CSID Journal of Infrastructure Development

Volume 5 | Issue 1 Article 9

12-31-2022

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Recommended Citation

Yuan, A., Pinka, D., & Setyowati, E. (2022). Evaluating The Implementation of Solar Home Systems (SHS) In Sumba – East Indonesia. *CSID Journal of Infrastructure Development, 5*(1), 112-121. https://doi.org/10.32783/csid-jid.v5i1.259

CSID Journal of Infrastructure Development (5) 1: 113-126
ISSN 2407-4438

EVALUATING THE IMPLEMENTATION OF SOLAR HOME SYSTEMS (SHS) IN SUMBA – EAST INDONESIA

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(Received: August 2022 / Revised: October 2022 / Accepted: December 2022)

ABSTRACT

The lowest electrification rate in Indonesia is in East Nusa Tenggara (NTT) province, leading to a high poverty rate and low education level. At the same time, NTT has higher solar irradiance than the Indonesian average, which can be used for electrification. In 2019-2021, seventeen (17) Solar Home Systems (SHS) were installed in churches with no electricity grid connection to address these challenges. These systems serve church community activities as well as learning centers for students. The first system design was improved and adopted in 2020 and 2021 to meet users' needs better. However, the COVID-19 pandemic made it difficult to visit and monitor the first installations for around two years. Therefore, the attempt to evaluate the SHS project remains a challenge. In March 2022, surveys were conducted in this study to assess the SHS' installation quality, the electrification situation, and how to improve existing and future SHS' installations. The results show that the electrification ratio was increasing fast, and SHS has a positive economic impact compared to diesel generators. Furthermore, to improve its usability and decrease its failure, active service is key to increasing working SHS and improving its usage.

Keywords: Electrification; Off-grid; Renewable Energy; Solar Home Systems (SHS); Sumba

1. INTRODUCTION

Sumba is one of the islands in the East Nusa Tenggara o(NTT) province of Indonesia. It has an area of about 11,000 square meters. Sumba's neighboring islands are Sumbawa to the northwest, Flores to the northeast, Timor to the east, and Australia to the south and southeast. The Sumba Strait is located on the island's north, while the Savu Sea lies to the east and the Indian Ocean to the south and west. According to the Central Bureau of Statistics (BPS) of East Nusa Tenggara (2021a), Sumba's population was estimated to be 788,189 in 2021.

The year in Sumba is divided into rainy and dry seasons, where the dry season is longer than the rainy season. The rainy season usually happens from December to April, and the remaining eight months are dry. The rainfall in Sumba ranges from 0 mm to 294 mm (BPS East Nusa Tenggara, 2021b). The highest number of rainy days is less than 25 days, while the national average number of rainy days is 226. The temperature range is about 15-36 degrees Celsius. Moreover, according to the Global Solar Atlas map, Sumba has huge potential for daily global horizontal solar irradiation of 4.8-6.0 kWh/m2, above Indonesia's average.

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DOI: 10.32783/csid-jid.v5i1.259

However, the electrification ratio of NTT Province in the last five years is the lowest among others in Indonesia. The electrification ratio is the ratio of the number of electrified household customers from PT PLN as the state electricity company and non-PLN electricity to the total number of households. Figure 1 shows the electrification ratio of East Nusa Tenggara compared to the national average (Ministry of Energy and Mineral Resource, 2018, 2019, 2020, 2022).

Figure 1. The electrification ratio of NTT compared to Indonesia

Sumba Timur has the highest number of poor people, 3.5 times higher than the national percentage. The percentage of poor people in Sumba is shown in Figure 2.

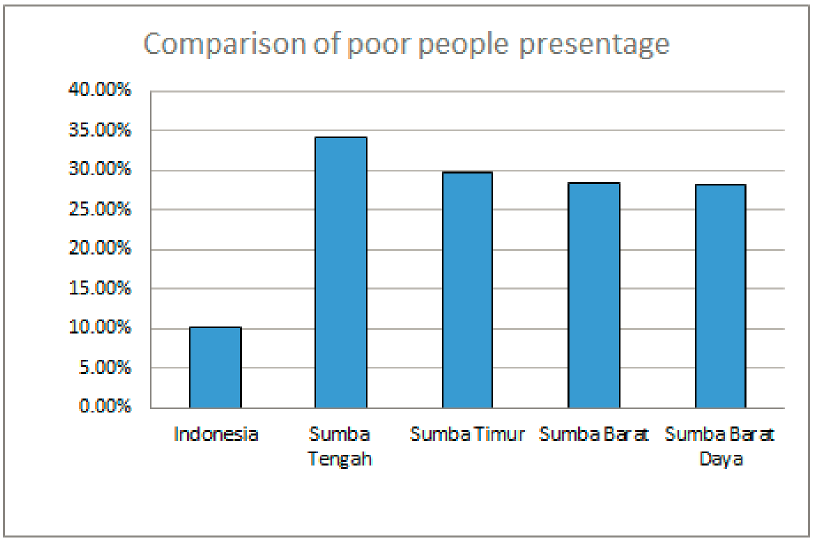

Figure 2. Percentage of poor people in Sumba compared to Indonesia

According to Indonesia's poverty data for the year 2021 from BPS Indonesia (2021), the percentage of poor people aged 15 years and older who completed their senior high school and higher education in NTT was 10 % lower than the national average. Figure 3 shows the percentage of poor people aged 15 years and older by provinces and senior high school education and higher education completed.

Energy is important in raising education levels that may lead to improved economic growth, allowing individuals to overcome poverty (Karekezi et al., 2012; Sule et al., 2022). The indirect benefit of utilizing solar home systems may lead to a better life and health quality, prolonged work duration, the creation of new businesses and new jobs, and adding at least two productive activities for people (GOGLA, 2018).

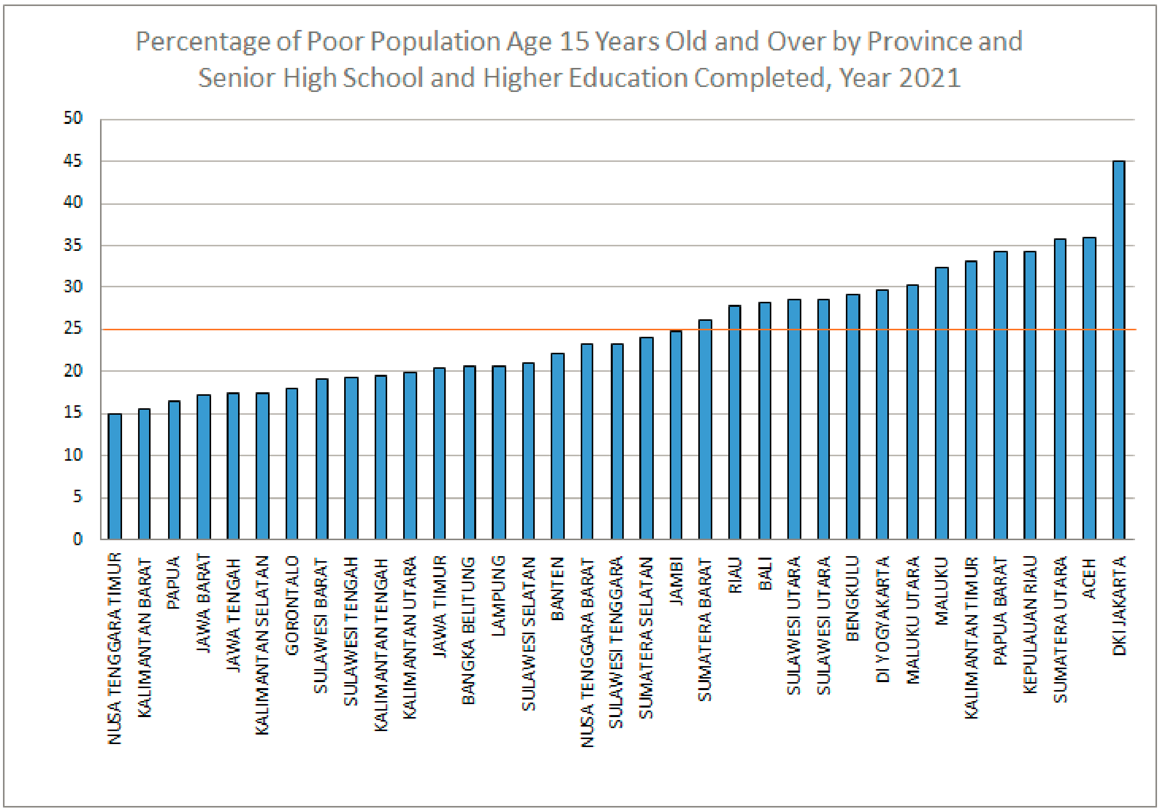

Figure 3. Percentage of poor people aged 15 years old and older by province and senior high school and higher education completed in 2021

The high solar irradiation levels make solar energy the most promising energy source that can be developed in Sumba to strengthen renewable energy sources (Budi et al., 2020). Depending on the village size and density, off-grid central solar systems or smaller capacities of individual Solar Home Systems (SHS) can supply energy. However, existing SHS installations face malfunction problems within a short period due to the lack of after-sales and maintenance services.

Some studies and surveys were conducted to understand the situation and the needs of the people before SHS installation (Apple et al., 2010; Lam et al., 2012). It was found that some remote villages in Sumba and Timor did not have electricity access. Even though some people already have small SHS for lighting; however, they must go to a nearby electrified village for phone charging at a rate of IDR 2,000 – 5,000 (EUR 0.12 – 0.30) per phone charge.

Meanwhile, people without electricity or SHS in their houses use kerosene lamps as lighting at night in a limited source. Therefore, children rarely learn in the evening. This lack of lighting also impacts security, for example, cases of theft of livestock, damage to agricultural land, and the destruction of public facilities. Furthermore, using kerosene lamps also has negative health impacts due to the high concentration of particulate matter (PM) 2.5 emissions.

Therefore, seventeen (17) SHS were installed at the churches in Sumba and Timor to provide electricity, starting from 2019 to 2021. Before the installation, SHS components and system simulations were conducted to meet the church's electricity needs. The churches were chosen since they were the central meeting points for the public. Monitoring and evaluation were held towards the installed SHS by visiting 9 (nine) churches in March 2022. Some system malfunctions were also analyzed and fixed to ensure system sustainability. Moreover, questionnaires were developed to evaluate the SHS installation, usage, and outcome. During the church's visitation, constructive dialogues were conducted with the user to understand project implementation better.

2. METHODS

2.1. Project Situation

The center for renewable energy development of Universitas Kristen Immanuel (UKRIM) installed SHS focused on Sumba's five churches not connected to the electricity grid in 2019. The churches usually rent generator sets (genset) for evening church activities, with total costs oat IDR 200.000 (€12) for one evening event. For economic reasons, annual evening events are often limited to only a few occasions, less than five per year.

After the installation in 2019, more churches asked for SHS to improve their situation. Until January 2022, 14 (fourteen) SHS were installed in Sumba and 3 (three) other systems in Timor. The location of SHS installed in Sumba in 2019-2020 can be seen in Figure 4, where blue spots are where the SHS were installed in 2019, green spots were installed in 2020, and red spots were installed in 2021.

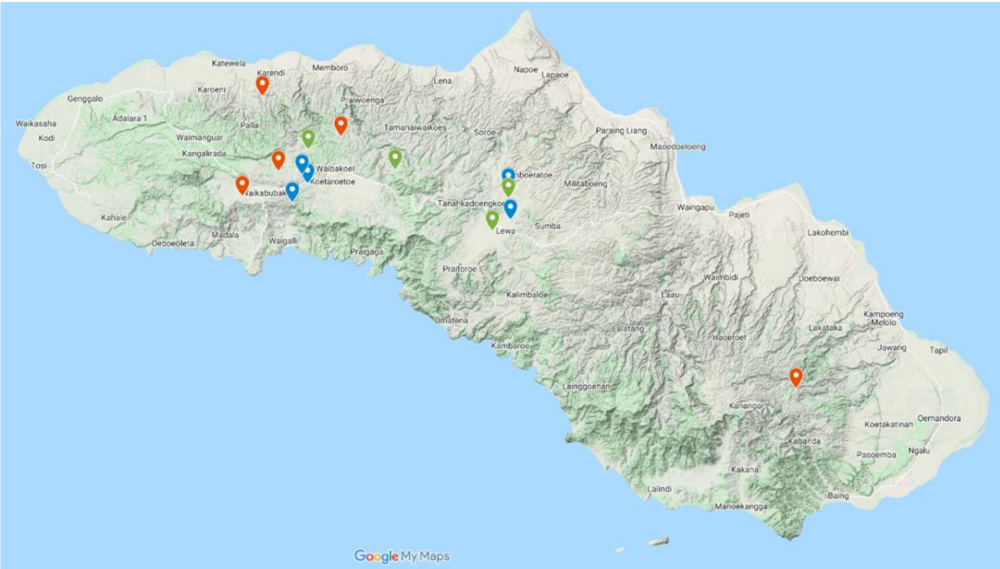

Figure 4. Location of SHS installations

2.2. The Objective of the SHS Installation in Churches

The projects were financially supported by the donor who wanted to help with the electricity situation at the churches. Churches are often used as gathering centers for people in NTT; therefore, more people can access the electricity for weekly worship and phone charging, while students living nearby can use it for studying at night. Moreover, churches are considered trusted institutions to use the system responsibly. The objective of the SHS installation was to provide reliable electricity for churches in remote areas. The church community can gather for evening events like Christmas service, but the light can also be used for other activities.

2.2. The Benefits of the SHS Installations

Our goal is to bring lighting to churches where there is no access to electricity and especially to people who live around churches. The installed SHS brings several benefits to the users. With adequate lighting, the church can organize evening activities, such as evening worship, holding community meetings, and making crafts, further strengthening the community, and increasing income. Learning centers can be arranged, and students can learn together and improve their educational level using the light. The security situation can be increased by using lights during the night. To charge their phones, people do not have to go to another electrified village but charge it (with permission from the church management) at the church. Internet connection has become more important, especially since digitalization increased during the covid19 pandemic. Compared to gensets, a solar home system is more economical. If the solar home system is used only twice a week, the return on investment is less than one year compared to fuel costs to run a genset. Moreover, the SHS does not produce noise or CO_2 emissions.

2.4. SHS Components

2.4.1. The SHS's main components

The SHS's main components consist of photovoltaic (PV) modules, a battery, and a solar charge controller. PV modules absorb and convert solar radiation as an energy source into electrical energy. A PV module is a connected assembly of several similar solar cells. The electricity generated from a PV module depends on the amount of radiation falling on the surface of the module, meaning that the orientation of the module, weather, and cleanliness must be considered (Quaschning, 2016).

The PV module size was calculated during the Internal Workshop at UKRIM in 2021), using the equations below:

$$PSH\ (h) = \frac{GHI\ (kWh/m^2/}{1000\ (W)} \quad (1)$$

$$Capacity\ needed\ (W) = \frac{Total\ daily\ consumption\ (}{PSH\ (h)} \quad (2)$$

Where Peak Sun Hour (PSH) is the equivalent area of total energy captured throughout the day, while Global Horizontal Irradiation (GHI) in Waikabubak, West Sumba, is 5.3 kWh/m²/day (Global Solar Atlas, 2022).

The battery is the next main SHS component. Since the PV modules produce electricity only during sun hours, the battery plays an important role in the energy system. Batteries are required for the storage of excess energy production from PV modules. The type of battery used is different from vehicle batteries. The battery used in the SHS installation in Sumba is a deep-cycle battery. This battery is a type of battery that is designed to produce stable energy (electric current) for a long period. The battery must be placed in a closed location with good air circulation (Quaschning, 2016).

The battery size was calculated as follows:

$$Energy\ requirement\ (Wh) = Total\ daily\ consumption\ (Wh) \times self\ sufficiency\ days\ (day) \times charge\ loss \quad (3)$$

$$Battery\ capacity\ (Ah) = \frac{Energy\ requirement\ (Wh)}{System\ voltage\ (V)} \quad (4)$$

The solar charge controller, or charge controller, is a voltage and current regulator to keep the battery from overcharging. This SHS main component regulates the voltage and current from the PV module to the battery. This appliance should be in a place that is safe from water and has easy access to fuses and electrical terminals (Fuentes et al., 2018; Mazibane et al., 2019).

2.4.1. The SHS's additional components

Some additional components in SHS include switch boxes, cables, and fuses. The switch box was used for connecting electronic equipment placed in several positions (e.g., main room lights, porch lights, small room lights) to the on/off switch of the lamps and other appliances. The switch box was designed and built by UKRIM students to help users save their electricity consumption. Although it is made with a waterproof box, the switch box should be placed indoors and kept away from water and insects to avoid connection failure.

Furthermore, cables must be properly labeled, color-coded, well-insulated, and adequately attached to the components to ensure a good installation. Selecting the correct cable size will reduce energy losses in system operation (Fuentes et al., 2018). In addition, fuses are important for overcurrent protection. The right fuse selection will secure the PV system and the connected electronic equipment. It can be placed between the PV module with the solar charge controller, between the solar charge controller and the battery, and between the Solar charge controller and the switch box (Mazibane et al., 2019). The circuit diagram of the installed SHS can be seen in Figure 5.

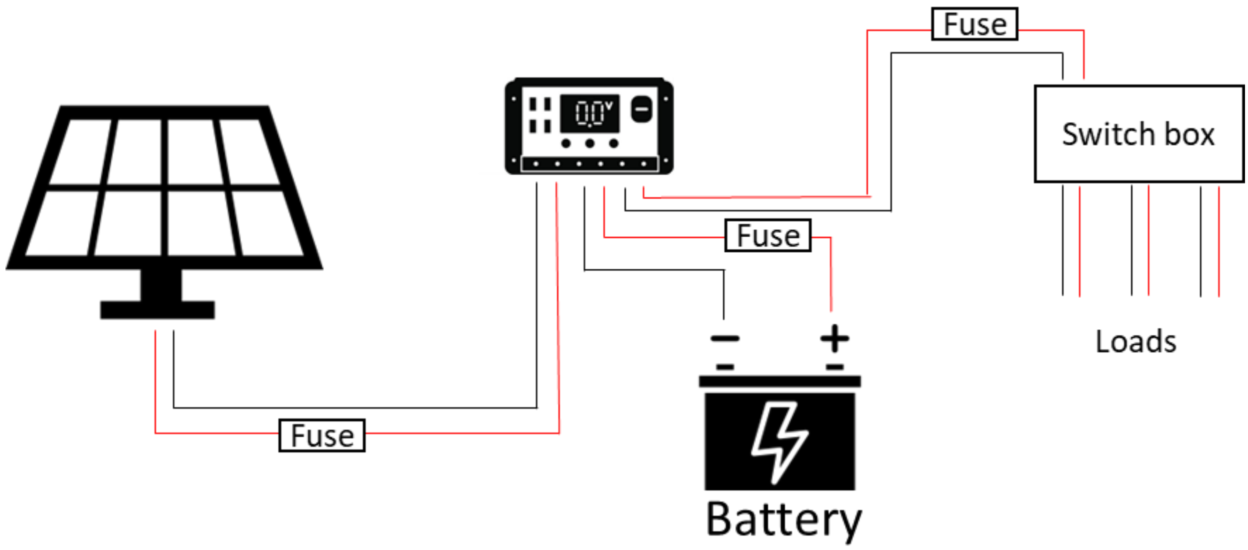

Figure 5. Diagram of SHS components

2.5. SHS Development

During the four years of this project, several improvements to several components were made, as can be seen in Table 1. During the 2019 project, the researchers got to know the situation better and improved the installations to meet the needs better. In 2020, it was discovered that some churches used loudspeakers by connecting the wires directly to the battery. For the safety and durability of the SHS and the appliances, the switch box was upgraded by adding 12 volts DC output plug that can be used for the loudspeaker system and other 12V devices. Since 2021, Solar Charge Controllers (SCS) has been used with a display showing the voltage and four-bar battery status so that users can manage energy consumption accordingly to the battery status. The SCS also has two integrated USB plugs; hence, the switch box design could be simplified. The size of the solar modules increased from 100Wp to 120 Wp for faster battery charging during the rainy season, and the battery capacity decreased from 100Ah to 80 Ah, as discussed in the subsection below.

Table 1. Description of Components of solar home system

Components	2019	2020	2021	2022
PV modules	Capacity: 100 Wp Series: Polycrystalline silicon / SW100P	Capacity: 100 Wp Series: Polycrystalline silicon / SW100P	Capacity: 120 Wp Series: Monocrystalline silicon	Capacity: 120 Wp Series: Monocrystalline silicon
Battery	Capacity: 100 Ah Series: LPC Series – Deep Cycle	Capacity: 100 Ah Series: LPC Series – Deep Cycle	Capacity: 80 Ah Series: SEG12-80/ gel series battery	Capacity: 80 Ah Series: JP80-12 G/ VRLA gel battery
Solar Charge Controller	Capacity: 12/24VDC, 10 A Series: PWM, LS2024R	Capacity: 12/24VDC, 10 A Series: PWM, LS2024R	Capacity: 12/24VDC, 20 A Series: PWM, VS2024AU with 2 USB plugs	Capacity: 12/24VDC, 20 A Series: PWM, VS2024AU with 2 USB plugs
Switch box	Three switches and one USB port	Three switches and one USB port	Three switches	Three switches
Survey	Without questionnaire	Paper-based questionnaire	Paper-based questionnaire	Online questionnaire and local assistants
Output	Five bulbs in total One USB port	Five bulbs in total One USB port One 12VDC port	Five bulbs in total Two USB ports One 12VDC port	Five bulbs in total Two USB ports One 12VDC port
Systems installed	Five systems	Four systems	Five systems + three systems at Soe	Five systems were installed in June 2022

2.6. Simulation Results

2.6.1. The SHS in 2019-2020

A simulation was run using the Photovoltaic Geographical Information System, accessed on the website https://re.jrc.ec.europa.eu/. In 2019, the system used a 100 Wp panel capacity and a 100 Ah battery. Table 2 and Figure 5 show the simulation results for systems with the above capacities.

Table 2. The simulation results for SHS in 2019-2020

Provided Inputs		**Simulation Outputs**	
PV installed [Wp]:	100	Percentage days with full battery [%]:	83.03
Battery capacity [Wh]:	1200	Percentage days with empty battery [%]:	1.44
Discharge cutoff limit [%]:	50	Average energy not captured [Wh]:	110.2
Consumption per day [Wh]:	300	Average energy missing [Wh]:	92.25
Slope angle [°]:	10		
Azimuth angle [°]:	180		

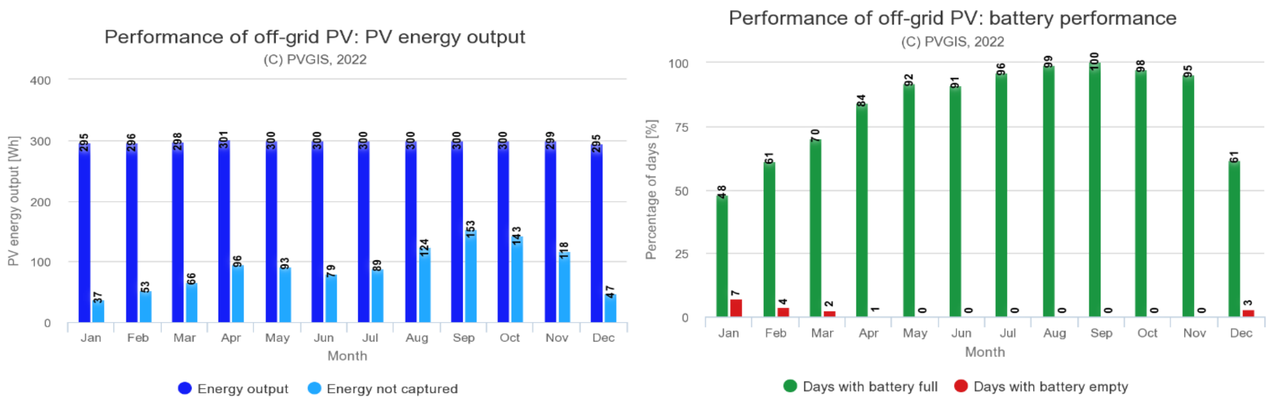

Figure 6. Simulation result of PV energy output and battery performance of SHS in 2019-2020

2.6.2. The SHS in 2021-2022

Based on reports from several users in 2019-2020, the solar charge controller often showed a red light indicating the battery was almost empty, even on sunny days. The report was finally evaluated and concluded to increase the capacity of the PV module to 120 Wp and reduce the battery capacity to 80 Ah. The lower battery capacity helps recharge it faster. Table 3 and Figure 7 show the simulation results for systems with the capacities. As a result, the days without batteries could be decreased by 50% from 16 to 8 days. Feedback from users confirmed that their systems no longer show a red light. The system costs did not change significantly as the smaller battery was cheaper, and the solar module prices decreased over the years.

Table 3. The simulation results for SHS in 2021-2022

Provided Inputs		**Simulation Outputs**	
PV installed [Wp]:	120	Percentage days with full battery [%]:	93.02
Battery capacity [Wh]:	960	Percentage days with empty battery [%]:	0.75
Provided inputs:		Simulation outputs:	
Discharge cutoff limit [%]:	50	Average energy not captured [Wh]:	181.47
Consumption per day [Wh]:	300	Average energy missing [Wh]:	81.86
Slope angle [Â°]:	10		
Azimuth angle [Â°]:	180		

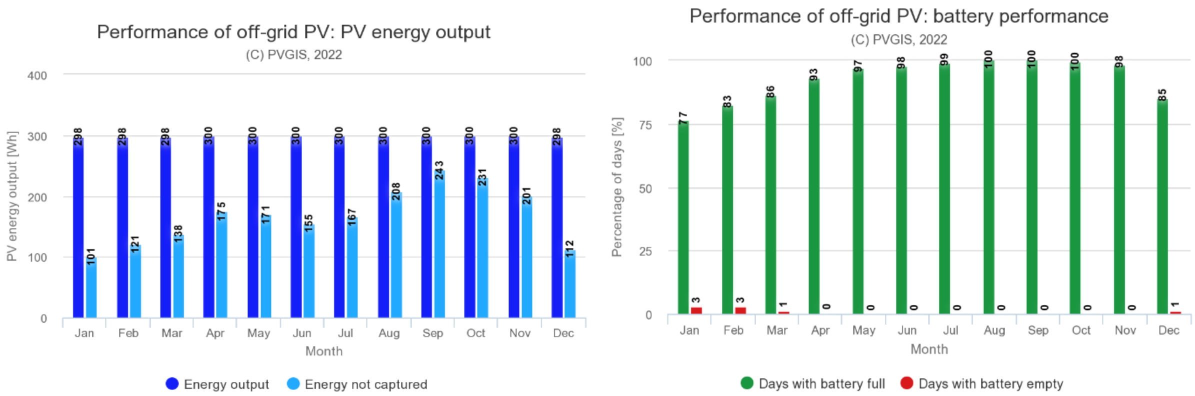

Figure 7. Simulation result of PV energy output and battery performance of SHS in 2021-2022

2.7. Evaluation of Installed SHS

Since the first project in 2019, questionnaires have been used to learn about the churches' situation before installation. The questionnaires were sent to a local contact and shared with the churches. The quality of the survey results was below the expectation since some respondents were not trained to read and file documents but had to fill out the questionnaire without help. Furthermore, the results were shared via instant messaging services and were often unreadable.

Based on this experience, an online questionnaire was developed to evaluate churches after the SHS installation. People from ten churches were interviewed face to face, with the data saved in an online database. Next to the location and biodata of the churches and contact persons, there were three questions mainly asked:

1. What is the status of the installation? What is working, and what is not working? Does the system produce enough electricity?
2. How is the electrification situation? Do you already have an electricity grid connection? Is a grid connection planned for this year?
3. How are you using the system? What are the benefits?

3. RESULTS

The interviews for this evaluation took place in March 2022. There were 14 SHS planned for evaluation using questionnaires and interviews, 9 SHS was visited directly by interview, 3 SHS information was obtained from local technicians and 2 SHS did not provide feedback and could not be visited due to the very remote location, but the electrical conditions of the SHS installation area is known. Percentages shown were based on the available amount of data.

3.1.1. What is the status of the installation? What is working, and what is not working? Does the system produce enough electricity?

Among the 12 systems covered in the survey, only five worked without problems. Seven systems did not have working lights. After checking the components, two churches did disconnect the switch box, and two churches did disconnect the solar battery and changed it to a small motorbike battery. It was found later that the motorbike battery was only temporarily connected to electricity use and in other areas for light.

Error analysis showed that all solar modules, all batteries, and all charge controllers were working fine. One charge controller had to be exchanged due to a bad thread for the battery connection.

In all cases of damaged solar systems, the main reason was broken LED light bulbs. Sometimes users replace the 12 V DC Light bulbs with 220 V AC light bulbs. The analysis was used to educate the user only to use 12 V DC lamps and warn them not to change cables without permission. Some systems built in 2019 were installed without a switch box and the information on the technician’s contact number. It can be perceived that the main reason for the high failure rate in 2019 is that the installation was not carried out by trained installers.

Moreover, cables were not properly connected; the locals were not trained to use the system and how to troubleshoot the system. Besides, switch boxes were not installed, and no contact number for technical support was provided. As users experience electricity for the first time, simple things like changing a light bulb - especially a 12 Volt DC bulb - are challenging without advice or technical training. The following simplification was made to quantify the results: Light is working=1, and Light is not working= 0. Figure 8 shows that none of the 2019 installations worked at the evaluation time.

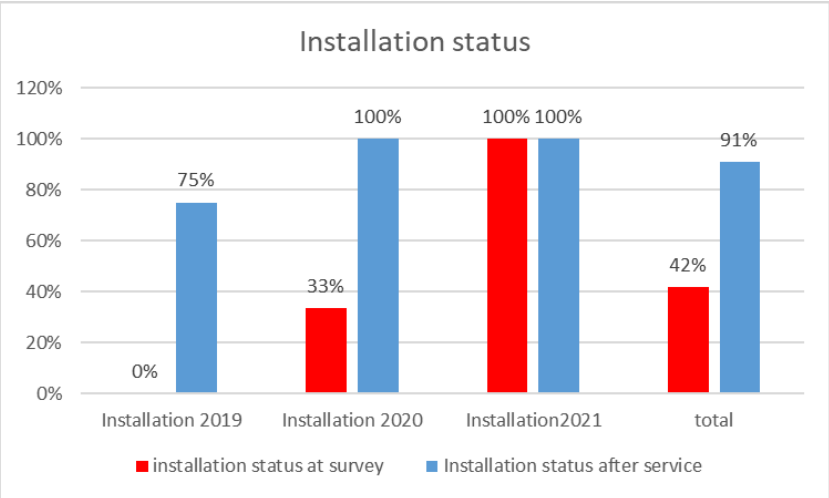

Figure 8. Percentage of installations that are fully working

After service, the number of running systems increased to 3 (75%) from 2019. One system was disconnected from an old building and not yet connected to the new building. The users mentioned that the building is used in the daytime. Furthermore, they are waiting for a grid connection this year. The survey and the subsequent service of defective systems could increase the installed running systems from 2019 - 2021 from 42% to 91% (11 of 12 systems).

3.1.2. How is the electrification situation? Do you already have an electricity grid connection? Is a grid connection planned for this year?

As mentioned earlier, the electrification ratio in Indonesia has been increasing fast in recent years. It is also reflected in the survey results, which can be seen in Figure 9. At the installation time, no location was connected to the electricity grid. Power poles were already installed in some places, but houses were not connected for several years. The electrification rate increased from 60% in 2017 to almost 90% in 2021. Users already connected to the grid still like to use the solar system as backup during frequently occurring power outages and to save electricity costs. The church's system, connected to the grid from 2019, could be installed in a church without a grid connection (not included in Figure 9 below).

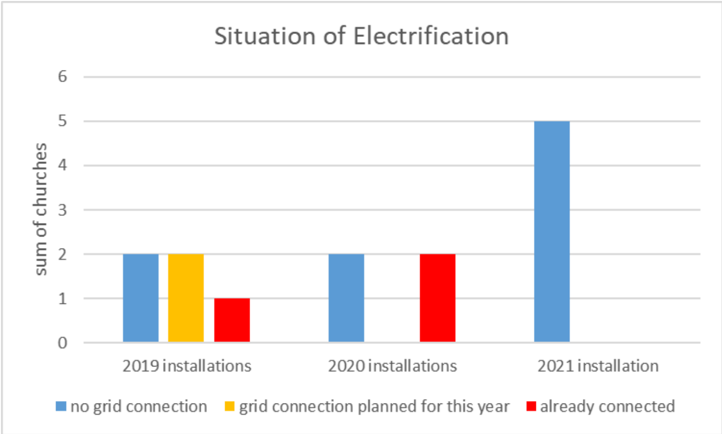

Figure 9. Current Situation of electrification of SHS installations

3.1.3. How are you using the system? What are the benefits?

The purpose of solar home systems installation in churches without grid connection is to support churches in their activities and serve the community. As mentioned earlier, electrification is key to increasing education and the economy. The third question should help to understand the usage and potential of the system.

Figure 10 shows that most churches mentioned using the system for evening church services and other evening activities from the church, like meetings and youth services. Depending on the church location, people often use the USB charger for phone charging, as five churches have mentioned. In villages without electricity, people often must go to a neighboring village to charge their phones. Four churches also mentioned using or wanting to use the system to have a learning center for students, especially in regions where homes also do not have electric lights. Two churches mentioned using or wanting to use the system so women can weave traditional Sumba cloth in the evening. It is crucial since Sumba cloth produced from the weaving activity can be sold at the local market or to tourists, increasing the economic situation. One church did not use the system as they only have services in the daytime.

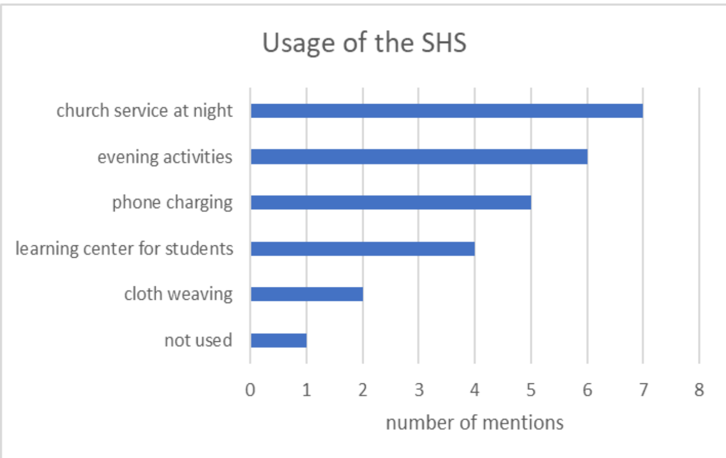

Figure 10. The usage of the SHS

4. DISCUSSION

A number of SHS was installed in 17 churches in Sumba and Timor and has been improved yearly to meet better the users' needs, e.g., by adding additional 12V outputs at the switch box. The system design was adapted to decrease the number of days with an empty battery from 16 to 8. Compared to a genset, the SHS is more economical and convenient as the user does not have to buy fuel and is not distracted by noise and pollution.

The first installation done by untrained technicians showed a high failure rate. Therefore, the installation quality was improved to reduce the system malfunctions for newer installations. Moreover, the most common reason for failure was defective DC lights. As a result of the evaluation, users need to be educated to use only 12V DC lights and contact the local technicians if the system is not working. In the future, the local technician will contact the users regularly to ask about the system's status to prevent downtime of SHS proactively.

Churches are chosen for SHS installation in this project since they are often used as gathering centers for people in NTT. The systems are used mostly for church evening activities, phone charging for the congregation, and learning activities for residents living around the church with permission from the church administrator. People are creative in ways of using it. Some church members also used the system for craft work and could increase their income. The usage of the system also depends on the location of the church. The community uses a church building close to neighboring houses more often than a stand-alone building.

The electrification ratio in Sumba has increased rapidly in the last few years. Therefore, to maximize the impact of SHS, the location should be selected more thoroughly to serve areas where no power grid is planned yet. Solar systems are still being used after PLN connection to save energy costs and as backup energy, as the grid connections are often unreliable, especially in rainy seasons. A contract needs to state that solar systems that are not “serving” the church anymore because of grid connection or lack of maintenance should be moved to a location with no grid connection and demand for the system.

Connecting the 100 Wp SHS to the grid is not recommended since it would involve more complex equipment and increase the project cost. Thus, for churches that PLN has electrified, it is suggested to move the systems to churches in greater need. However, if there is a church that can take good care of SHS and wants to continue using SHS, this is a good sign because it shows that the church already understands the benefits of SHS. They can use SHS to save on electricity costs and as a backup in the event of a power outage.

Active service is key for working systems that will impact the community. Some users do not use the service contact number for help but try to fix problems themselves. A more proactive service can prevent the installations from being misused and the system from malfunctioning. In the future, a good financing model should be developed so that small repairs can be financed by the user, leading to more sustainable use of the system.

5. CONCLUSION

Seventeen SHS were installed in Sumba and Timor churches and mostly used for evening activities, phone charging, and learning. From the study carried out in this paper, it can be concluded that installation quality and active service ensure a working system and high user satisfaction. Technical training for users to solve simple problems needs to be conducted. Moreover, the technician’s contact number also needs to be added so the users can contact the technician as soon as the system is not working properly. Furthermore, locations should be more thoroughly investigated to estimate the possibility of grid connection in the short future to maximize the use of solar systems.

5. ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support through the Organization of Mike Quinlan, the local support organization by Alfons Tonu Lewa, and local technical support by Febrianto Bokol.

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