Microgrid Solar-PV Power System Socio-Economic Benefits and Challenges

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Abstract**—***Globalization and long-term growth necessitate an enormous amount of energy from various sources. Since fossil-based fuels are depleting and harm the environment, renewables are being viewed as viable alternatives for sustained growth. Despite the rising need for electricity, rural populations in many developing countries are yet to be connected to the grid. Objective: The study aimed at determining the socio-economic benefits and challenges of a microgrid solar-PV power system.* ***Method****: A survey and a focus group discussion were conducted in a village of about 100 families to know their electricity requirements. A 50-kW off-grid solar-PV power plant was designed and installed, eventually supplying electricity to the community houses.* ***Findings****: The 50-kW off-grid solar PV system, which includes 168 300-Wp PV panels, ten 4.8-kW inverters, and two sets of 84 100-Ah 12-V batteries, harvested and provided an average of 210.14 kWh of solar electricity per day, enough to cover the people's daily 210.10 kWh electricity need.* ***Conclusion****: Solar-PV is a suitable power technology for supplying clean electricity even in rural areas. It allows community members to spend time with their families at night, equipping them to prepare farm produce and creating a new industry that provides a source of income. Nonetheless, the community's inability to pay is a major stumbling block that must be solved for the operation to continue.*

Keywords. Microgrid, Solar-PV, Socio-Economic, Benefits and Challenges, Community People, Mandaya

I. INTRODUCTION

Globalization and long-term growth necessitate an enormous amount of energy from various sources [1]. Since fossil-based fuels are depleting and harm the environment, renewables are being viewed as viable alternatives for sustained growth [2], [3]. Despite the rising need for electricity, rural populations in many developing countries are yet to be connected to the grid. A billion people worldwide cannot access electricity, let alone reliable power. In rural communities, electricity is critical for meeting basic human needs [4].

The conventional distribution grid structure is changing due to the increased use of distributed energy resources, which could make managing and operating it more difficult [5]. Microgrids are recommended for the proliferation of these technologies as they can potentially lessen or completely eradicate any negative impacts and even enable their planned growth and improvement of advantages [5], [6]. Microgrids are one of the most promising innovative grid designs, allowing several micropower plants to be linked [7]. Local supply and demand balancing is made possible by microgrid communities, which also involve the local population in the energy system [4], [6].

Demand for microgrids is expected to rise as renewable energy technologies mature and become more cost-effective. Microgrids can provide several socio-economic benefits to users and communities. Microgrids are the most practical solution for bringing power to such remote locations. A solar-PV power system on a microgrid offers several advantages. A microgrid can be built far from the main grid, providing opportunities to residents in its service area. It is possible to mitigate the effects of climate change, energy security, and affordability by using solar energy to generate power [8]. A microgrid may also improve power quality and extend electricity supply while providing energy justice to consumers [4]. Similarly, clean electricity generation in remote microgrids can serve as a lifeline for residents and a dependable service for farmers. However, several challenges must be overcome before microgrids can be widely adopted [5], [9].

The Philippine government passed the Renewable Energy Act (RA 9513) to aid in the electrification of remote communities, including income tax holidays, duty-free importation of renewable energy machinery, zero-rate VAT for domestic capital equipment, and priority connection to the power grid. The law is intended to encourage investment and help businesses transition to renewable energy. Similarly, the EPIRA Law (RA 9136), which governs the entire Philippine electric power industry and is the primary legislation governing renewable energy developers in the country, was enacted. The Philippine Constitution also includes several important principles for renewable energy development. Furthermore, the Microgrid Systems Act (R.A. 11646) was enacted to permit the installation of microgrid systems in remote communities.

Microgrids provide various socio-economic benefits and challenges, necessitating appropriate decision-making for sustainable growth [9], [10]. To better understand the operation of a microgrid solar-PV power system, the study aimed to determine the socio-economic impact and how a remote community in the Philippines benefited and was challenged by its usage. It is hoped that the result of the study may provide a policy for sustaining the operation of a microgrid solar-PV power system in the Philippines and other countries.

II. METHODS AND MATERIALS

Face-to-face surveys and focus group discussions (FGD) were conducted before the design and implementation to understand the demographics and determine the needs of people living in the community. The collected data was the foundation for the design and capacity building required to keep the microgrid solar-PV system running.

Appreciating how people and institutions understand the technology and its application is critical in promoting innovation in support of renewable energy, such as the Solar-PV power system [3], [7]. Recognizing the value of technology, organizational readiness to adopt it, perception of how it could work, competence to manage it, and perceived barriers and pathways to its long-term use are all important. The immediately enumerated dimensions are among the contextual factors referred to in this study.

A microgrid is a small, integrated localized electrical system that can operate independently or connect to the larger power grid [4], [5]. It can generate, store, and distribute electricity to users. Microgrids are used in various applications like military bases, communication towers, and remote communities that have no, limited, or unreliable electric grid access [3]. Microgrids comprise one or more distributed energy resources (DERs), including power generation, storage, and loads. The grid connects the various DERs and the centralized system operator for control and communication. Microgrids have the potential to provide higher levels of reliability and resilience depending on the size, configuration, and operation of the DERs [5]. See Figure 1 for the architecture of the microgrid solar-PV power system.

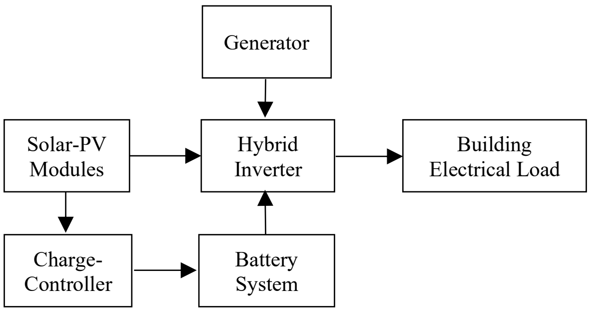

Figure 1. Microgrid Solar-PV Power System Architecture

A microgrid solar-PV system was designed and installed in Macopa, Manurigao, New Bataan, Davao de Oro, Philippines, based on the electricity demand. To ensure the long-term operation of the microgrid solar-PV power system, the research was conducted by the Ateneo de Davao University (ADDU) in collaboration with the Davao de Oro Provincial Government, the municipality of New Bataan, and the Department of Science and Technology (DOST).

III. RESULTS AND ANALYSIS

A microgrid solar-PV power system was installed to provide clean electricity to the residents of Macopa, Manurigao, New Bataan, Davao de Oro, the Philippines, for lighting, household appliances, milling, other machines, and other relevant uses. The following sections will discuss the installed technology's socio-economic benefits and challenges.

A. The Macopa Community

Macopa is a small village or 'Sitio' in the Philippines, located 34.5 kilometers from the municipality of New Bataan and 132.0 kilometers from the city of Davao. In 2021, Manurigao had a population of 1,739 people or 375 households. Macopa is one of the sitios of Manurigao with 371 residents (69 families).

Everyone in Macopa is a 'Mandaya,' speaking the tribe's dialect. 'Mandaya' refers to an ethnic group or indigenous community in Davao de Oro, Philippines. Farming is the Mandaya's main source of income. Upland rice, corn, peanuts, and abaca are grown on small farms within the sitio. Macopa was rebuilt after Typhoon Pablo devastated the Province of Davao de Oro in December 2012. The government provided a house to the displaced families. Manurigao is reachable by motorcycle from the nearest accessible station in the town of New Bataan for US$ 20.00. Residents who cannot afford the fare must walk from New Bataan for 7 to 13 hours.

Macopa cannot get government funds and must rely on local government units and private organizations for development projects. There is currently no electricity in the area, which is ostensibly served by Northern Davao Electric Cooperative (NORDECO). The nearest power grid is approximately 20 kilometers away. Residents continue to use traditional night lighting methods such as gasoline-powered lamps.

B. Solar Electricity Consumption

To provide clean electricity to the community, a microgrid solar-PV power system was designed to meet the electricity requirement of 210.10 kWh per day (Table 1). For a 24-hour cycle, only one refrigerator or freezer is expected to be used. LED lighting will consume no more than 40 Watts per household but is allocated 48.0 kWh per day for 12-hour use of 100 homes.

The time it takes to use the harvested electricity is one of the challenges of the solar-PV standalone power system. The sun rises at 5:30 a.m. and sets around 5:30 p.m. As a result, a battery system is required to meet the demand for electricity at any given time. Figure 2 depicts the consumption pattern of electricity.

Table 1. Estimated Electrical Load

Equipment	Rated Power (W)	Qty.	Electrical Load (W)	Est. Daily Use (Hours)	Est. Daily Consumption (kWh/Day)
Households Lights (LED)	40	100	4,000	12	48.00
Television/PC/Others	150	20	3,000	12	36.00
Domestic Appliances	250	10	2,500	8	20.00
Refrigerator/freezer	500	1	500	24	12.00
Dish and Cloth Washer	1,000	4	4,000	8	32.00
Other uses (streetlights, etc.)	6,350	1	6,350	6	38.10
Stand-by consumers	1,000	1	1,000	24	24.00
Total		134	21,350		210.10

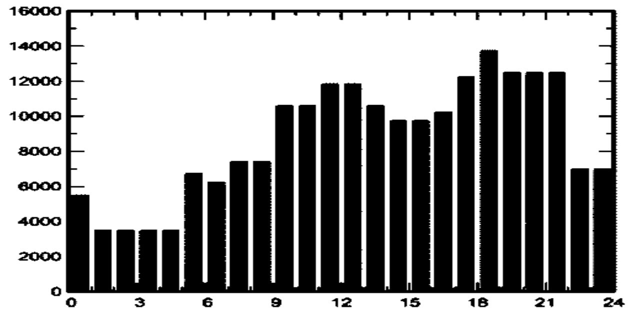

Figure 2. A Pattern of Electricity Consumption in Macopa

Since solar radiation begins to decline at 3:00 p.m., the battery system will provide users with energy starting at 3:00 p.m. and peaking at 6:00 p.m. up to 9:00 p.m. To maximize the use of the solar-PV power system, energy use should be assigned as much as possible from 9:00 a.m. to 2:00 p.m.

C. Solar-PV Power System Design Parameters

A microgrid solar-PV power system was designed based on the estimated energy consumption to efficiently provide electricity to Macopa, Manurigao, New Bataan, Davao de Oro residents.

1. Solar Radiation

Any solar-PV power system's output is determined by the availability and intensity of solar radiation. As a result, the most important consideration for collecting solar radiation is determining the proper tilt and azimuth angles in relation to the global position of the installed solar-PV power system [11]. Similarly, the shading factor must be considered to maintain the highest possible energy production.

2. GPS Location

Macopa, Manurigao, New Bataan, Davao de Oro, Philippines, is located at 7°29'55" north (latitude) and 126°17'14" east (longitude). Since the earth is tilted by approximately 22½°, each rotation of the Sun causes a change in its true position relative to a collector plane or solar-PV panel on a specific surface of the earth. The tilt and azimuth angles are crucial parameters for optimal energy production [12]. Solar-PV panels can be placed in a tracking structure that automatically adjusts the look angle to optimize solar radiation harvesting (i.e., tilt and azimuth angles). However, this approach may incur additional costs.

3. Tilt Angle

Tilt angle is the inclination of the collector plane or solar-PV panels in relation to the horizontal earth surface [11]. The tilt angle should be set so that the Sun's rays are perpendicular to the surface of the solar-PV panels for optimal solar radiation harvesting. As a rule of thumb, use the latitude of the desired location to estimate the tilt angle; in the case of Macopa, Manurigao, New Bataan, Davao de Oro, Philippines, the optimal tilt angle was 7° to harvest an average of 5.53 kWh/m2/day (Table 2). However, for optimal solar radiation harvesting, use variable tilt every month to capture 5.77 kWh/m^2/day or a tracking angle to capture 6.86 kWh/m^2/day.

4. Azimuth Angle

The azimuth angle is the angle between the North and the collector plane in the Southern hemisphere and is considered negative towards the east [12]. The azimuth angle is the second most important factor when maximizing solar radiation collection—setting the azimuth angle to 0° and at different tilt angles results in the solar radiation reflected in Table 2. It is worth noting that the Sun's relative position shifts from true South to true North (January to June) and vice versa (July to December). In the case of Macopa, Manurigao, New Bataan, Davao de Oro, Philippines, the azimuth angle varies from 0° from October to March (IV & I Quarters) to 180° from April to September (II & III Quarters).

Because a tracking structure to hold the solar-PV panels is more expensive than a fixed structure, an appropriate tilt angle and azimuth angle should be selected for optimal solar radiation harvesting.

5. Horizontal Solar Radiation, I_{HORIZ} (Watt/m^2)

The one-year horizontal solar radiation (I_{horiz}) at Macopa was generated using PVSyst, a solar-PV simulation software. The horizontal solar radiation (I_{horiz}) can be obtained by tilting the collector plane and the solar radiation meter to 0° or tilt angles (Table 2).

In general, the horizontal solar radiation ((I_{horiz}) differs from one location to another. In Davao de Oro, the horizontal solar radiation ((I_{horiz})) is relatively lower than in other places.

Table 2. Solar Radiation (kWh/m2/day)

Quarter	I			II			III			IV			Mean
Tilt, θ	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
0	5.16	5.19	5.74	5.87	6.01	5.34	5.43	5.59	5.66	5.72	5.21	5.03	5.50
-8	4.82	4.96	5.61	5.88	6.14	5.49	5.56	5.64	5.59	5.49	4.89	4.66	5.39
7	5.44	5.35	5.79	5.79	5.81	5.12	5.23	5.47	5.66	5.86	5.46	5.33	5.53
22	5.78	5.46	5.68	5.41	5.17	4.51	4.64	5.03	5.45	5.93	5.75	5.73	5.38
90	3.69	2.90	2.19	1.53	1.38	1.41	1.42	1.47	1.82	2.85	3.51	3.83	2.33
OPT	5.84	5.46	5.79	5.89	6.19	5.57	5.62	5.64	5.67	5.94	5.78	5.82	5.77
[1]OPT ANG	31.50	21.50	9.50	-4.50	-15.50	-19.50	-17.50	-9.00	4.00	18.50	29.50	34.50	
Track	6.96	6.48	6.97	7.04	7.39	6.46	6.55	6.66	6.78	7.23	6.91	6.91	6.86

[1]OPT ANG – Optimal Angle (in degrees)

6. Availability of Solar Radiation

The intensity of solar radiation is critical in optimizing solar energy production. Furthermore, knowing its availability is vital as well. According to NASA-SSE data, available insolation was 83.23 percent over consecutive days (NASA, 2020). Over a month, the minimum availability of solar radiation can be equated to 5.07 black days or no-sun days (Table 3).

Table 3. Daylight Cloud Amount and No-Sun Days

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Available Insolation (%)	70.3	76.7	79.7	80.4	90.3	87.0	89.5	86.6	88.6	88.7	84.2	76.7	3.23
No-Sun Days	9.19	6.49	6.27	5.87	2.98	3.87	3.22	4.15	3.39	3.47	4.73	7.19	5.07

7. Shading

Shade is another important factor to consider when harvesting solar radiation. Solar-PV panels are vulnerable to changes in solar radiation intensity. A slight change in intensity on a specific portion of the solar-PV panels due to shading will reduce its overall efficiency. Shading can take many forms. The most common type of shade is the dense cloud cover that constantly obscures the path of the sun's rays. A flying bird or an airplane passing over a specific area that shades the solar-PV panel is an example of a simple type of shade. Additionally, shadows cast by nearby trees, buildings, or structures can significantly reduce the efficiency and output of a solar-PV energy system.

D. Design of a Microgrid Solar-PV Energy System

It is essential to properly design the solar-PV energy system to convert the harvested solar radiation into useful solar electricity. To optimally design an off-grid solar-PV energy system, the first step is to know the size of the solar-PV array; hence, there is a need to determine the technical specifications of the solar-PV panel first. The second important step is to select an appropriate off-grid inverter. Note that there are three central inverters: grid-interactive, off-grid, and hybrid. Improper selection of an inverter may not optimize the production of energy. Other components can be suitably added once the optimal combination of the solar-PV panel and inverter is known. Moreover, in the case of an off-grid system, there is also a need to determine the optimal combination of batteries.

1. Solar-PV Panel

The study used a 300-Watt monocrystalline Solar-PV produced by Gintung-Tatung (Taiwan). Table 4 shows the panel's details. Other solar-PV models can also be used.

Table 4. Solar-PV Panel Specification

Particular	Metric
1. Model	GTEC-300G6S6A
2. Cell Type	Monocrystalline
3. Dimension of Cell	156mm x 156mm
4. No. of cells and connections	60 in series (6x10)
5. Dimension of Panel	1629x989x40mm
6. Weight	19.0 kg
7. Power	300.00 Watts
8. Max. power voltage (V_M)	31.51 Volts
9. Maximum power current (I_M)	9.52 Amperes
10. Open circuit voltage	39.24 Volts
11. Short circuit current	9.93 Amperes
12. Module Efficiency	18% to 19%
13. Operating Temperature	-40 to+85°C

2. Off-Grid Inverter

Ten (10) 5-kWp off-grid inverter sets were used. The Off-Grid inverter's specifications can be found in Table 5. Each inverter has a voltage range of 36 to 145 volts and a maximum power output of 4.8kW.

Table 5. Off-Grid Inverter

Particular	Metric
1. Model	Sunsee-5K
2. Output Power Rating	5000 VA
3. Input Voltage	36-145 V
4. Output Voltage	90-280 V
5. Output Power	4.8 kW
6. Rate grid frequency range	50Hz/60Hz
7. Maximum Efficiency	98.0%
8. Dimensions (W*H*D)	550*1500*425 mm
9. Net Weight	10.8 KG
10. Number of strings	4.0-9.0

3. Battery Storage System

There were two (2) sets of battery storage systems used. The specification of the Valve Regulated Lead-Acid Deep Cycle Battery can be found in Table 6. Each set has 84 batteries, each storing up to 1.2kWh of energy.

Table 6. Battery Storage

Particular	Metric
1. Model	SM100
2. Type	Valve Regulated Lead Acid, Deep-cycle
3. Voltage	12-Volt
4. Carrying Capacity	100-AH
5. Rated Energy Capacity	1.2-kWhr
6. Charging Voltage	14.4-Vmax
7. Dimensions (WxHxD)	392x200x230 mm
8. Net Weight	21.40 kgs
9. Number of Cells	12 Cells

4. Diesel Engine Generator

Two 32-hp diesel engine generator sets were used. One generator set was linked to the solar-PV power system, and another backup generator was kept. The diesel engine generator's specifications are shown in Table 7. The engine generator was activated when none of the solar panels were available.

Table 7. Diesel Engine Generator

Particular	Metric
1. Model	ZS1132NL
2. Type	Single Cylinder, Horizontal, 4-Stroke
3. Combustion System	Direct Injection
4. Cooling Method	Radiator
5. Lubrication Method	Combined Pressure and Splashing
6. Starting Method	Hand Start
7. Bore x stroke	130*125mm
8. Rated Power	32hp/23.53kw
9. Max Power	35.2hp/25.88kw
10. Rated Speed	2200 rpm
11. Fuel Consumption	252.7g/Kw·H
12. Oil Consumption	1.7g/Kw·H
13. Net Weight	210 kgs

E. Microgrid Solar-PV Power System Design

After determining the energy demand and identifying the solar-PV panels and balance of system (BOS) components, the solar-PV system will be sized.

1. Size of the Solar-PV Array

To maximize solar electricity production, the solar-PV array should be appropriately sized. To size, the solar-PV array, determine the load current or the current drawn from the system. The solar-PV current can be calculated after selecting the load current (I_L). I_L is the ratio between the Energy Demand (E_L) and the product of the number of hours (H) of use and the DC voltage (V_{DC}) or $I_L = E_L/(HxV_{DC})$. I_L is the most important parameter to consider because it determines the number of solar-PV panels used in the solar-PV energy system.

For optimal solar electricity harvesting, the solar-PV system must be properly sized. Also, the type of inverter to be used, on the other hand, presents a challenge in optimizing solar electricity generation. The detailed technical information on the inverter should be carefully considered, particularly the operating voltage range. Table 8 shows the size of the solar-PV power system appropriate for the Macopa community. The performance ratio (PR) is a quality factor that describes how closely the PV system's performance approaches ideal performance during real-life operation, regardless of location [11]. It should be noted that the calculations are not detailed in this article but can be found.

Table 8. Size of Off-Grid Solar-PV Energy System

Metric	Qty.	Unit
Load current (I_L)	179.49	Amps
Mean PV array current (I_P)	390.50	Amps
No. of parallel PV panels (N_P)	42.00	Pieces
No. of series PV panels (N_S)	4.00	Pieces
Total no. of PV panels (N_T)	168.00	Pieces
Capacity per solar-PV panel	300.00	Watts
Solar-PV Array Total Capacity	50.40	kiloWatts
Solar-PV Desired Capacity	50.00	kiloWatts
Performance Ratio	74.40	%
Off-grid Inverter	4.00	Strings
Rated Capacity per String	4.80	kiloWatts

2. Solar-PV Design Specification

With reference to the preceding section, the required solar-PV power system for Macopa has a capacity of 50.40-kWp (Table 8). This is the result of multiplying 168 panels by 300 watts per panel. Table 9 lists the specifications of the microgrid solar-PV power system. Other factors, such as inefficiency and losses in the different stages of the solar-PV power system, resulted in a derating factor of 74.55 percent (Table 10). The derating factor can be as low as 0.00 percent and as high as 97.30 percent. Acceptable values are assigned arbitrarily and fundamentally based on the range of values provided. The derating factor's goal is to determine the expected energy production. Nonetheless, setting values does not guarantee the solar-PV energy system's natural energy production. Based on the solar-PV system's designed capacity and desired output, a performance ratio of 74.40 percent is a better option, as shown in Table 8.

Table 9. Microgrid Solar-PV Energy System Specifications

Particular	Metric	Unit
DC Rating	50.40	kiloWatts
Number of 300-Watt Panels	168.00	Pieces
Number of Inverters	10.00	Pieces
DC to AC Derate Factor	74.38	%
AC Rating	37.50	kiloWatts
Solar-PV Array Type	Fixed tilt	
Solar-PV Array Tilt Angle	7.00	degrees
Solar-PV Array Azimuth	67.00	degrees
Solar-PV Life Cycle	25	years

The performance ratio (PR) and derating factor (DF) can be interchanged to avoid confusion. When the optimal angles were used, the performance ratio (PR) was an integral part of the design; however, the derating factor (DF) is rated based on the eleven (11) parameters. For technical accuracy, the derating factor (DF) is used to understand the actual energy production of the microgrid solar-PV power system.

The arbitrary assignment of acceptable values is one of the limitations of determining the derating factor. Verifying the exact value to be assigned to specific parameters is more difficult.

Table 10. Derating Parameters

Component	Range of Assumed Values	Acceptable Value	Comments
1. PV module DC rating	0.8-1.05	0.950	Medium quality solar-PV panels are used
2. Inverter and Transformer	0.88-0.96	0.960	Maximum efficiency of the inverter
3. Mismatch	0.97-0.995	0.970	A maximum mismatch between connectors
4. Diodes and Connection	0.99-0.997	0.990	Maximum connection loss
5. DC wiring	0.97-0.99	0.970	Maximum DC wiring losses

6. AC wiring	0.98-0.993	0.980	Maximum AC wiring losses
7. Soiling	0.3-0.995	0.950	5% Soil Contamination
8. System availability	0.00-0.995	0.990	Maximum System Availability
9. Shading	0.00-1.00	1.000	No adjacent buildings & continuous arrangement of solar-PV panels
10. Tilt and Azimuth	0.95-1.00	0.950	Optimal Design of the System
11. Age	0.7-1.00	1.000	New solar-PV energy system
Derating Factor		74.38%	

F. Implementation of the 50-kW Solar-PV Power System

The Provincial Government of Davao de Oro, the Municipality of New Bataan, the Department of Science and Technology – Region XI, and Ateneo de Davao University signed an agreement to fund and support the establishment of the Microgrid Solar-PV Power System.

1. Installation of the Solar-PV Power System

The installation of the microgrid Solar-PV power system began after the technical and socio-economic study was completed. Before installation, some residents were trained and hired to build and install the solar-PV power system. An elevated solar-PV structure was created to make the most of available space. Ten (10) off-grid inverters and 168 units of 100-AH, 12-Volt Deep Cycled Batteries were used.

The distribution system was also laid out and installed with the assistance of community members and technical personnel from Nabunturan, Davao de Oro. Around 50 posts were erected, and kilometers of wires were laid.

2. Monthly Solar Electricity Production

Given a global position of 7°29'55" North (latitude) and 126°17'14" East (longitude), the monthly horizontal global radiation (GlobHor) and global incident radiation (GlobInc) are shown in Table 11. The installed 50.40-kWp solar-PV system generates an average of 6,514.42 kWh of energy per month.

Table 11. Available Radiation and the Generated Energy

Month	GlobHor (kWh/m^2)	GlobInc (kWh/m^2)	Available Energy (kWh)
January	138.20	140.10	5,789.00
February	144.90	144.90	5,939.00
March	161.10	159.90	6,556.00
April	163.40	161.60	6,567.00
May	168.10	165.10	6,751.00
June	164.00	160.20	6,593.00
July	167.60	164.20	6,721.00
August	183.70	180.60	7,371.00
September	173.30	172.20	7,045.00
October	171.00	173.00	6,995.00
November	150.20	153.00	6,283.00
December	132.10	133.50	5,563.00
Sum	1,917.60	1,908.30	78,173.00
Mean	159.80	159.03	6,514.42

3. Solar Energy Production per Inverter

It is interesting to determine the amount of electricity produced by each inverter. The Sunsee-5k off-grid inverter with a rated capacity of 5-kVA was used. It includes a charge controller to charge and control the battery system's power supply. The charge controller ensures that DC solar energy is harvested and stored efficiently. If an electrical load is connected during the day, harvested DC power will be directly supplied to the connected load; otherwise, the battery will be charged for later use.

Each 300-Watt solar-PV panel was connected to a 100-AH, 12V Deep Cycled Battery. Every 300-Watt panel can charge the 100-AH, 12-Volt battery at an average rate of 5.53 kWh/m^2/day. The 300-Watt solar-PV panel has a 1.611 m^2 surface area (1.692m x 0.989m) and an efficiency of 18.6 percent. The capacity of each 100-AH 12-Volt battery is 1,200 VA-Hr (100-AH x 12-Volt) or 1.2 kWh. There may be some excesses on sunny days, but batteries may not be fully charged on cloudy days.

Each 5-kW off-grid system is expected to provide the connected load with 19.10 kWh/day or 592.33 kWh/month (Table 12). However, monitoring actual production was difficult due to the limited capabilities of the Sunsee-5k off-grid inverter. Other off-grid inverters can monitor the charging and delivery of DC solar energy.

Table 12. Energy Production per Inverter (kWh/Month)

INV #	No. of Panels Connected	Rated Power per Panel (W)	Rated Capacity (kW)	Daily Production (kWh/ Day)	Monthly Production (kWh/ month)
1	16	300	4.80	15.12	468.67
2	16	300	4.80	16.83	521.63
3	16	300	4.80	19.40	601.25
3	16	300	4.80	22.53	698.51
4	16	300	4.80	16.26	503.98
5	16	300	4.80	20.53	636.55
6	16	300	4.80	17.69	548.28
7	16	300	4.80	18.83	583.59
8	16	300	4.80	17.69	548.28
9	20	300	6.00	26.38	817.76
10	20	300	6.00	18.90	585.92
			Sum	210.14	6,514.44
			Mean	19.10	592.22

With Sunsee-5k off-grid inverter, the delivered AC solar electricity can be determined based on the users' actual consumption, including some power losses during electricity distribution.

G. Benefits of Solar-PV Power System

Numerous factors influence the performance of a solar-PV module [7]. These considerations are related to the panel, the system itself, location, environment, and other relevant aspects. Awareness, perceived ease of use, observability, behavioral control, attitude, trialability, compatibility, subjective norms, government activities, and support influence household solar-PV use intent [5].

The perceptions of the 100 percent Mandaya (Indigenous People) population on solar-PV were identified for the efficient utilization of the installed solar-PV in Manurigao and are presented in the succeeding sections.

1. Mandaya Belief about the Sun

Mandaya is a local native in Davao de Oro, Philippines, and 88.50 percent of them believed that the Sun is the source of light, 71.3 percent thought that the Sun is the source of energy, 58.6 percent believed that the Sun is a symbol of God/Goddess, and 50.60 percent thought that the Sun has a healing power over people. Because the Sun is believed to be the source of light, 71.3 percent of locals felt that it could supply clean energy, and 71.3 percent thought it was a great alternative to producing power. Because sunshine is free, 62.1 percent believe it might help reduce overall energy costs. However, a minority (4.6 percent) argued that solar-PV is unsafe, while 5.7 percent claimed it could ruin the scenery. Although 58.6 percent said it could supply renewable energy and 44.8 percent said it might help prevent climate change, only 1.1 percent said it could help eliminate poverty.

2. The Importance of Solar PV in the Community

As a result of the survey conducted on solar-PV, 94 percent of the residents said it would primarily provide light at night, 85.4 percent said it would allow their children to do their homework at home, 78.6 percent said it is essential for their livelihood, and 70.2 percent said it is necessary for daily activities and to modernize their lifestyle. Overall, locals anticipated that solar-PV would aid them in their daily activities, including watching television and using other appliances.

Additionally, because solar energy can provide electricity at night, 82.8 percent of residents believed it could help their children in school, particularly when doing homework (85.4 percent), 79 percent thought it could reduce their energy costs, and 77 percent said it would create more job opportunities. Notably, 80.5 percent thought it could be a source of empowerment for the Mandaya.

On a personal level, 88.5 percent said they could do more housework with solar power, 83.9 percent said they would earn more money, and 66.7 percent said they would have more employment opportunities. With more light at night, 81.6 percent of residents will have more time for themselves.

3. Solar Electricity Consumption

After the installation was completed, the actual electrical load was only 10.21% versus the designed load (Table 13). The actual consumption is only 12.97% (27.25 kWh/Day / 210.14 kWh/Day) relative to the expected production per inverter. This shows that, at present, the installed microgrid Solar-PV is more than enough to supply the requirement of the community.

Table 13. Actual Installed Electrical Load

Appliance	Rated Power (W)	Qty	Electrical Load (W)	Est. Daily Use (Hrs)	Est. Daily Consumption (kWh/ Day)
Household Lights (LED)	5	261	1,305	10	13.05
Television	50	9	450	8	3.60
	75	10	750	8	6.00
	100	2	200	8	1.60
Streetlights (LED)	5	50	250	12	3.00
Total		307	2,955		27.25

a. Households Lights (LED)

Each home received and used three (3) units of 5 Watt LEDs. Due to the availability of lights, children can study for longer periods [7]. At a 10-hour consumption, the 87 connected households use only 13.05 kWh daily. Each house was expected to use 40 Watts of lighting for at least 12 hours daily. As the community adds more fittings and lighting, additional lighting will be employed in the coming months.

b. Television and Other Appliances

Since each house was also provided with convenience outlets to connect their electrical devices, twenty-one (21) households connect Television and other appliances with a rated power of 50-W, 75-W, and 100-W. Overall, energy consumed was 11.2 kWh each day. This electricity consumption is significantly lower than the community's daily allocation of approximately 56.0 kWh.

With electricity, the residents can already use mobile phones, radios, and televisions which improves the residents' access to information. Previously, information was very limited, but with the microgrid, the Mandaya could readily communicate and receive news through radios and television.

c. Streetlights

Fifty (50) electrical posts were attached with 5-Watt LED lights to make the street clear and safer during nighttime. Each night streetlights were started for twelve (12) hours consuming 3.00 kWh daily.

d. Industrial Applications

Electricity empowers women [7]; it allows them to work during the nighttime. Likewise, their husbands can help them during the night after farm work. Children are also helping their parents while watching a television program or doing homework at night.

Abaca is one of the most abundant resources in the area, according to 64.4 percent of locals. Hence, abaca weaving is one of their sources of income. Women and children can work even at night due to the availability of lights. Also, they use electricity to run a low-powered weaving machine and other machines. It is envisaged that the introduction of power would eventually lead to creating jobs in the community [7].

e. Environmental Protection

Using clean and renewable energy sources to create electricity, such as solar energy, minimizes the emissions of CO_2 [7]. Also, 71.3 percent of the residents believed that solar-PV could supply them with clean energy, which is one way of protecting the environment.

4. Monthly Energy Consumption

With the installation of power in the village, the Mandaya began to consume energy, which entails cost. Each digital meter was connected to at least one household. Watt meters were fitted to measure energy consumption. Each meter recorded an average of 16.81 kWh monthly, 756.64 kWh for the entire village (Table 14). This consumption represents 11.62 percent of the potential energy generated by the installed microgrid solar-PV power system.

Table 14. Energy Consumption (Daily and Monthly)

	Lights (LED)	Appliance	Average	
	Watts	Watts	Daily (kWh)	Monthly (kWh)
Sum	1,305.00	1,360.00	25.28	756.66
Mean	29.00	64.76	0.56	16.81
Max	30.00	100.00	1.26	37.38
Min	15.00	10.00	0.18	5.18

H. Challenges of Solar-PV

At the project's outset, most residents (69.0 percent) saw no issues installing solar PV in the community. However, 20.7 percent of residents were concerned about the cost of operation, and 19.5 percent said it would be difficult to maintain. Furthermore, 8.0 percent believe solar-PV will cause conflict due to misunderstanding, and 3.4 percent think it will disrupt Mandaya's traditional activities.

Nonetheless, the Mandaya may use the microgrid efficiently due to their faith in the Sun and perceptions of its benefits. Other contextual factors were not determined during the study because the solar-PV power system was still in its early stages of operation. Solar electricity was primarily used for lighting purposes only. The microgrid installation appears to have provided numerous benefits to the village, yet, the community must also learn how to deal with the microgrid's problems to operate correctly and sustainably [7].

The following sections will present some challenges in operating and maintaining a microgrid solar-PV power system.

1. Cost of Electricity

The most difficult challenge is the cost and corresponding tariff to continue supporting the microgrid solar-PV power system operation [7]. The overall cost of the installed microgrid solar-PV power system that can produce 78.17 MWh per year is about US$ 320,110.61 (Table 11 and Table 15). This does not include costs incurred by the Ateneo de Davao University (ADDU) or indirect costs incurred by the Department of Science and Technology (DOST). Based on this cost, an electricity tariff or cost can be established to recover the installation cost and sustain the operation [1], [13].

Table 15. Microgrid Solar-PV Installation Cost

Item	Qty.	Unit	Cost (US$)	Total (US$)
PV Modules				
GTEC-300G6S6A	168	panel	264.24	44,392.52
Support Modules	168	sets	103.82	17,442.00
Batteries	168	pieces	176.02	29,571.83
Controllers	10	sets	1,016.25	10,162.47
Back-up Generator	2	sets	1,224.01	2,448.01
Components				
Wiring	1	lot	21,675.19	21,675.19
Monitoring & Control System	1	lot	37,993.78	37,993.78
Measurement system	50	pieces	135.24	6,762.00
Studies				
Engineering	1	lot	99,777.41	99,777.41
Installation				
Transport	1	lot	21,398.16	21,398.16
Settings	1	lot	28,487.24	28,487.24
Total				320,110.61

Additionally, the operating cost for the lean operation is about US$ 12,616.41 per year (Table 16). This cost assumes that the inverter will not be broken during the entire solar-PV operation, and there is no major replacement of the battery storage system.

Table 16. Operating Cost (US$ per year)

Particular	Total (US$/Year)
Salaries	2,514.00
Provision for Battery Replacement	9,226.14
Fuel for Back-up Generator	508.80
Total	12,248.94
Including inflation (3%)	12,616.41

Assuming the community invests US$ 320,110.61 in installation costs and an annual operating cost of US$ 12,616.41, a tariff of US$ 0.39 per kWh is required for a 20-year to recoup the investment. This also assumes that there is no interest in the money and that the energy produced is fully utilized. However, the tariff will be US$ 2.87 per kWh if the system is used only at 13.93 percent (27.25 kWh/Day/195.56 kWh/Day). The Mandaya cannot afford this tariff due to their very limited income. The cost of electricity or tariff is only US$ 0.18 per kWh if the government fully subsidizes installation costs, such as the Department of Science and Technology (DOST) or Department of Energy (DoE). Further, the collected tariff will only be used for operation and maintenance.

The community can set tariffs for solar electricity, either feed-in or consumption, as long as they are not higher than what the community can afford to pay. To ensure continued operation and use of electricity, a minimum amount of US$ 0.18 per kWh can be set in the fully subsidized project.

2. Technological and Management Capacity

The other difficult aspect of operating the microgrid solar-PV power system is its maintenance; it is difficult to maintain due to the intricacy of the control mechanisms and electricity storage and distribution [14]. Since only 22.9 percent of the population has completed at least high school, finding people to run and manage the system was difficult. To ensure the system's proper operation, selected community people were given orientation and training in electronics, electrical, battery systems, and other relevant technical areas. One issue was that people left the community to find work in other towns after training.

In addition, a management team through a cooperative was established to manage and operate the system. However, while the initiative was being carried out, difficulties were encountered.

3. Road Infrastructure Impediment

The community where the microgrid solar-PV power system was installed is approximately 34.5 kilometers away and has extremely rough terrain with no suitable road network. It takes 10-12 hours to walk to the area and 5-6 hours to ride a motorcycle, which is the only mode of transportation. Researchers and technical personnel had difficulty accessing the site during installation and site visits. Transporting the materials to the site was difficult and costly.

Furthermore, providing technical and management support is difficult due to lacking a good road network. Furthermore, purchasing fuel and small components takes time due to road network issues, transportation costs, and a lack of funds.

4. Other Inadvertent Challenges

There were some difficulties encountered during the study. Macopa is a small village with no road access, making it an ideal base for insurgents. During the study, there were some clashes between government forces and insurgent groups.

One of the issues that hampered the project's efficient implementation was the COVID-19 pandemic. Mobility was severely limited. Apart from the ban on traveling to and visiting the site, obtaining necessary materials was extremely difficult. It was difficult to request and demand critical activities from domestic and international partners.

However, these issues may not arise during the system's long-term operation. People in the community may adapt to the recurring insurgent situation, and the COVID-19 may have already been eradicated.

IV. CONCLUSION

The 50.40-kW microgrid solar-PV power system that generates 210.14 kWh/day enables the community, the Mandaya, to use electricity in their daily life by working for prolonged periods, assisting children in their education, gaining access to information, strolling safely at night, and operating machinery for industrial purposes. The cost of maintaining the system, on the other hand, is quite high. Due to a lack of earning options, residents may be unable to afford the tariff of US$ 0.40 per kWh or the subsidized tariff of US$ 0.18 per kWh. The village's low economic activity is caused by its remote location and lack of a road network.

Furthermore, insurgency and unanticipated disruptions, such as the COVID-19, upset the Mandaya's usual day-to-day tasks. On the other hand, the government can develop and implement policies and regulations to assist poor and disadvantaged individuals in maintaining the operation of microgrids.

The potential socio-economic benefits of microgrid solar-PV power systems have encouraged governments and various organizations to support their development. However, before microgrids can be extensively adopted, several problems must be addressed, including the requirement for cost-effective energy solutions, integration of microgrids into main grids, developing cost-effective ways to fund microgrid installations, applying technology standards, construction of road networks, creation of industry especially in remote communities, and crafting of policies to provide appropriate incentives to the developers, consumer, and prosumers. Many of these difficulties are ubiquitous in the energy sector and will not be resolved just through the expansion of microgrids.

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