. Having immediate access to the underground clean water, multiple lighting devices, and non-ownership of the open-fire firewood stove may have increased their sense of safety.

The test results of the gender responses reveal that there is no identifiable difference between responses of the male and female respondents in terms of their satisfaction level to the selected Hirmer's wheel social values. However, in terms of total household energy expenditure, female respondents reported lower values than their male counterparts. Fig. 10 shows that female respondents reported lower expenditures on gasoline (commonly used for motorbike fuel or diesel engine) and male respondents reported lower expenditures on LPG (commonly used for cooking) and kerosene (for cooking and/or lighting).

4.2. Techno-economic Aspect: HOMER and Sensitivity Analysis Results

This study designed a hybrid PV and wind power system to provide electricity for residential consumption in Karya Jadi village. The HOMER software conducted the simulation to optimize the designed system configuration in response to the load profile. The obtained results are presented in this section. In addition, we inputted several parameters for the sensitivity analysis.

The first one is the diesel price. Indonesia has become a net oil importer since 2004 (Energy Information Administration, 2015), and subsidies for oil products such as kerosene have been lifted. Therefore, it is expected that the price of diesel fuel will also significantly increase in the future. With these considerations, we set the price of diesel fuel at 0.7 USD/l, which is the current price, and at 1.4 USD/l for the pessimistic scenario. The second sensitivity parameter is the wind speed. Based on our observation of the wind speed discrepancies between what is reported by BMKG and NASA, we set the wind speed at 1.89 m/s, 3 m/s, and 8 m/s.

The results show that the NPC is significantly higher in the lower wind speed scenario. As power generation with a wind turbine is only possible at a minimum of 3.5 m/s, the system with wind power is only viable in the 8 m/s scenarios. If the 8 m/s wind speed scenario can be guaranteed, with the current price of diesel fuel (0.7 USD/l), the NPC and COE are lowest if the wind turbine operates by itself and is not hybridized with PV. However, this scenario is too optimistic and may be too vulnerable due to intermittency. On the other hand, installing PVs can only make sense if the diesel price increases to 1.4 USD/l, resulting in 15,407 USD NPC and 0.451 USD COE.

Figs. 11 and 12 show the monthly electric production in the case of the baseline scenario (fuel = 0.7 USD/l, Wind = 3 m/s) and optimistic scenario (fuel = 1.4 USD/l, Wind = 8 m/s), respectively. The wind turbine is not viable in the baseline scenario; therefore, electricity is

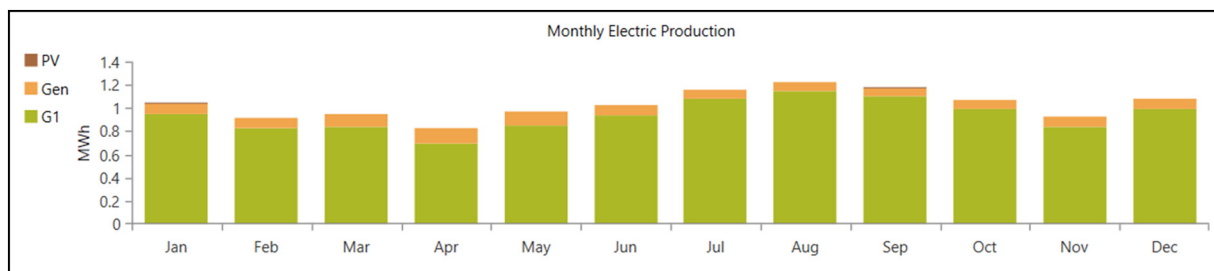


Fig. 12. Monthly average electricity production of the PV/wind hybrid system (fuel = 1.4 USD/l, Wind = 8 m/s).

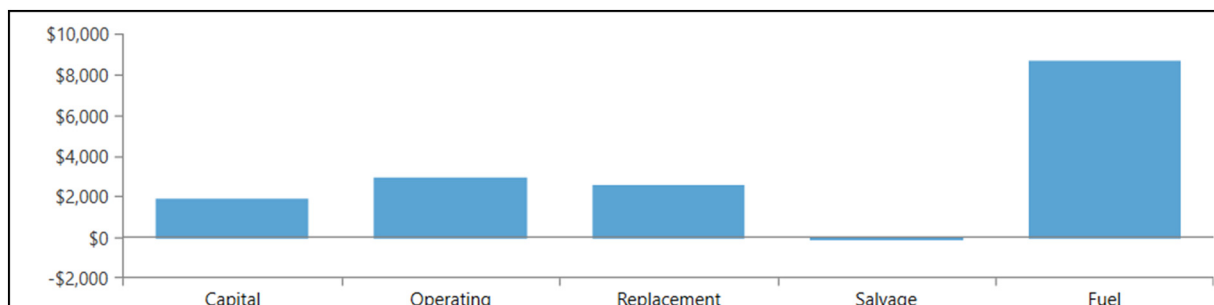


Fig. 13. Cost summary of the PV system (fuel = 0.7 USD/l, Wind = 3 m/s).

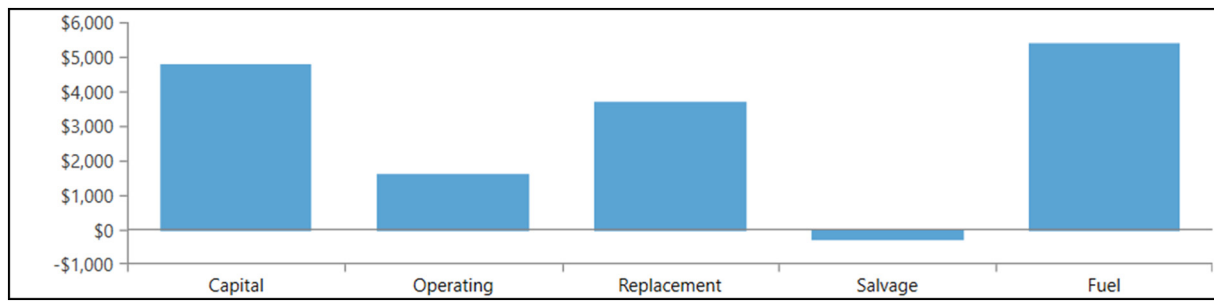


Fig. 14. Cost summary of the PV/wind hybrid system (fuel = 1.4 USD/l, Wind = 8 m/s).

generated only from PV and diesel-fuelled generators. The renewable fraction is also very small at 7.6%. In the optimistic scenario, a significant amount of electricity is generated from the wind turbine (G1), and the total renewable fraction is very high at 70.9%. The simple payback time is not much different between the two scenarios: 1.11 years for the baseline scenario and 1.19 for the optimistic scenario.

In terms of cost expenditures, in the baseline scenario (Fig. 13), the highest cost is used for purchasing fuel because a significant amount

of electricity is generated by the diesel generator. In the optimistic scenario (Fig. 14), the cost for capital and fuel is almost equal. However, the total cost of both scenarios is not very different. The baseline scenario totals 16,191 USD, while the optimistic scenario totals 15,407 USD (Table 8).

Observing the results, the price caps introduced by the state-owned electricity company (PLN) may hinder the financial sustainability of the proposed plant. The electricity price cap set by PLN for the South Kali-

Table 8
Sensitivity analysis results for the PV/wind hybrid system.

Sensitivity	Architecture	Cost												
Diesel fuel price (USD/L)	Wind scaled average (m/s)	PV	Wind	Generator	Battery	PV (kW)	G1	Gen (kW)	1kWh LA	Converter (kW)	NPC (USD)	COE (USD)	Operating Cost (USD/year)	Initial Capital
0.700	3.00	✓	×	✓	✓	0.602		3.90	3	0.705	16,191	0.474	1573	1916
0.700	8.00	×	✓	✓	✓		2	3.90	4	1.90	12,451	0.365	975.24	3599
1.40	1.89	✓	×	✓	✓	2.19		3.90	7	1.05	23,755	0.696	2156	4182
1.40	3.00	✓	×	✓	✓	1.90		3.90	7	1.01	23,765	0.696	2184	3942
1.40	8.00	✓	✓	✓	✓	0.027	3	3.90	5	2.61	15,407	0.451	1164	4841

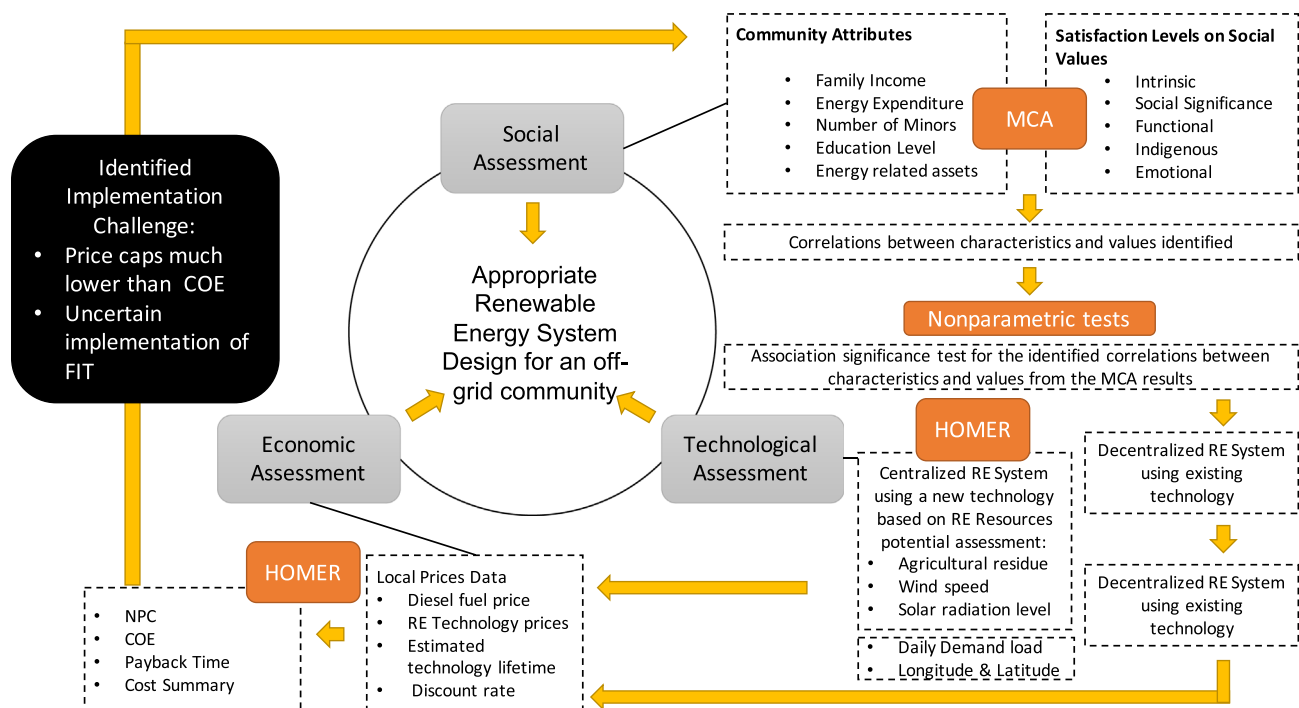


Fig. 15. Appropriate RE system design process.

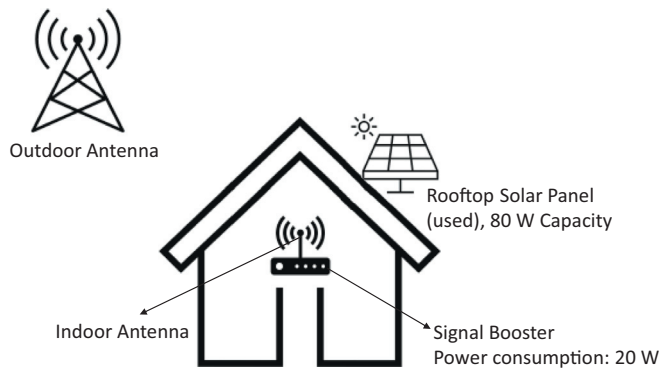


Fig. 16. Cellphone signal booster installation diagram using the existing solar panel.

mantan region is approximately 0.08 USD/kWh (Bridle et al., 2018). The COE of the proposed centralized PV system in this study is 0.474 USD/kWh under the assumption that the diesel fuel price does not increase and 0.696 USD/kWh when the diesel fuel price doubles (Table 8). The gap between these prices is tremendous and would be unsustainable without a feed-in tariff (FIT) covering the difference. The International Institute for Sustainable Development (IISD) reported that the FIT incentive is already in place in Indonesia. However, the mechanism of how PLN reimburses the extra cost remains unclear (Bridle et al., 2018). Price caps are introduced by governments to ensure affordability; however, the present study witnessed that such intention does not work in the favor of the remote communities where the cost of grid extension is exorbitant and off-grid system becomes the only option. Partnerships with the private sector may become necessary but would only work if profit can be generated. A study in Ghana (Korzhenyevych and Owusu, 2021) reported a case community that shows willingness to pay (WTP) appropriate to the cost for electricity generation; therefore, one should not immediately assume incompatible WTP for all remote areas. Policy on energy pricing is a great example of “one size-does not fit-all”, which was one of the main lessons gained almost a decade ago (UN News, 2010) when the world transitioned from the commitment to Millenium Development Goals (MDGs) to the SDGs agenda.

4.3. The Developed Framework for an Appropriate Off-grid RE System Design

This study has demonstrated the process of designing an appropriate RE system for a community living in a remote agricultural village by analysing the user attributes and their satisfaction level with a selection of social values from Hirmer's wheel, assessing the RE resource potential, and price sensitivity. The steps of the process are summarized in Fig. 15 as a framework.

5. Discussion

Compared to a previous study employing MCA in a solar powered fishermen village in the Philippines (Hong and Abe, 2012), the present study provides insights into agricultural village energy needs by performing the MCA and the nonparametric (Chi-Square, Cramer's V, and Fisher's Exact) tests on various respondents' attributes and assets. While the previous study has identified the non-correlation between income-generating activities and electricity as a reason for unsustainable electricity intervention, the present study revealed the challenges of other forms of energy supply, such as transporting clean energy for cooking, the problem of cellphone signals, the relationship of income and modern technology adoption, the relationship of values on cultural preservation and maintaining traditional practices, and relationship between sense of safety and access to clean water, lighting, and safer cooking devices. The strongest correlation indicated by the Cramer's V value is between high income and cellphone ownership, with a value of 0.552 (Table 6), which is considered as the higher end of a moderate relationship (IBM, 2022). This relationship may indicate an important role of information and communication access in income generation. The energy system introduced in this study should be used to answer the needs of reliable cellphone signals so that a link between the village residents' needs and energy system can be created. This, in turn, will hopefully contribute to better sustainability of the system. Reusing the currently available solar panel is also a potentially good idea for immediate, low-cost solutions. Fig. 16 shows an example of a household signal booster installation diagram using the existing solar panel. Another idea to address the transportation cost issue is to use the proposed energy system or the existing solar panels to power electric motorbike charging stations (Fig. 17). The Indonesian government is currently offering various incentives for the affordable electric vehicle

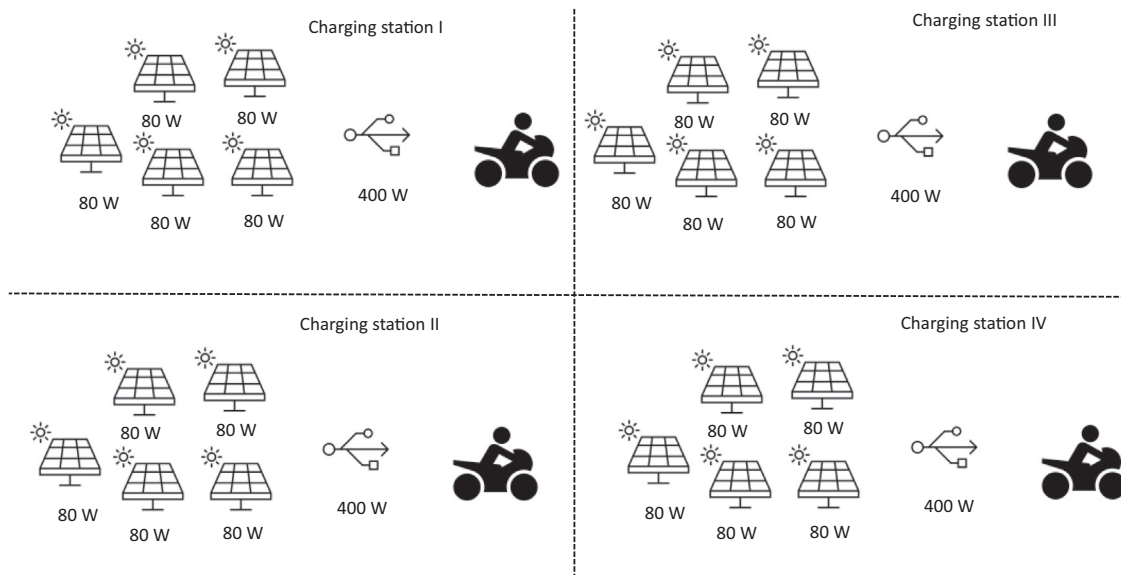


Fig. 17. Reusing existing solar panels as electric motorbike chargers (Pandyaswargo et al., 2021b).

Table 9

Best COE in other techno-economic assessment studies for renewable off-grid electrification using HOMER.

Literature (Author(s), year)	Location of study	Best COE (USD/kWh) ^a
(Vendoti et al., 2021)	India	0.214
(Sen and Bhattacharyya, 2014)	India	0.42
(Shahzad et al., 2017)	Pakistan	0.032
(Islam et al., 2018)	Bangladesh	0.20
(Chambon et al., 2020)	India	0.17
(Castellanos et al., 2015)	India	0.282
(El Zein and Gebresenbet, 2021)	Sweden	0.31
(Veilleux et al., 2020)	Thailand	0.29
(Xu et al., 2019)	Myanmar	0.3

^a Converted to USD using the February 2022 conversion rate when value is presented in local currency in the study.

industry and end-users to reduce air pollution and mobilize RE (Pandyaswargo et al., 2021a). This opportunity should be taken advantage of.

The second and third strongest correlations are between low satisfaction levels of transportation costs with LPG tank (0.516) and gas stove (0.509) ownership. With limited modes of transportation and poor access to the village, transporting heavy commodities such as the LPG tanks, comes at a high cost. This situation may indicate the need for a more appropriate energy technology for cooking, such as solar stoves to reduce their reliability on LPG. Solar stoves are known to be cost-effective (Liyew et al., 2021), and the resource assessment in this study revealed that the village has good solar radiation rates.

Other studies using HOMER for off-grid RE techno-economic assessment have generated various COEs (Table 9). It can be observed from the table that many of them are lower than the COE generated in the present study (0.474 USD/kWh). This is because most of the case studies summarized in the table were suitable for a multiple resource RE system (hybrid). The resource assessment exercised in the present study indicated that the case environment does not qualify for such system. The COE of the present study is comparable with the single RE system (Solar PV + Diesel Engine + Battery) case studies from Myanmar (Xu et al., 2019) and India (Castellanos et al., 2015), which is 0.425 USD/kWh and 0.409 USD/kWh, respectively. The two studies also demonstrated that combining PV with biomass energy can reduce COE. It is well documented that the present worldwide trend of RE systems that utilize biomass, geothermal energy, and hydropower can produce the lowest COEs, often lower than grid fossil fuel-based energy systems (IRENA, 2020).

The most significant response difference between genders in this study is on the reported amount of total household energy expenditure. While the female respondents reported lower expenditure for transportation fuel, the male respondents reported lower expenditure for cooking. In this particular village, the majority of the male occupation as farmers requires high mobility to cover the plantation area. On the other hand, many of the female residents are homemakers responsible for cooking. Considering a significant share of monthly energy expenditure both for mobility and cooking, energy policy studies should include both genders to obtain accurate numbers from both domains. Other studies have also emphasize the importance of gender inclusiveness in energy policy making (Shrestha et al., 2021).

In relation to providing access to the COVID-19 vaccine, refrigeration is vital for transport and storage. The proposed centralized RE system can support the electricity required to operate a refrigerator in the village's clinic. Although the shelf life of an mRNA COVID-19 vaccine can be extended to six months in ultralow temperature freezers (requiring extensive energy), the vaccine can still be stored in 2–8 °C conditions for 31 days (Pfizer-BioNTech, 2022), which should be sufficient to cover the 60 household members in the village. However, access to

the community itself poses a challenging road infrastructure. Therefore, efficient logistics for small size refrigeration that can be transported on narrow roads or air modes would be necessary.

The developed framework in this study (Fig. 15) can be applied to design an energy system in various communities especially in remote areas less likely to be electrified by grid extension. By following the steps in the framework, the social, technology, and economic issues surrounding the energy system can be observed. However, to implement and sustain the developed design, externalities such as policy challenges must be addressed. Most importantly, the social issues identified should be addressed appropriately where necessary. By employing a socio-techno-economic assessment, potential problems surrounding the energy system that could directly or indirectly impact the sustainability of the system can be anticipated, and potentials for innovative solutions can be identified.

6. Conclusion

As an approach to understanding the needs of a community living in a remote agricultural area, an MCA and nonparametric tests were exercised in this study to identify and verify the correlations between residents' attributes and satisfaction levels on social values. Observation of the results revealed that transportation is among the most problematic aspects, as the plantation community is quite isolated, especially to transport clean energy for cooking. This finding indicated a need for a more appropriate technology for cooking such as the solar stove to reduce dependency on LPG. This study also highlighted close relationships between higher income and ownership of cellphones and motorbikes and with non-ownership of kerosene lamps and bicycles. These findings may indicate the role of modern technology adoption and access to information and communication in income generation and suggest the necessity of linking the proposed energy system with improving cellphone signal stability.

The resource assessment of wind, biomass, and solar power in the case study village reveals that wind and biomass are not feasible because the supply rates did not meet the minimum requirement for the technology to operate. While a centralized solar-powered electricity generation system paired with diesel engines was deemed feasible, it must be supported by ensuring the deliverability of FIT to overcome the extra COE against the price caps enforced by the national electric company. Calculation of the solar power generation potential, in particular, can be further refined by using daily or hourly data where available. By doing so, the need to use specific real condition parameters such as arbitrary slope, orientation, shadows from hills and mountains, and panel efficiency, can be compensated. The present study has a resource limitation to perform the analysis to such extent but recommends it for future studies.

For the governments, this study recommends price cap exemptions for off-grid areas and encourages clear mechanisms and guarantees for FIT implementation. This study also highlighted the necessity of improving transportation access to villages to allow better access and affordability for education and nonelectric energy supplies.

For practitioners, it necessary to create a people-centered public-private partnership business model to be paired with the appropriate system design to address common sustainability issues of off-grid RE systems. Furthermore, identifying a site-specific social values and challenges is necessary to ensure social acceptance of the proposed system. By designing the system appropriately, practitioners can avoid unnecessary economic loss and identify business potentials.

Last, because this study was only applied to an agricultural village, future studies applying the developed framework to other remote areas with the challenge of access to the grid, such as isolated islands and communities living in vast forestry areas, are necessary for comparative assessments. Such studies may provide an understanding of the needs particular to various environment and community settings.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.spc.2022.03.009>.

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