Chapter 3
Turning on the Lights with Renewable Energy: Solar PV Mini-Grid System for Lighting in Myanmar

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Abstract Myanmar targets 100% electrification by 2030 through both of grid extension and off-grid electrification under the National Electrification Plan (NEP). Despite all the policies and plans of the government, a significant population living in remote rural areas will remain far from the nation grid and unable to afford connection fees in the distant future. The Myanmar Department of Rural Development, which is the leading government agency in implementing the off-grid component of the NEP, therefore seeks assistance from advanced countries and international societies, including Taiwan. Based on the local conditions of targeted villages, the International Cooperation Development Fund proposes a tailored pilot project for rural Myanmar. The project achieved the development goals of inclusive growth and environmental protection through access to affordable and renewable energy and demonstrated that even the poor or vulnerable groups in developing countries can contribute to a net-zero society.

Keywords Myanmar · Mini-grids · Solar PV · Rural area · Sustainable · Electrification

3.1 Introduction

Countries with higher levels of poverty often have limited access to modern energy services (World Bank 2017). Universal access to electricity is widely regarded as a prerequisite for alleviating poverty to stimulate economic growth, expand employment opportunities, and support human development. Electricity access is critical for achieving the UN's 2030 Agenda for Sustainable Development, and one of the targets for Sustainable Development Goal 7 is to expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing states, and

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land-locked developing countries, in accordance with their respective programs of support.

The number of people worldwide without electricity fell from 1.7 billion in 2000 to 1.1 billion in 2016. By 2030, that number is expected to drop to 674 million (International Energy Agency (IEA) 2017a). Among them, developing countries in Southeast Asia have made significant progress, with a high level of electrification, approximately 90% of Southeast Asians have access to electricity (International Energy Agency (IEA) 2017b). But, due to the diversity of economic development conditions, resources endowment types, and graphical features in the region, there is still room for improving electricity access (Nakano and Naimoli 2018). In fact, 65 million people in the region remain without electricity access. Of those without access, over 95% live in four countries: Indonesia (23 million), Myanmar (22 million), Philippines (11 million), and Cambodia (6 million) (International Energy Agency (IEA) 2017a).

Myanmar is the second largest country in Southeast Asia and contains over 676,000 km^2 of land and a total population of about 53.4 million. The rural population is high, accounting for 69% of the total in 2018. The country is the fourth-smallest economy in the Association of Southeast Asian Nations (ASEAN) group, with a Gross Domestic Production (GDP) of about $69 billion in 2019. It is also one of the fastest growing economies in group. Myanmar's GDP growth rate in 2016–2018 has been robust, averaging around 7.5%. However, Myanmar is classified as a least developed country by the United Nations. The proportion of the population living under the national poverty line is 24.8% in 2017. In 2005–2017, the absolute number of poor people declined from 18.7 million to 11.8 million. Most of the poor live in rural areas, around 87% of the total population in the country. Poverty rate is 2.7 times higher in rural areas, where 30.2% of the population is estimated to be poor compared with 11.3% in urban areas (United Nations Conference on Trade and Development (UNCAD) 2021).

The power sector of Myanmar is one of the least developed in Southeast Asia with more half of the population not connected to the nation grid and the rest subject to prolonged and frequent power disruptions. The lack and reliability of power is a key constraint to doing business in Myanmar (United Nations Conference on Trade and Development (UNCAD) 2021). Only 35% of Myanmar's people had access to electricity in 2016, and the gap between urban and rural areas is huge. The highest electrification rate was 78% in Yangon, while some of the poorest districts had the lowest, between 9 and 16% (Asian Development Bank (ADB) 2018). In addition, widespread use of traditional biomass is common in rural areas. In 2014, 69% of the population uses firewood as a main energy source for cooking and 46% uses kerosene, candles, or batteries as the main energy sources for lighting (The Republic of the Union of Myanmar 2015).

To increase the nation's electricity access and support boarder economic development, the government of Myanmar launched the National Energy Policy in 2015, which outlines a comprehensive plan for how to develop the energy sector to reach full national electrification (Asian Development Bank (ADB) 2016). The policy includes plans to promote government driven community-based renewable energy projects as a means to poverty reduction. The National Electrification Plan (NEP), developed by the World Bank in collaboration with the government of Myanmar, also targets 100% electrification by 2030 through both of grid extension and off-grid electrification, particularly in areas that will not connected to the nation grid by the target date. In addition, electrifying the country is also a major national development goal in the Myanmar Sustainable Development Plan 2018–2030, in which the government aims to provide affordable low-carbon energy to all classes of consumers, especially those in rural areas.

Despite all the goals, policies, and plans of the government, a significant population living in remote rural areas will remain far from the nation grid and unable to afford connection fees in the distant future. In general, the farther the village was from the grid, the lower the average income and ability to pay for energy services. The government estimates that of the 64,000 villages in Myanmar, about 40,000 are un-electrified. The geographical diversity makes it difficult to provide grid electricity to these isolated villages.

The Myanmar Department of Rural Development (DRD) under the Ministry of Agriculture, Livestock and Irrigation, which is the leading government agency in implementing the off-grid component of the NEP, seeks assistance from advanced countries and international societies, including the Taiwanese government. The International Cooperation and Development Fund (TaiwanICDF or Fund) subsequently starts a dialogue with the DRD to understand existing government and donor off-grid electrification programs.

The TaiwanICDF, established in 1996, has been dedicated to boosting socioeconomic development, enhancing human resources, and promoting economic relations in a range of developing partner countries. It also offers humanitarian assistance and provide aid in the event of natural disasters or international refugee crises. It offers a range of assistance that centers on four core operations: lending and investment, technical cooperation, humanitarian assistance, and international education and training. The work is tailored to the local needs of each of its partner countries, with assistance covering a variety of contemporary development issues such as environment, public health and medicine, agriculture, education small and medium enterprises, as well as information and communications technology. At present, the Fund operates overseas missions and implements special projects across Africa, Latin America, the Caribbean, Asia–Pacific, and West Asia, dispatching technicians, project managers, overseas volunteers, and Taiwan youth overseas servicemen to carry out or to assist such operations.

Using off-grid systems to electrify rural Myanmar had played a key role for thousands of villages, not an endeavor unique to the Fund. The primary sources of off-grid electricity by generation type in rural areas of Myanmar are micro-hydro, diesel generators, and solar PV. Most of such solar PV means individual solar home systems (SHS), and only in very few cases signifies solar PV connected to mini-grids (Greacen 2016). We also found that the existing market for off-grid renewable energy systems was dominated by small SHS, especially in rural areas. In general, the quality of most of the SHS installations in quite low and failure rate are high (Greacen 2015). Thus, mini-grid solutions have been considered as a third alternative to rural electrification between the option of grid extension and SHS or solar lanterns (Pedersen 2016). Additionally, the generators (micro-hydro, diesel, and biomass) that energize Myanmar mini-grid are often inefficient and unsafe, and with limited access to the engineering expertise and constrained by limited budgets, they still have significant issue with quality and reliability.

Further, Myanmar has a strong solar radiation level, and around 60% of the land area suitable for solar PV installation (Asian Development Bank (ADB) 2016). Given the country's high radiation rates, of the renewable energy technologies available for off-grid use in Myanmar, solar technology has become particularly popular among international donor community. The solar PV modules has fallen by more than 80% since 2009, while the global cost of solar PV power declined over 70% from 2010 to 2017 (International Renewable Energy Agency (IERNA) 2018). With globally rapidly declining price of PV systems and widespread use of highly efficient light-emitting diode bulbs in Myanmar, renewable energy solutions may be a cost-competitive option to expand electricity access.

During the inception stage, the Fund conducts field visits to potential sites to do fact-finding and data gathering work, according to a list of several villages provided by the Myanmar government. In general, people of these villages have to rely on kerosene lamps candles for lighting their houses in the evening, only a very few better-off families could afford solar home systems. Since most villagers are engaged in subsistence agriculture and livestock rearing, although they are willing to pay for electricity services, their ability to pay is limited. Based on the local conditions of targeted villages, the Fund proposes a tailored pilot project, with the expected outcomes include: (1) design and installation of solar PV mini-grid systems; (2) community-based business models for mini-grids, including operation and maintenance, payment mechanisms, tariff settings.

The main focus of the project is the solar PV technology and the nature of mini-grids. In the policy framework of Myanmar, the primary purpose of mini-grids is to fill the time-gap for many communities in rural areas until they connect to the national grid. However, some villages are simply difficult to access, hence the grid is not likely to extend to them in near future, possibly over 10 years. This is exactly the situation faced by some of the villages in the project. Therefore, for vulnerable groups and rural areas, the sustainability of solar PV mini-grids is even more critical, and in the interests of governments and communities.

3.2 Project Assessment and Technical Design

The project team identified the specific sites from a list of villages provided by the government of Myanmar. Key parameters for site selection include geographical suitability, renewable energy resource potential, existing economic activity, population density, distance of main grid arrival, as well as the commitment and willingness of local communities. It also included a comprehensive survey of potential socioeconomic and environmental impacts. The team identified two project sites:

- Site I: Inbingan Village
- Site II: Bawdigone Village, ChiYarPinSu Village, Zeephyjim Village, Payagone Village.

These five villages are located in the Magway and Sagaing regions of the central dry zone of Myanmar. The locations of these two sites are described in Table 3.1.

The average irradiation in Site I is estimated to be approximately 5.34 kWh/m^2/day and 4.78 kWh/m^2/day in Site II—both are suitable for developing PV-based power applications.

Inbingan Village at Site I had a population of 589 residents in 128 households. The male-to-female ratio was 1:1.16. Agriculture is the major economic activity for most households in the village, and their main agricultural products are sesame and soybeans; the cultivation seasons vary by crop, but land lies fallow for an average of four months of the year. Villagers lead regular schedules in their daily lives. Almost every household is self-sufficient in terms of animal husbandry, mainly raising swine. Normally, villagers rise early at dawn and rest by approximately 17:00 in the evening. Electricity demand increases significantly at night, although there is only one 3 kW diesel-electric set in the temple. The lighting resources in this village were inadequate. Villagers commonly use candles or battery-operated portable lamps. There were 91 children in a village primary school. Village leaders expressed that if the project could provide lighting, the children could study at night.

Bawdigone Village, ChiYarPinSu Village, Zeephyjim Village, and Payagone Village of Site II have 2181 residents in 453 households. The male-to-female ratio was 1:1.07. Almost every family relies on agriculture for a living, mainly producing paddy rice. To maintain a self-sufficient food supply, almost every family keeps a small amount of livestock, mainly raising chickens. Villagers rise at dawn to work early and rest early—by approximately 17:30 in the evening. Electricity demand increases significantly at night. There were 195 primary school students and 150 junior high school students; however, the schools had no lighting devices. The lack of power might limit children's opportunities to access knowledge and information. These villages are located at a great distance from major cities. The remoteness and difficult traffic conditions have prevented villagers from engaging in other part-time jobs or performing non-agricultural work. The satellite images of these five villages illustrated in Fig. 3.1.

In the technical design process, several factors need to be accessed and considered by the project team, including the choice of generation technology, storage technology, grid size, and configuration, as well as the distribution system. A PV solution with batteries was chosen, of course, because of good irradiation levels. Due to its nature of intermittency, the choice of energy storage plays a key role in PV mini-grids. The project team chooses lithium-ion batteries because they have more life cycles than lead-acid batteries, require less maintenance, and are environmentally friendly.

The system architecture of the solar PV mini-grid system conceived in the project proposal consists of a solar PV module, PV mounting system, PV charge controller, inverter/charger, village grid, and other components required for the balance of

Table 3.1 Locations of Site I and Site II

Site	Region	District	Township	Village	Latitude/Longitude
I	Magway	Magway	Magway	Inbingan	19.902/95.25
II	Sagaing	Katha	Kawlin	Bawdigone/ChiYarPinSu/Zeephyjim/Payagone	23.753/95.432

Source Compiled by the author

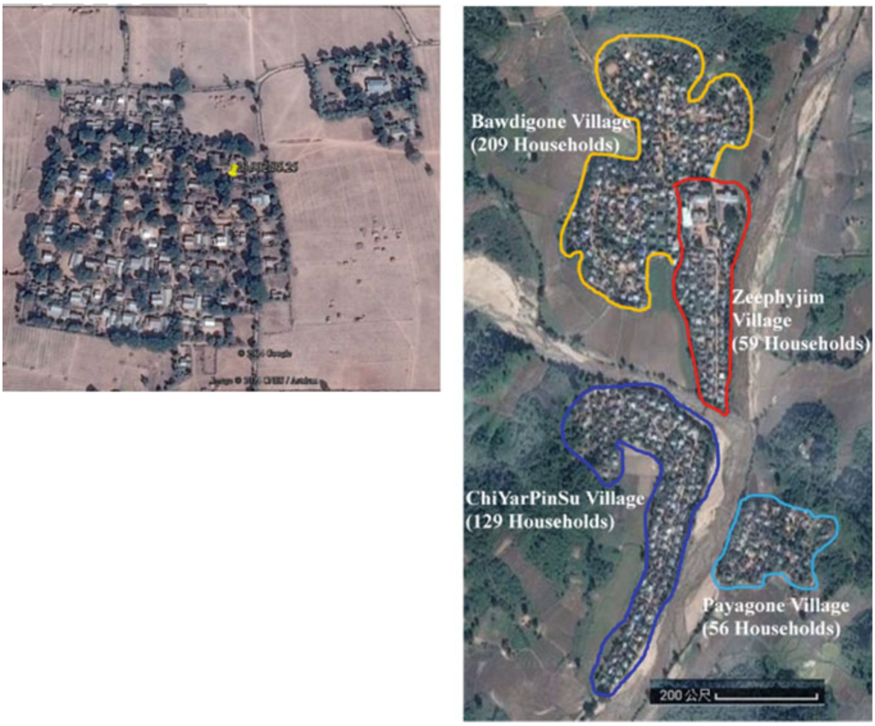

Fig. 3.1 Satellite image of villages (Left: Inbingan Village, Magway Region; Right: Bawdigone/ChiYarPinSu/Zeephyjim/Payagone Villages, Sagaing Region). *Source* Compiled by the author

the system. The system generates a centralized power supply to offer households and public facilities electricity for lighting through a newly established distribution network. Energy-saving products can also be used for lighting.

Regarding the design of the power supply system, scalable architecture was used to manage the expected increase in load in the foreseeable future, given an increase in electricity consumption. This architecture is also expandable by using an inverter/charger to optimize energy management by including and controlling different power supply sources.

In addition, considering the solar radiation conditions of the two sites, the PV arrays were mounted facing south at a 24-degree angle of inclination. In principle, the PV array should be mounted in an environment that is free of shade from approximately 08:00 to 16:00 throughout the year.

3.3 Project Implementation

The PV system was ground and mounted in the open space next to the village temple. The foundation was constructed in cement in the pile type. To encourage villager participation, the installation contractor commissioned the cement foundation construction and electrical room work to the management committee of the villages. The electrical room for Site II was built over the existing temple pavilion. All of the construction works met the required specifications and were accepted by the installing contractor.

The installation of electrical poles and power grids was next and reflected villagers' active participation. Wooden rods are required for installing electrical poles. The specified height of the poles is seven meters, and the required diameter of the poles is 0.2 m. The villagers prepared the wooden poles to meet these requirements. The poles were positioned in cooperation with the management committee and local villagers within these villages. The poles were positioned according to the design diagram, and the distance between the poles was approximately 25 m. The installation contractor instructed the management committee in the required specifications of a hole for the pole to be buried (buried depth of the electrical pole was 1–1.2 m), directed the installation of the pole with a cross pad, and demonstrated the setup operation of the electrical pole to facilitate the pole installation work by local villagers.

Regarding the power grid, the main line uses a 35 mm^2 aluminum conductor steel reinforced (ACSR) cable, the branch line uses a 25 mm^2 ACSR cable, and the service line uses a BVVB 2 $\times$ 3029 cable. Eighteen step-down transformers (460 V/230 V, 300 VA) and overcurrent protection devices were also installed in boxes on the electrical poles.

The main power supply circuit is divided into four main areas: temple area, school area, electrical room, and village power supply. All four areas are independent power supply control circuits. The installation of household lights was performed by local villagers under the guidance of the installation contractor. Installation work included connecting the service line box, fuse, LED lamp and holders, and indoor wiring. After the installation was confirmed as correct, a warning seal in Myanmar was adhered to the riding seam of the service line box to prevent users from replacing existing fuses with a larger capacity fuse and to ensure their electricity safety. Photographs of the installation and construction are shown in Figs. 3.2 and 3.3.

According to the organization chart (Fig. 3.4) designed by the project team, the committee was organized by the villagers, who were divided into two groups: technical maintenance and operation management. The former is responsible for the daily operation of the equipment, household power checks, and system component replacements. The latter is responsible for electricity tariff calculations and collection, tariff fund account management, and education advocacy. The functions of the management committees are illustrated in Fig. 3.5.

To advance the villagers' power usage knowledge and develop basic electric power engineering knowledge and technical capacity, the project team encouraged villagers

Fig. 3.2 Solar PV system and LED lights installation. *Source* Compiled by the author

to actively participate in system construction and maintenance and participate in the technology training courses offered by this project. These experiences are expected to contribute to the villagers' future development of specialty skills. Electricity tariffs collected from the villagers would be used as funding for future power supply system maintenance work, such as the replacement of battery banks, PV charge controllers, inverter equipment, fuse replacements, and power line maintenance, for the long-term operation of the power supply station to ensure the sustainability of the project.

Fig. 3.3 Village view of Site. *Source* Compiled by the author

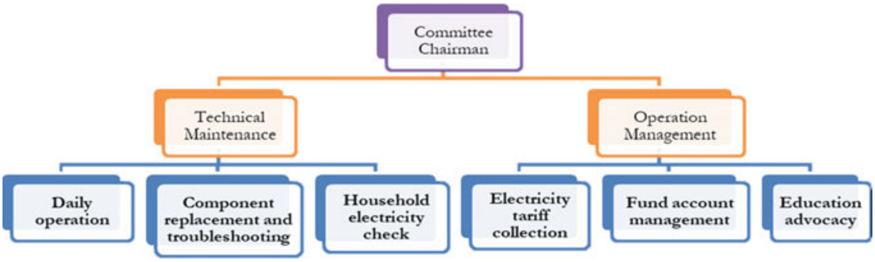

Fig. 3.4 Organization of power supply system management committee. *Source* Compiled by the author

3.4 Project Impact Assessment

The project team recorded the changes in the village lifestyle after the power systems were put into operation by interviewing villagers and distributing questionnaires. The objects include ordinary households and members of the power supply system management committee of the five villages. The questionnaire asked villagers to assess the degree of influence of their nighttime lifestyles. The impact of lighting on local lifestyles ranged from L1 to L5. The higher the number, the greater the impact, with L1 having the weakest impact and L5 having the strongest impact.

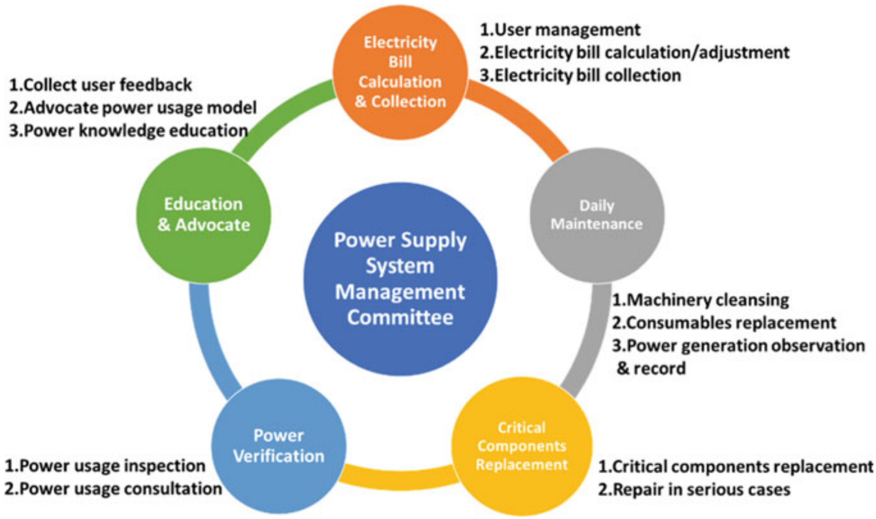

Fig. 3.5 Functions of power supply system management committee. *Source* Compiled by the author

3.4.1 Result of Site I

A total of 60 questionnaires were distributed to the villagers in the Inbingan Village of Magway Region, and 57 were collected. After filtering out questionnaires with serious omissions, 53 were considered valid. Furthermore, 15 questionnaires were distributed to and collected from the management committee. After filtering out the severely missed questionnaires, 12 questionnaires were considered valid. The data analysis results showed that nighttime lighting allows children to read at night, village shops can operate for a longer period, owners' incomes increased, village meetings could be conducted later in the evening, and some villagers continued agricultural work (Fig. 3.6).

Definition of statistical chart items:

- Study: beneficial for children to study and do homework after dark.
- Contact: beneficial for villagers to visit each other after dark.
- Shop: shop hours could be extended.
- Eating: dinner time could be postponed.
- Farming: villagers could do simple farm work after dark, such as feeding cows and arranging farm tools.
- House Keeping: housework could be done after dark.
- Sewing and Handicraft: sewing and handicraft could be done after dark as a secondary source of income.
- Bath: bath time could be postponed.

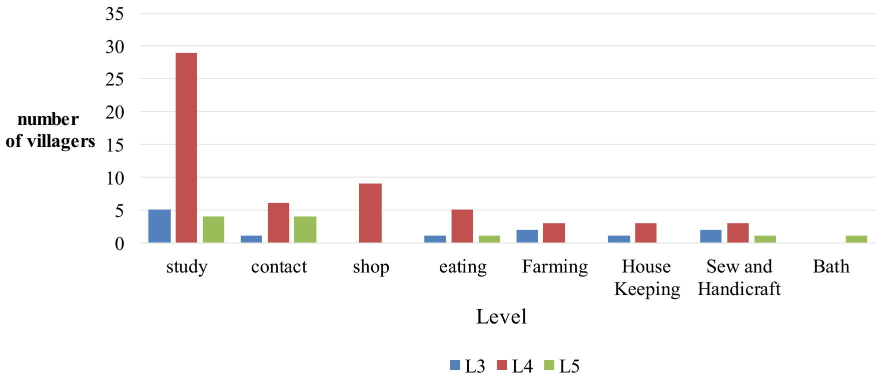

Fig. 3.6 Lifestyle impacts after system installation—Inbingan village, Magway Region. *Source* Compiled by the author

3.4.2 Result of Site II

A total of 120 questionnaires were distributed to villagers in the four villages of the Sagaing Region, and 113 were collected. After filtering out questionnaires with serious omissions, 66 were considered valid. Again, 15 questionnaires were distributed to the management committee, and 15 were considered valid. According to the data analysis, the results found that the positive impacts of nighttime lighting included allowing nighttime reading time for children, enabling villagers to continue housework or engage in light economic activities—sewing, cleaning, and farm work, such as screening peanuts—and feeding cattle. Lighting also ensures the safety of the villagers when they visit neighboring households at night, promoting better interpersonal communication within the village (Fig. 3.7).

Definition of statistical chart items:

- Study: beneficial for children to study and do homework after dark
- Shop: shop hours could be extended
- Farming: villagers could perform simple farm work after dark, such as feeding the cows, selecting peanuts, weaving ropes, and arranging farm tools
- House Keeping: housework could be done after dark
- Sew and Handicraft: sewing, weaving, and handicraft can be done after dark as a secondary source of income
- Safety and Health: increased safety for walking after dark; lighting distracts mosquitoes from biting villagers and increases general health
- Increase Income: beneficial for increasing income (income increase source and methods unspecified)
- Contact and socialization: beneficial for improving relations through general socialization and home visitations between villagers after dark
- Other benefits (such as cooking or improving mood) or if the survey taker indicated positive impacts but did not specify details.

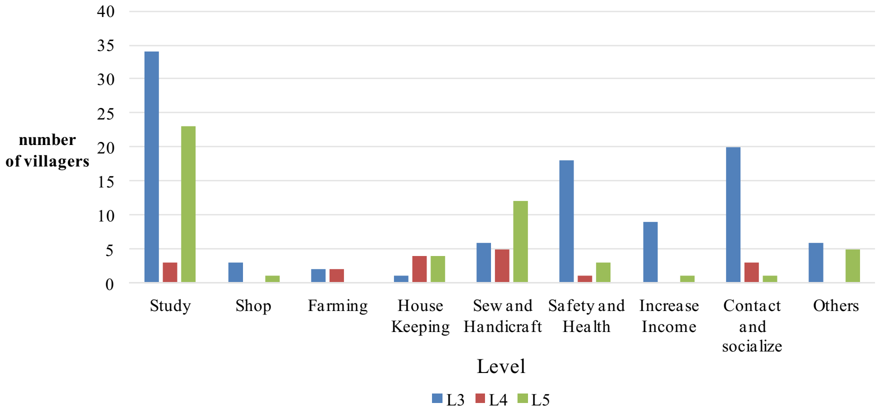

Fig. 3.7 Lifestyle impacts after system installation—Bawdigone/ChiYarPinSu/Zeephyjim/Payagone Village, Sagaing Region. *Source* Compiled by the author

In addition, all of the members of the power supply system management committee at the two sites held a positive view of the solar PV system. After participating in system installation and management, villagers have a clearer understanding of power consumption, system management, and fund management.

3.5 Project Outcomes

Solar PV mini-grid systems have been undertaken and operated since 2018 by the power supply system management committee of the two sites and provided lighting and public electricity for 560 households in those five villages. The systems improved the nighttime reading environment for school children, extended the time spent by villagers in home economic activities, increased family incomes, and improved interpersonal relationships between villagers. For participating households, the most immediate benefit is saving the cost of buying candles or kerosene. For the project level, the indirect benefit is the reduction in CO_2 emissions from burning fossil fuels. Such achievements are in line with the sustainable development goals of environmental protection and economic development. The project also demonstrated the operation model of the solar PV mini-grid system, lighting applications, and the establishment and operational mode of the power supply system management committee.

The project team believes that the success of this project is attributed to the following features:

1. Considering the remote location of the sites, once system failure occurs and maintenance is difficult, the project team designed higher-quality system equipment from the very beginning. The project's overall solution was planned by

Taiwanese experts from the Industrial Technology Research Institute who were also in charge of the formulation of the hardware specifications and construction quality supervision. The system architecture was designed to be scalable, with high-quality and reliable key components to ensure that the power supply system has high operational availability. Although the investment cost was higher, the lifespan of the equipment and storage battery was extended, and maintenance problems were reduced.

2. Based on the project sustainability goal, the project team assisted the villages in establishing a power supply system management committee and encouraged the committee to participate in the planning, design, installation, testing, and operation of the solar PV mini-grid system. Committee members also received good training on the operation and management of the power system to have sufficient skills to carry out basic troubleshooting.
3. The project team encouraged villagers to actively participate in the project startup process, including assisting in PV system installation, electrical room construction, power grid extension, installation of home lighting, and public electricity outlets, to strengthen the recognition of ownership over the system. Seminars were designed and held to train villagers in basic electric consumption safety knowledge to improve the safety and reliability of the power supply system. In addition, the project introduced the user pay mechanism and successfully assisted the power supply system management committee in establishing an electrical tariff fund management model. The fund is expected to be used for the future operation and maintenance of power supply systems.

In sum, renewable energy mini-grids can address power poverty in remote areas and enhance the awareness of energy autonomy and ownership of rural villages. Active engagement with communities from the beginning is critical. In terms of financial success, tariffs should be designed carefully to generate enough revenue to cover operational expenses yet remain affordable for villagers. These remote villages in Myanmar are similar to isolated islands in the mountains, and we believe that the project's experience and lessons can be replicated on small islands. Finally, this case shows that, in addition to developed countries, developing countries can make their own contributions to the road to achieving net-zero emissions globally.

3.6 Lesson-Learned from Project

Economic progress in Myanmar is at a quick pace, and demand for electricity is expected to increase rapidly. The planning and design of solar PV mini-grid power supply systems for similar rural areas must be considered for villagers who can afford additional electricity for the television, refrigerator, radio, mobile phone, electric fans, and other needs, in addition to basic lighting. Based on the diversified demand for electricity, the solar PV mini-grid power supply system could adopt a hybrid power supply mode, such as the PV/diesel/battery mini-grid system. Through technical and economic analysis, the most suitable power system capacity and energy mix could be selected to maintain reasonable system installation, operation, and maintenance costs. In the user pay model, smart meter applications, such as electricity prepayment mechanisms, can be introduced into rural areas to calculate electricity consumption and charges. Furthermore, in regions with good network communication, remote monitoring and system control can be introduced into mini-grid systems. System installers can troubleshoot simple problems and remotely control and adjust the system operation parameters and monitoring to strengthen the reliability and economic benefits of the power supply system.

Each village has its own characteristics, and the tariff collection model should be designed according to local needs. When guiding villagers to form their power management policies, the importance of system maintenance and fund management should also be emphasized to avoid affecting the normal operation of the system because of insufficient funds. Given the gradual development of Myanmar's economy, the demand for electrical appliances and electricity is also rising. Regarding the issue of electricity tariff collection, in addition to the current fixed charging model, other charging methods, such as surcharges based on kilowatt-hours, can also be adopted. The electrification and living conditions of the village are improved because a surcharge is imposed on those with higher electricity consumption to obtain more electricity.

Government support when communicating with villagers is important to assist with site selection, the smooth implementation of village-level communication, and on-site investigations. The Burmese government can assist the project team in choosing villages with strong teamwork and deep relationships, which might affect the sustainable operation and functioning of the power supply system management committee. Whether a village is suitable for power plant installation requires that the project team visit the village multiple times to discuss the details of the power supply and its benefits. If local government officials can accompany or support project team in their endeavor to communicate with the villagers, they will be more willing to communicate. Consequently, the site survey, villager willingness assessment, and other relevant evaluations could be conducted smoothly.

The vast territory and low population density across various villages and underdeveloped infrastructure, such as local transportation networks and power, make it difficult for private sector companies to consider investing in power generation in rural Myanmar. The initial investment cost of rural power generation plants is much higher than that of other countries. To rapidly increase the electrification level of villages in Myanmar and encourage private investments, the central and local governments should play a more active role in providing incentives, offering communication channels with villages, and lowering investment barriers to attract more private investments in power systems in villages.

The quality and capability of the hardware equipment of the power supply system, the establishment and training of the power supply system management committee, and the participation of villagers in the startup of the power supply system are all key elements for the project's sustainable operation. According to the actual implementation experience of the two sites, a positive correlation indeed exists among the sustainability of the electrification project and good quality system hardware, good execution of the power supply system management committee, and active participation of the villagers. Therefore, when conducting a pre-operation survey on the candidate villages, the willingness of villagers to participate, villagers' local commitment and responsibility, evaluation of the members of the power supply system management committee staff, electricity demand, affordability of electricity charges, and the installation environment are all important factors that should be included in the feasibility assessment. Finally, seasonal factors should be considered when implementing the project. Construction scheduling should avoid the rainy season in Myanmar. Construction might be delayed because of poor road conditions. In addition, considering that most villagers can only have income after the harvest season, it is recommended that the electricity tariff payment method and timing be designed according to the seasonal characteristics of the village.

3.7 Conclusion

In remote area of Myanmar, kerosene lamps and candles are still widely used for lighting purposes. The illumination provided by these sources is poor. And, pollution from kerosene lamps used for lighting by rural households contributes to greenhouse gas (GHG) emissions. The generally accepted estimate is that for every liter of kerosene burned, 2.6 kg of CO_2 is released (Global Off-Grid Lighting Association (GOGLA) 2020). In addition to CO_2, kerosene lamps also produce black carbon during combustion, greatly increasing their contribution to GHGs.

As stated in the project outcomes, kerosene lamps and candles that the villagers had previously relied on have been replaced with LED lighting based on renewable energy, thus avoiding the accumulation of CO_2 and black carbon over the expected lifetime of the system. Solar PV technologies make it possible to the improvement for general CO_2 mitigation and even indoor air quality for households without energy access in rural Myanmar. In addition to reducing CO_2, increasing access to affordable, reliable and modern energy can improve productivity, increase incomes, and boost socioeconomic development, even in the results presented by the project that provides only basic light and low-power services in rural Myanmar. This consideration is especially important, as 78% of the world's poor people live in rural areas and rely on farming, livestock aquaculture, and other agricultural work (World Bank Group 2014).

As economies of scale gradually take hold in the mini-grid sector, and the costs of PV panels and batteries decrease over time, overall system costs are falling. With falling costs and increased reliability, mini-grids have become more attractive to both the public and private sectors. We can say that solar mini-grids have found their place in between solar home systems and national grid extension, depending on population density and distance from the main grid.

Sustainability in mini-grids means technically sound and reliable operation, high-quality power service and economical profitability. Without the latter, the other two sustainability criteria cannot be achieved. Solar mini-grids in particular typically face relatively high capital expenditures. Therefore, even with high grant funding, require a certain level of revenue to operate sustainably. It is noteworthy, however, that the renewable energy mini-grid sector is still largely financed through grants and non-commercial capital. Fully privately funded mini-grids are difficult to achieve in any case without subsidies due to the challenges of rural power supply. The challenges include the logistical challenges of installing systems on-site and maintaining remote operations and relatively low household affordability and willingness.

Due to modern energy access is central to achieving the Sustainable Development Goals, governments should consider all opportunities offered by mini-grid renewable energy solutions to expand access to affordable, reliable, and sustainable energy and to support livelihoods and delivery of basic services. For sustainable development, mini-grids require comprehensive, long-term political commitment and a stable, reliable policy framework. Regulation is especially important for renewable energy mini-grids in areas where governments are responsible for ensuring economic viability and ensuring that tariffs for underserved households are not too high. In terms of public assistance, there can be in the form of both direct fiscal support measures and complementary indirect incentives. For example, government can make grant contribution to subsidize some or all of the initial/upfront investment and be exempt from taxes and duties.

According to the ASEAN State of Climate Change Report, ASEAN needs to achieve net-zero CO_2 emissions by 2050 and net-zero GHG missions by 2065 for the emissions pathway aligned with the global 1.5 °C target. To achieve its goals, ASEAN also needs to adopt low- to zero-carbon energy sources in its long-term strategy. For renewable energy, a diversified renewable energy mix and accelerated diffusion are seen as crucial, and rural electrification is a priority in most countries (Association of Southeast Asian Nations (ASEAN) 2021). As for the Myanmar government, it has updated the Nationally Determined Contributions (NDCs) in 2021. Based on its NDCs, the country aims to increasing the total share of renewable energy to 53.5% by 2030, thereby achieving the conditional annual target of avoiding 144 million tCO_2e emissions. Under its national program for rural electrification, renewable energy technologies contribute 166.4 MW of electricity generation per year, of which 44.41 MW is generated through renewable energy mini-grids to power 1.8 million people of the off-grid rural population. As compared to alternative energy source using standard diesel generators, mini-grid renewable energy will generate 564,000 tons of CO_2e in emissions avoided cumulatively by 2030 (The Republic of the Union of Myanmar 2021).

Mini-grid renewable energy solutions represent a viable electrification and indeed a fast way to supply highly reliable electricity to remote rural and isolated areas. They are also environmentally sustainable solutions that support both ASEAN's efforts to achieve net-zero emission targets and Myanmar's commitment to NDCs. The project in Myanmar could be seen as a case of developing solar PV systems on mini-grids to implement rural electrification, and the lessons learned can be referenced and replicated in rural areas or island settings with similar characteristics. In addition, the project achieved the development goals of inclusive growth and environmental protection through access to affordable and renewable energy and demonstrated that even the poor or vulnerable groups in developing countries can contribute to a net-zero society.

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