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Reusing solar panels to improve access to information and communication in an off-grid village: A financial feasibility assessment

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Abstract

Pursuing Sustainable Development Goal (SDG) number 7, to "Ensure access to affordable, reliable, sustainable and modern energy for all," many off-grid villages received solar panels from external supports. However, these communities rarely have the capacity for reinvestment when the battery deteriorates. This study proposes reusing the abandoned solar panels as a power supply for cellphone charging stations and signal boosters. Taking an off-grid agricultural village in Indonesia as a case study, a cost–benefit analysis (CBA), net present value (NPV), and payback time estimation were conducted to determine the financial feasibility of the proposed strategy. The results identified that paired with an existing business, a four months payback time can be achieved under a standard scenario. Moreover, solar panels' end-of-life poses an environmental burden. A sustainable use that can take full advantage of the technology's lifespan should be considered when donating technologies to the bottom billions.
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Keywords: Off-grid electrification; Renewable energy; Solar panel; Sustainable development; Cellphone signal booster; Information technology

1. Introduction

The rate of access to electricity worldwide reached over 90% in 2019 [1]. However, some countries, especially in sub-Saharan Africa and Asia, still have millions living without access to electricity [2]. The world has pledged to "leave no one behind" under the Sustainable Development Goals (SDGs) [3]. Represented by SDG 7 on affordable and clean energy, efforts should be made to achieve that "last mile." National governments, international organizations, development aid agencies, and other types of development-oriented institutions have been providing

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philanthropies for communities living in remote areas, usually as a donation of renewable energy (RE) technology [4–6]. The solar panel is one of the most common RE technologies used in such initiatives, mainly because its price has plummeted in the past several years [7]. Additionally, installing solar panels is considered more straightforward and quicker than other stand-alone RE technologies, such as wind turbines, which may take several years to install [8]. However, not all solar panel assistance is provided with support through the lifespan of the technology. The lifespan of a solar panel can reach approximately 25 years [9]. Such duration is far beyond many assistance project lengths and the duration of the position of the political government in power. For example, many government-assisted rooftop solar panels for villages in Indonesia lasted only three years [6,10]. The short lifespan was because standard commercialized batteries and inverters of a solar energy system usually become fully deteriorated after three years [11–13]. Without the reinvestment of an energy storage unit, the energy generated by the solar panel cannot be used in the nighttime. With the low economic power of the receiving communities, failure to reinvest batteries has been identified as the leading cause of premature abandonment of RE systems in off-grid villages.

The present study aims to address such common challenges in the developing world by identifying social concerns and needs through surveys and then linking the result with the existing resources. The present study did this based on the understanding that energy system designers for remote communities should move away from a technology-centric approach and adopt needs or people-centric approaches to improve sustainability. Furthermore, solar panel end-of-life treatment poses a significant environmental burden. By extending the life and reaping the benefits of solar panels to their maximum lifetime, such an environmental burden can be reduced. This study shows an example of how to develop an appropriate solution and present a financial assessment to show that it can be done reasonably and economically.

2. Data and methodology

2.1. Solar panel users' attributes and needs identification

This study takes an off-grid agricultural village in Indonesia as a case study. A government program donated rooftop solar panels to households in Karya Jadi village community units 6 and 7 (Indonesian villages are commonly divided into several *Rukun Tetangga* (RT) or community units referred to as Karya Jadi village in the southern part of Borneo in Indonesia). The solar panels were distributed in 2014 [10]. However, the batteries have fully deteriorated after approximately three years from the distribution. Meanwhile, the solar panels, which are each 80 W in capacity, are still functional. These solar panels are currently used to power light bulbs during the daytime. However, this use is not optimal, as the most significant lighting demands occur early in the morning before the sun rises for morning prayers and cooking and during the evening for dinner time and leisure before bedtime [10]. It is important to note that the solar panels' ownership belongs to each household, and they are free to do whatever they wish to the panels even after the program.

The Karya Jadi village residents mainly work as farmers in oil palm and rubber tree plantations or their rice fields. The Karya Jadi village population has approximately 60 households located sparsely by a few hundred meters between houses. Public facilities existing in the village include a mosque and an elementary school. There is also a palm oil mill located just next to the village. This study collected a survey questionnaire and interviewed village residents and the head of the village (solar panel users) in 2019 and 2021. We summarized the socioeconomic attributes of 54 solar panel users in the village in Table 1.

Approximately 41.5% of the Karya Jadi village residents own a cellphone [10] with poor signal connectivity. Our recent survey revealed that access to communication and information is among the community's poorest satisfaction levels among other social services and values after energy quality and ease of transportation (Fig. 1). Cellphones owned by village residents are charged mainly with rechargeable lead–acid batteries (88%) commonly used for internal combustion engine (ICE) motored vehicles. Several respondents who do not own such batteries reported charging their cellphones in their neighbor's house.

2.2. People's needs significance verification and linking it with the existing solar panels

The previous subsection identified poor communication and information access as one of the most concerning needs in the village. Existing studies have identified the benefit of access to information and communication technologies (ICT) for women's empowerment, such as helping women gain employment [14], reducing barriers to

Table 1. Socioeconomic attributes of the solar panel users from the 2019 survey.

PV user characteristics, $n = 54$	Average or %	Min	Max
Age of respondents	41	17	86
Education level			
Never went to school	15		
Elementary school	63		
Junior high school	13		
High school	7		
University or vocational school	2		
Number of household member	4	1	6
Number of female household member	2	0	3
Number of male household member	2	0	3
Number of household members under 17 years old	2	0	4
Cellphone ownership	41.5		
Ways to charge cellphones			
By own Lead–Acid battery	88		
By own Solar Panel	4.7		
By neighbor's battery or solar panel	7.1		
Monthly household income[a]	95.24 USD	1.39 USD	389.92 USD
Monthly household expenditure[a]	62.13 USD	1.74 USD	178.6 USD
Monthly household expenditure for cellphone data[a]	3.06 USD	0.70 USD	8.01 USD

[a]Converted using IDR to USD conversion rate in January 2022.

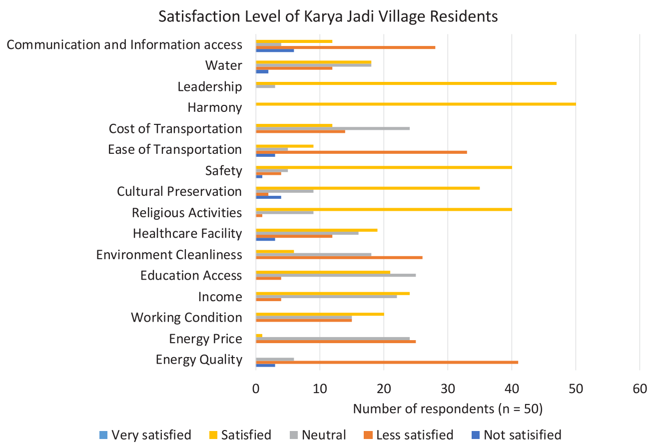

Fig. 1. Satisfaction Level of the Karya Jadi Village Social Services and Values (based on the 2021 survey).

information search [15], and increasing their economic power [16]. As developing countries are often characterized by a larger young population, providing access to ICT is vital to aid this pool of potential to the job market. A study from rural India showed that rural youth use cellphones to access education to improve their skills and employability [17]. It is then essential to identify the relationship between survey respondents who have expressed their need for better access to information and communication and their income levels. For that purpose, this study (1) categorizes the respondents' income level into low, medium, and high based on the sample quartile, (2) categorizes satisfaction level into "high" for "very satisfied" and "satisfied", "medium" for "neutral", and "low" for "less satisfied" and "not satisfied", and (3) tests the relationship between the two parameters with a Chi-square test. The Chi-square test is a nonparametric measurement to verify whether a relationship is significant and does not happen by chance. The test result is considered significant when the value falls below 0.05. However, if there are parameters with cells with less than 5 values, an exact test, such as Fisher's test, is conducted for a more precise result. When found significant, the test is followed by a strength statistic such as Cramer's V to show how strong the relationship is [18]. Table 2 summarizes the results. It can be observed that the relationship is significant and is at the upper end of

Table 2. Summary of nonparametric test results.

Crosstable parameters	Results Value			
	Chi-square test p value	Cramer's V	Number of cells with an expected count less than 5a	Fisher's Exact Test p value
Income level * Satisfaction level of access to information and communication ($n = 50$)	0.019	0.344	6 cells (66.7%)	0.028

Table 3. Summary of the expected and observed values of each parameter.

			Satisfaction level on access to Information and Communication			Total
			High	Low	Medium	
Income	High	Count	2	13	0	15
		Expected Count	3.6	10.2	1.2	15.0
	Low	Count	5	7	4	16
		Expected Count	3.8	10.9	1.3	16.0
	Medium	Count	5	14	0	19
		Expected Count	4.6	12.9	1.5	19.0
Total		Count	12	34	4	50
		Expected Count	12.0	34.0	4.0	50.0

a medium-strength relationship. Table 3 summarizes the expected and observed values. There are more respondents with higher income who have low satisfaction with the current access to information and communication.

By combining the two problems faced by off-grid rural villages, abandoned donated solar panels and poor access to communication and information, the present study proposes to reuse solar panels as an energy generation system to power a mobile phone charging station and signal boosters.

2.3. Cost and design for the cellphone charging station and signal booster

This study proposes reusing solar panels to create a cellphone battery charging station and signal booster. Tables 4–6 present the costs related to purchasing the required parts of the charging station and signal booster. Cost data are based on local prices to reflect the actual situation in Karya Jadi village. All prices are converted from the Indonesian rupiah (IDR) currency to USD using a conversion rate in January 2022 and incorporate the expected 5% increase because of added transportation costs to the village.

Table 4. Costs of charging station components (compiled by authors from [19,20]).

Cellphone Charging Station Components	Costs (USD)
12 V Battery	65.9085
AC Power Meter	8.0325
220 V outlet for charging	6.93
Data Logger	20.0865
Inverter	11.6865

2.4. A small business model to sustain the proposed designs

Previous studies have identified that RE technologies are at risk of being abandoned when they are not directly related to income-generating activities [26]. The introduction of off-grid electrification is also linked to increase in employment opportunities and income generation [27,28]. Considering these evidences, the present study proposes a small business model to generate income and sustain the technology, as presented in the design diagrams (Figs. 2 and 3). A few house-front shops commonly run by women residents in Karya Jadi village are potentially excellent

Table 5. Costs of the common cellphone brands' charging cable/adapters in Karya Jadi Village.

Cellphone brands (type)	Cost of the charging cable (USD/unit)	Number of units required[a]
Nokia (regular cellphone)	2.57	5
Samsung (regular cellphone)	5.88	3
Vivo (smartphone)	3.68	2
Samsung (smartphone)	16.54	1
Xiaomi (smartphone)	5.88	2

[a]The number of units is determined by considering the estimated ownership of cellphone brands in the village. Prices are from field survey 2022 with an anticipated 5% increase in transportation cost to the village.

Table 6. Costs of Cellphone Signal booster system components (compiled by authors from [21–24]).

Signal Booster Components	Costs (USD)
Cellphone signal booster	38.325
Outdoor Antenna, Grid Type 24dbi 2,4 GHz	8.0325
Indoor Antenna, Omni Type 3 dB/5 dBi, 800∼2700 MHz	6.93
Coax Cable for Outdoor Antenna, 30 M	20.0865
Coax Cable for Indoor Antenna, 5 M	11.6865

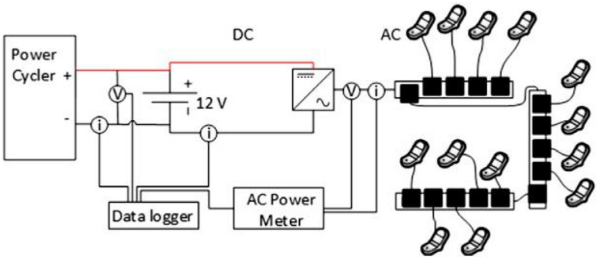

Fig. 2. Cellphone charging station diagram.
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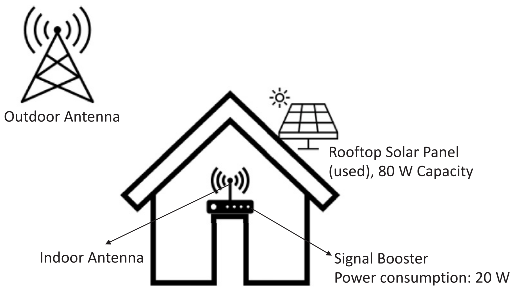

Fig. 3. Cellphone signal booster system diagram.
Source: Used with copyright permission from [25].

places to run the proposed business model. These shops sell daily necessities and gasoline for motorbike fuel in 1-liter bottles. One shop also operates a motorbike maintenance service business. The business idea is to provide a cellphone charging station in the shop where people can charge their cellphones while waiting for their motorbike to be serviced. While it is challenging to gain income from people using the improved cellphone signal in the vicinity, it is expected to attract customers to come, even those without intention to service their motorbike. The distance between houses in the village is commonly several hundred meters. Because the cellphone signal is poor throughout the village, one may come to obtain a better signal near the shop, and when the cellphone battery is empty, the charging station in the shop can provide some convenience. With this business model in mind, an additional initial investment that must be borne is the charging cable of several common brands of cellphones used in the village (Table 7). Considering the local prices from several years ago [29], the proposed fee for charging is 5000 IDR or approximately 0.35 USD for one-time charging or until the cellphone battery is full. The number of units of charged cellphones per day and increased revenue from other income in the shop is estimated from a reported experience by a similar business in the country during its peak and low season [30]. Table 5 presents the benefits of introducing the business model.

Table 7. Financial benefits from the proposed business model and parameters for sensitivity analysis.

Income sources	Benefit	Sensitivity Analysis	
		Pessimistic Scenario	Optimistic Scenario
1 time charging fee/unit cellphone until fully charged	0.35 USD, 10 units/day	0.2 USD, 2 units/day	0.7 USD, 20 units/day
[a]Increased revenue from the shop	3%	0%	5%
[a]Increased revenue from the motorbike service	3%	0%	5%

[a]The current revenue of the shop and the motorbike service is 6.96 USD/month each.

2.5. Financial assessment methods

To conduct a cost–benefit analysis (CBA), this study employs the Benefit-Cost Ratio (BCR) formula (1), Net Present Value formula (NPV) (2), and payback time formula, which are commonly used to test a project's financial feasibility [31,32].

$$\mathrm{BCR} = \frac{\sum_{t=0}^{n} B_t/(1+r)^t}{\sum_{t=0}^{n} C_t/(1+r)^t} \tag{1}$$

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t} \tag{2}$$

where B is the benefit, C is the cost, i is the discount rate, and t is the cash flow time. The BCR is calculated as the present value of the benefit divided by the present cost value. It shows the number of benefits returned for each dollar invested. The larger the BCR is, the greater the benefit a project generates for each dollar invested. NPV is defined as a measure of discounted cash inflow to present cash outflow to determine whether a prospective investment will be profitable. A positive NPV means that the project would be profitable, and a negative NPV means that the project would not be profitable. Finally, the payback time is calculated as the total year from investment to when the cumulative cash flow becomes positive during the project's lifetime.

The assumed annual working days is 313, considering six working days per week minus the national holidays, in the Indonesian calendar of 2022. Therefore, the discount rate is considered to be 3.5% (2021 discount rate) [33], and the cash flow time is determined to be three years, considering the average lifespan of a cellphone charger.

3. Results and discussions

The BCR of the proposed business model calculated with (1) is 13.03 for the standard scenario, 0.71 for the pessimistic scenario, and 37.49 for the optimistic scenario. These findings imply that other than the pessimistic scenario, the proposed business model would be beneficial (BCR of over 1.00), with the optimistic scenario generating the highest benefits. The zero maintenance and operational costs influenced high BCR rates in the standard and optimistic scenarios. In on-grid areas, the operational cost of a charging station comes from the electricity supply. With the present case study being in an off-grid area using a donated solar panel, the electricity cost is zero. Additionally, considering the size of the panel, which is only approximately 1.5 × 1.5 m, daily wiping to remove debris to maintain the condition of the solar panel is negligible.

The NPV of the proposed business model calculated with (2) is identified as 2861.85 USD under the standard scenario, −68.60 USD under the pessimistic scenario, and 8683.24 USD under the optimistic scenario. These findings imply that, other than the pessimistic scenario, the proposed business model will be profitable. The payback time of the standard scenario is less than half a year (in the 4th month), with a positive cash flow of 881.75 USD in the first year alone. In the pessimistic scenario, the payback time cannot be achieved over the three years expected lifespan of the cellphone charger. However, under circumstances of a longer lifespan because of minimum usage of the chargers, a payback time could be achieved near the end of the 4th year (in the 52nd month). Last, the optimistic scenario shows a payback time on the 3rd month with a positive cash flow of 3033.19 USD in the first year alone (Fig. 4).

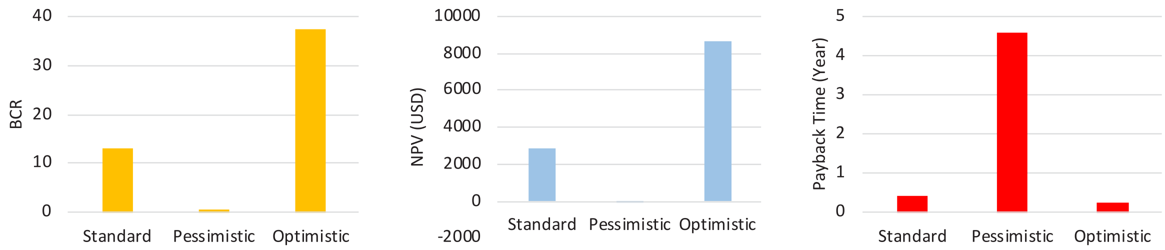

Fig. 4. (a) BCR; (b) NPV; (c) Payback time.

Considering the outputs of the BCR, NPV, and payback time of all scenarios, it can be concluded that the proposed business model of reusing solar panels for cellphone battery charging and signal booster would bring a promising financial benefit, especially when paired with an existing business. Some factors supporting the promising financial output are as follows: (1) The existing small shop businesses are strategically located as the residents of Karya Jadi village already regularly use the service and know the location well. This would eliminate the need for marketing-related costs and efforts. (2) The initial cost of solar panels and the operational cost of electricity supply are zero. (3) There is an existing demand for cellphone charging and a stronger cellphone signal.

While there are risks of slight inaccuracy in the estimation of prices and willingness to pay (WTP) in this study, low-to-moderate prices considering the local prices are already incorporated into the study. A pessimistic scenario was also presented to demonstrate how the proposed business would perform under such circumstances. The results showed that even under the pessimistic scenario, the payback time would still be achieved within a two-year delay from the predicted technology life span as long as the chargers' lifespan can accommodate. The most significant limitation in this study would be the assumption that the initial cost comes from the business owner's saving so that a hefty interest rate can be avoided. However, considering the highest household income and expenditure in the village (Table 1), an initial total cost of 263.85 USD (85.06 USD for the cellphone signal booster and 178.79 USD for charging station) is predicted to be securable within the village's community, especially considering the promising high BCR, NPV, and a quick payback time.

4. Conclusion

The off-grid environment of Karya Jadi village has imposed a barrier to the community in accessing information and communication. With no reliable electricity supply and poor signal for cellphones, the village needs better charging and cellphone signal infrastructures. Solar panels distributed by the government in 2014 have become dormant because of the lack of reinvestment for the deteriorated battery and inverter. On the other hand, almost half of the households own a cellphone. The nonparametric tests performed in this study showed a correlation between income level and satisfaction level to information and communication access.

The present study proposed a business model and showed the financial feasibility of reusing solar panels to improve access to information and communication. The three financial feasibility analysis tools (BCR, NPV, and payback time) exercised in this study showed positive outputs. Except for the pessimistic scenario, healthy financial cash flows are predicted to be achievable throughout the lifetime of the proposed business model.

Improved connectivity of an off-grid village is known to support the residents' access to better-paying jobs, access to capacity building, and better life opportunities and conditions, especially for the young and the women. This study has shown an innovative way to open such possibilities. Further studies are encouraged to seek solutions that answer the needs of the bottom billion living in other off-grid rural areas. This study emphasizes the importance of a needs-based solution rather than a technology-centric solution and recommends a social analysis prior to the design stage, as demonstrated in this study (Fig. 1).

Declaration of competing 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.

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