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*Research Article*

# Technical Evaluation of Photovoltaic Systems in the Bamenda Municipality of the North West Region of Cameroon

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In the Bamenda Municipality of Cameroon households are adopting Solar Photovoltaic Systems (SPVS). The penetration of SPVS in this Municipality depends on their technical performance. The study aimed to evaluate the technical installation of SPVS within the Municipality. A field inspection and administration of a questionnaire was conducted. The field inspection evaluated the respect of technical installation norms for SPVS. The questionnaire captured data on the technical situation of the SPVS. The SPVS installed included PV and grid to power separate loads, and PV and grid to power same loads. The installed loads were a mix of AC and DC loads of capacity from 360 W to 10000 W. The load powered by the installed SPVS varied from 300 W to 7000 W. The PV array varied from 200 W to 3200 W and battery bank capacity of 100 Ah to 800 Ah. The PV arrays were mostly installed on roof tops. Only 5% of the SPVS were installed by certified personnel. More than 50% of the installed SPVS operated below designed operation time. Failures in installed systems were related to inverters (36 %) and battery banks (36 %). Most of the PV arrays were installed on rooftops at tilt angles between 20° and 50°. More than 50 % of the PV arrays were oriented to directions other than South. Protective devices were installed in only 14 % of the installed systems. Some of the SPVS were not properly dimensioned. It may be concluded that most of the installed SPVS do not respect the technical installation norms and were not dimensioned according to users' needs. The survival and penetration of SPVS technology in the Bamenda Municipality, Cameroon, and other sub-Saharan communities requires awareness and capacity building, policies, and regulations in the design and installation of this technology.

## 1. Introduction

It is no longer an emphasis that energy is essential for human well-being, poverty reduction, and sustainable development [1–5]. It is projected that the demand for energy will increase significantly by 2035 due to demographic growth and mobility, economic development, urbanization, technological changes, and climate change. However, clean energy is a major requirement for sustainable human development. About 1.1 billion people worldwide are without access to electricity [6, 7]. Sub-Sahara Africa (SSA) is host to 620 million people without access to electricity [3, 6, 8, 9]. Nearly 1 billion people in SSA are projected to have access to electricity by 2040; however, due to population growth, about 530 million people will still be without access to electricity in SSA [2]. Harnessing the abundant renewable energy potential of this Region could provide more than 40 % of the power generated with mini- and off-grid solutions, powered by solar photovoltaic, small hydropower, or wind [2]. Between 50 % and 61 % of Cameroonians have access to electricity? This electricity access rate varies between urban and rural areas. While the Urban centers have an access rate of between 88% and 93%, the rural areas have an access rate of only between 17 % and 24 % by 2017 [10–12]. By 2018, the installed power generation capacity of Cameroon stood at 999 MW with 732 MW from hydro, 267 MW from thermal and 0.186 MW from renewables. The country needs an additional capacity of 100 MW every year to satisfy the growing demand [11]. The shortage in power supply has resulted in load shedding and constant outages. While waiting for this additional power demands to be met, Cameroonian households in the urban centers have sought alternative energy sources to either deal with power outages or the power supply insufficiency. In the Bamenda Municipality of the North West Region of Cameroon, many a households are adopting Solar Photovoltaic Systems (SPVS) to meet their household energy challenges. Users' satisfaction is crucial for the success of these SPVS in the Bamenda Municipality [1]. Users' satisfaction depends on the technical performance of the SPVS which is a function of system design, the component used (type and size of inverter, battery, and charge controller), quality of system installation, orientation, amongst other technical factors. The penetration of SPVS in the Bamenda Municipality and other communities of Cameroon as well as in other countries in sub-Sahara Africa depends very much on the technical performance and the satisfaction users derive from this technology [1, 4, 13].

## 2. Literature Review

In order to scale up access to electricity, an assessment of the technical prospects, amongst other factors, for electricity generation and delivery technologies is required. Off-grid technologies such as Solar Photovoltaic Systems (SPVS) are being deployed in developing countries [14]. There are various types of these SPVS disseminated globally which include PV powered AC systems, DC-coupled PV systems (with DC loads), PV systems with both DC and AC loads, PV hybrid systems with both DC and AC loads, DC-coupled PV systems with AC loads and the DC-coupled PV hybrid systems with AC loads. An appreciation of the technical evaluation of these SPVS, deployed in the Bamenda Municipality, may be through a review of the technical option of SPVS for households, installation norms, expertise required for installation of the SPVS and factors which may affect the performance of these systems. The technical options for SPVS may take either of the following: Solar Pico Systems (less than 10 Wp) and Solar Home System (10–130 Wp). The classical Solar Home Systems may have a PV array of up to 250 Wp. The third category of SPVS is referred to as Solar Residential Systems (SRS) with PV array of 500–4000 Wp. The fourth category of SPVS is the Solar Mini-Grids which have an array capacity of greater than 5 kWp [4, 5, 15]. The Solar Pico Systems (SPS), Solar Home Systems (SHS), and Solar Residential Systems (SRS) are the SPVS mostly applicable for household energy services. The SPS are usually equipped with rechargeable battery, a charge controller, and power, mostly DC loads, of either lighting only or also additional electrical services such as mobile phone charger and radio. SPS systems offer some technical, economic, and commercial advantages [5, 15]. The SHS, in addition to PV array, comprises other components such as batteries, inverter, and charge controller. SHS may be designs to power several lamps, a radio, a TV, and refrigerators. The loads powered by SHS may either be DC or AC loads. The design, installation, and suitable operation and maintenance of SHS require highly trained technicians [4, 5]. The SRS have a PV array of 500–4000 Wp, inverter, charge controller, and a battery bank with an operating voltage of 12 V to 48 V. SRS are designed to power mostly AC loads [5]. The mini-grid systems are usually applicable for hospitals, hotels, or whole communities. Such systems are hybridized to include other energy sources such as Diesel generators.

Several factors may influence the performance of a PV system such as plane of array irradiance, ambient temperature, module temperature, module technology, inverter size, and efficiency. The PV module temperature may be influenced by the installation method and hence the performance of the systems [16]. There are several methods for the installation of the PV arrays in a SPVS. These include Building Integrated PV (BIPV), Building Applied PV (BAPV), and Ground-Mounted PV (GMPV) [16]. Whether the PV array is BIPV, BAPV, or GMPV, the inclination of the array is one of the factors which influence the performance of the SPVS. Therefore, the installation of PV array on the roof of a building either as BIPV or BAPV must take into consideration the roof profile. The installation of the PV array on the roof should meet roof requirements [17]. The slope of the roof is a factor that influences the inclination of the PV array in the case of BAPV. The recommended optimal inclination of flat plat PV array is approximated to the latitude of the location of installation facing south for installations in the northern hemisphere [18]. Also, a minimum tilt of 10° is recommended in order to take advantage of self-cleaning of the panels, especially during the rainy season.

The successful installation, operation and maintenance of SPVS Systems require some level of competences, without which the system may fail and the technology receives a bad reputation [15]. Some of the challenges PV-based system encounter includes reliability and appropriate sizing of the system components [15]. Sizing of PV systems is usually based on the power and energy demands of the household. Reliability of the systems depends on appropriate technical specification, regular field inspections, in-depth field evaluation few years after installations. Therefore, absence of local operation and maintenance services could be a significant weakness to the performance of PV systems. SPVS have a great potential as an electricity source for the more the 620 million persons in SSA without access to electricity. An assessment of the technical aspects, amongst other factors, for electricity generation from SPVS deployed in developing countries is required. Best to the knowledge of the authors, there is very little in the literature on the on-site technical evaluation of SPVS deployed in developing countries. It is the aim of this paper to contribute to the knowledge on the technical situation of SPVS systems deployed in developing countries. The overall objective of this study was to investigate the technical situation of SPVS installed within the Bamenda municipality. The specific objectives included:

(i) To identify the electrical energy sources used by households in the Bamenda municipality.
(ii) To identify the types of loads and load capacity installed in the households.
(iii) To examine the capacity of installed SPVS vis-à-vis electrical loads in Households.
(iv) To investigate whether the installed SPVS respect design and installation norms.
(v) To identify the installation method used and whether these methods follow the technical installation norms for SPVS.
(vi) To identify the expertise involved in the installation SPVS in the study area.

## 3. Materials and Methods

*3.1. The Study Area.* The study was carried out in the Bamenda Municipality which consist of administrative subdivisions of Bamenda I, II, and III of Mezam Division of the North West Region (NWR) of Cameroon. These administrative subdivisions also coincide with the Bamenda I, II, and II Councils. Less than 32 % of households in five out of ten regions of Cameroon have access to electricity through connection to the public grid. The North West Region, where the Bamenda Municipality is located, has less than 20 % of households connected to the public grid [19]. Like other areas of the country, the Bamenda Municipality experiences frequency electricity outages. Such outages have push households to seek alternative electrical energy sources. The SPVS is one of such alternative electrical energy sources in households in Cameroon. Thus, the technical situation of SPVS in the Bamenda municipality may be similar to those in other areas of Cameroon. The Bamenda Municipality is the seat of the regional administrative headquarters of the NWR. The population of the NWR was estimated 2,369,058 inhabitants while that of the Bamenda Municipality was estimated to be about 442,432 inhabitants [20]. The Bamenda Municipality is located between latitude 5°94′N and 5°98′N and longitude 10°15′E and 10°18′E and about 366 km North West of Yaoundé the administrative capital of Cameroon. Figure 1 shows the location of the study area in the NWR [21].

The study was realized through a field survey of SPVS installed in households in the Bamenda Municipality. Though Cameroon has a commitment of attaining 25 % of her energy production from renewable energy sources, with solar contributing up to 6 % of the total energy production by 2035, the share of electricity production from renewable energy sources, excluding hydropower, by 2017 was still less than 1% with solar contributing about 0.23 % [22, 23]. From the foregoing, it could be projected than less than 0.23 % of an estimated 80,000 households in the Bamenda municipality have installed SPVS. It may be estimated that about 200 households in the Bamenda Municipality have installed SPVS. Questionnaires were administered to 30 households, purposively sampled. The survey comprised of two main parts: physical inspection of the installed systems and administration of a survey questionnaire. The objective of the field physical inspection of the installed systems was to evaluate the respect of technical installation norms for SPVS. The technical installation norms observed through physical inspection included installation method of the PV arrays, the angle of inclination or tilt angle and orientation of the PV array, the presence of shadings around the PV array, the presence of system's protective devices. The on-site required optimum tilt angle, $\beta$, of PV arrays was determined as described in [24] using the following equation:

$$\beta = |\varnothing - \delta|, \tag{1}$$

where $\beta$ is the angle of tilt between the panel and the horizontal plane Ø is the latitude angle of the site where the PV arrays were installed. $\delta$ is the solar declination determined using equation (2) $n$ is the day of the year, with the 1st of January assumed as the start.

$$\delta = 23.45 \sin\left[360\left(\frac{284 + n}{365}\right)\right]. \tag{2}$$

The on-site orientation of the PV array was determines using a hand-held compass. A checklist was use to collect data on the presence of SPVS protective devices, installation methods and possible shadings on the PV array.

The survey questionnaire was designed to capture data on the technical situation of the SPVS in each surveyed household. The questionnaire was divided into two main sections. Questions in the first section were designed to capture data on the technical situation of the installed SPVS. These data included electrical energy sources for the household, the types of SPVS, household installed load capacity, types of loads, PV array capacity, share of load powered by SPVS, battery bank capacity. The second section of the questionnaire contained questions designed to capture data on expertise used to design and installed the SPVS, technical failures encountered by the SPVS, size of SPVS vis-à-vis the load demand and appropriate sizing of the SPVS for the household.

In order to evaluate the appropriate sizing of the systems, a home was randomly selected and, a load and energy demands assessment was done. The total power demanded, total daily energy demands, PV generator size, battery capacity, charge controller, and inverter size were determined using standard formulae [25, 26] as in equations (3)–(9)

$$P_T = \sum_{k=1}^{N} n_k P_k, \tag{3}$$

where $P_T$ = total power demanded by the household (W). $n_k$ = number of appliances with power rating, and $P_k$ = power rating of the $k$th appliance (W).

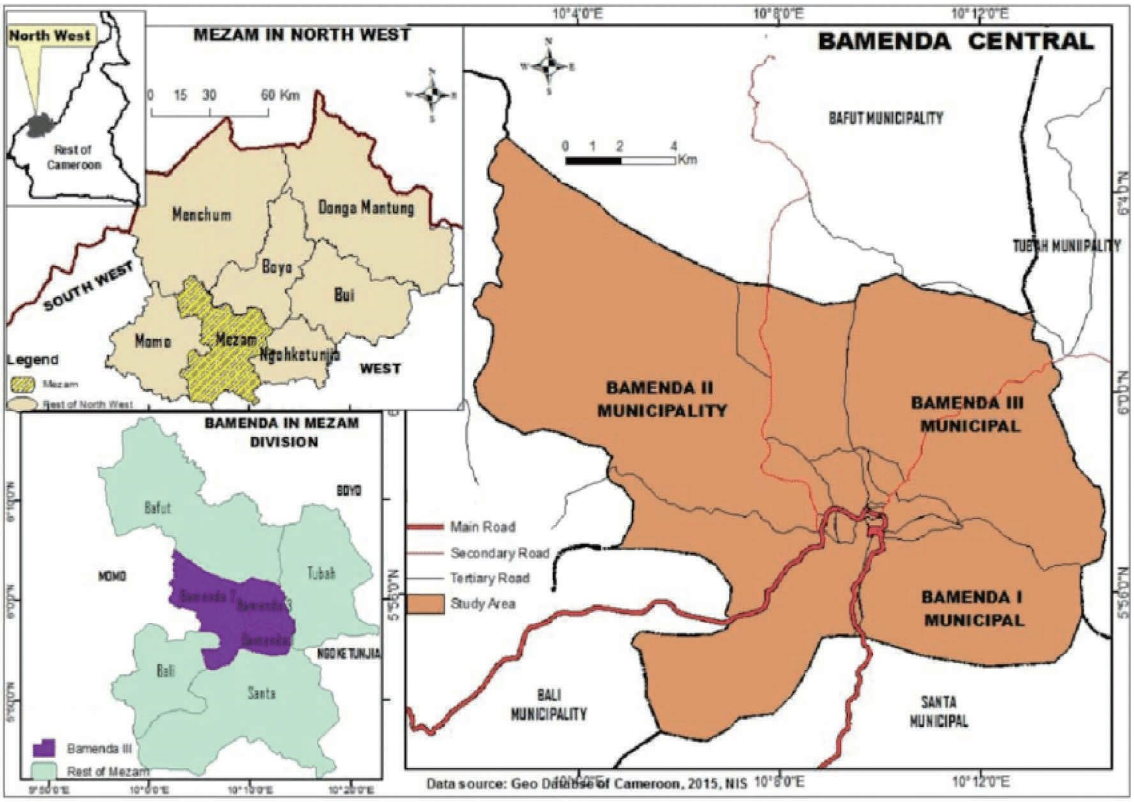


Figure 1: Bamenda municipality within the North West Region of Cameroon.

$$E_L = \sum_{k}^{N} n_k P_k t_k, \tag{4}$$

where $E_L$ = energy consumption by all appliances (Wh), $n_k$ = number of appliances with power rating $P_k$, $P_k$ = power rating of the $k$th appliance (W), and $t_k$ = daily operation time of the $k$th appliance (h).

$$P_c = \frac{E_l}{\mathrm{KI}_{\mathrm{rav}}}, \tag{5}$$

where $P_c$ = peak power of the PV generator (W), $E_L$ = total daily energy demand of the load as determined in equation (4), $K$ = efficiency of the PV system, and $I_{\mathrm{rav}}$ = peak sun hour or the horizontal daily average irradiation

$$C_B = \frac{E_l * N_A}{\eta_B * \mathrm{DOD} * B_V} \tag{6}$$

where $C_B$ = battery capacity (Ampere-hour or Ah), $E_L$ = daily energy consumption (Wh), $\eta_B$ = battery charging efficiency (normally 0.8 to 0.95), $B_V$ = battery nominal voltage (V), $N_A$ = number of days to be operated without sunshine (Autonomy Days), and DOD = depth of discharge of the battery

$$I_{\mathrm{CC}} \geq 2 \max\left(I_{L\max}\right), \tag{7}$$

where $I_{\mathrm{CC}}$ is the charge controller rating (A), and $I_{\mathrm{sc}}$ = short circuit current of the selected PV modules IL max is the maximum battery to load current given by the following equation:

$$I_{L\max} = \frac{P_T}{B_V}. \tag{8}$$

$B_V$ = battery nominal voltage (V), and $P_T$ = total power demanded by the household (W).

$$S_{\mathrm{inv}} = \frac{P_T}{\mathrm{PF} * n_{\mathrm{inv}}}, \tag{9}$$

where $S_{\mathrm{inv}}$ = inverter apparent power (VA), $P_T$ = total load power demanded by household (W), $P_F$ = load power factor, and $n_{\mathrm{inv}}$ = inverter Efficiency.

For the selection of the inverter, the power factor PF was taken as 0.8 and the inverter efficiency was taken as 0.8 according to the inverters available in the local market.

## 4. Results and Discussion

### *4.1. Results*

*4.1.1. Electrical Power Supply Sources to the Households.* The households installed different combinations of power sources to meet their household energy challenges. These electrical power sources included PV only, PV and grid separated with segmented loads, hybrid systems, PV, and Grid with the same loads, PV and Diesel generator, PV, Grid, and Diesel Generator. Figure 2 shows the shares of the type of electrical power sources installed by the households. Most of the households (45 %) installed PV and Grid separated with segmented loads power source, followed by PV only (18%) and PV and Grid with same loads (18 %), hybrid systems (14 %), and PV and Diesel Generator (5 %). Amongst the households investigated, none installed PV, Grid, and Diesel Generator power sources.

*4.1.2. Installed Load Capacity and Type of Loads in the Household.* In most of the households, the installed load capacity ranged from 300 W to 10 kW. Very few households had installed load capacity of less than 1 kW. The electrical power sources presented in Figure 3 were intended to power different types of loads installed in the households. These loads could either be AC or DC loads. About 50% of the investigated households had a mixed of AC and DC loads, while 45 % had only AC loads. Figure 3 presents the share of loads in the households.

*4.1.3. Size of the PV Array and Load Powered by the SPVS.* In none of the households was the PV array less than 100 Wp. The size of the solar PV array installed by the households varied from 200 W to 3210 W. In fact, 86 % of the households had a PV array of between 200 Wp and 1000 Wp; 14% of the households had PV array greater than 1000 Wp. Not all the installed loads (power demanded) in the households were supplied by the installed SPVS. The size of the load powered by the installed PV system varied from one household to another. The load size powered by SPVS varied from 50 W to 5400 W. In Figure 4, in only 27 % of the households the installed SPVS was designed to power 100% of installed load in the household. In 68 % of the households, less than 50% of the installed loads were powered by the installed SPVS.

*4.1.4. Battery Bank Capacity in the SPVS.* The battery in the installed SPVS ranged from 100 Ah to 800 Ah. The average battery capacity installed was 253 Ah. 64 % of the households had less than or equal to 200 Ah battery capacity installed with their SPVS. Figure 5 shows the battery bank capacity installed with the SPVS in the households.

*4.1.5. Expertise Used for the Installation of the System.* Various expertises were used for the installation of the SPVS. More than 50% of the SPVS were installed by freelance solar energy technicians. Only 18 % were installed by a solar energy company or an electrician and 5 % by freelance solar energy engineers. Up to 9 % of the SPVS systems were installed by the users. Figure 6 shows the share of the expertise used in the installation of the SPVS.

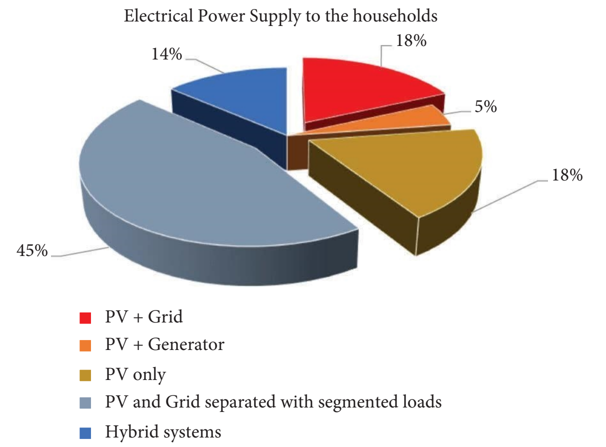


Figure 2: Types of electrical power sources installed by households.

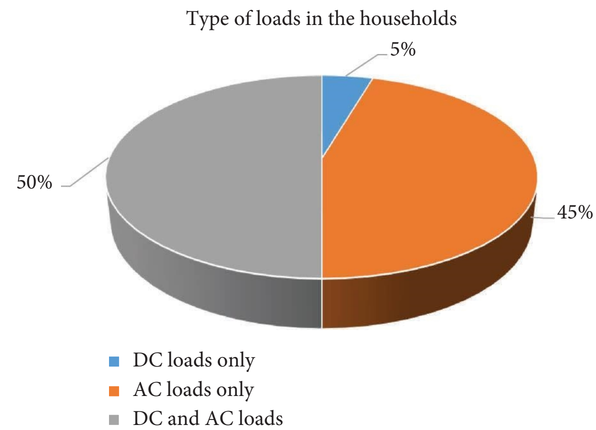


Figure 3: Types of loads in the households.

*4.1.6. Frequency of Failure and Components Which Fail in the SPVS.* The frequency of failure of the SPVS to provided energy to the households was investigated. None of the SPVS recorded frequent failures. Only 5 % of the SPVS had consistent failures in the night times. About 45 % of the installed systems hardly failed. In the case where the SPVS failed the type of technical failure varied from one system to another. The failures were mostly related to the inverter, battery, or simply disconnection of some connecting cables. Figure 7 shows the frequency of failure of the SPVs, and Figure 8 shows the system components which usually cause system failures. In about 62 % of the SPVS the failures were from failed inverters and battery bank, 23 % of the system had cable disconnections or the PV array was destroyed by strong winds.

*4.1.7. Size of SPVS Vis-à-Vis the Installed Load and Appropriate Sizing of the System.* A household was selected at random and sizing of the SPVS was done. The selected household had a SPVS with components as in Table 1.

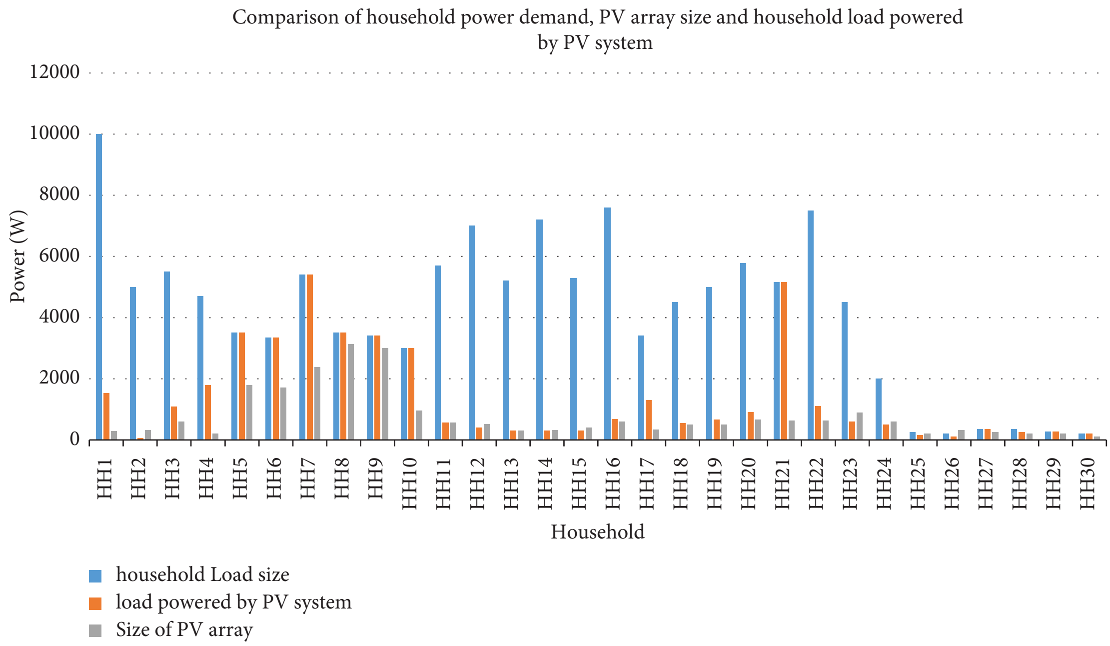


Figure 4: Installed household load, PV array size, and loads powered by the PV system.

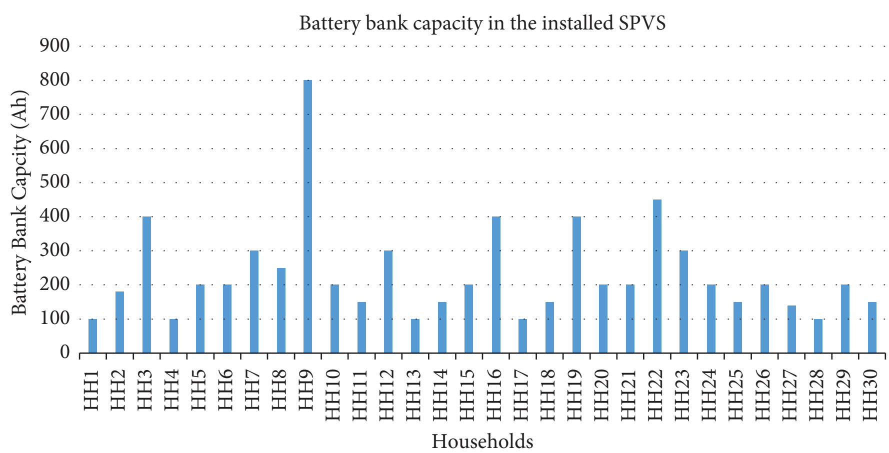


Figure 5: Capacity of the battery bank in the installed SPVS.

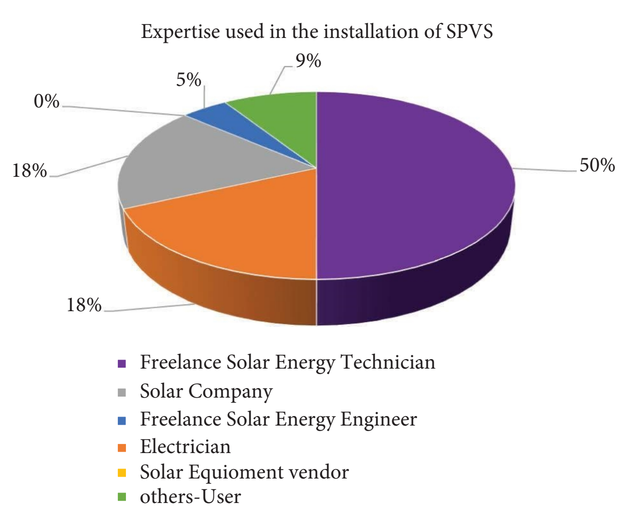


Figure 6: Expertise used in the installation of the SPVS.

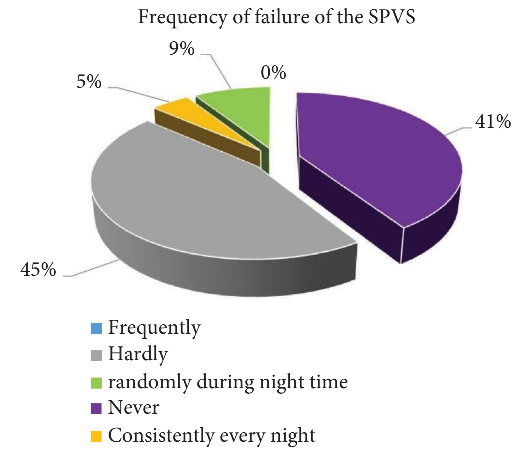


Figure 7: Frequency of failure of SPVS in the households.

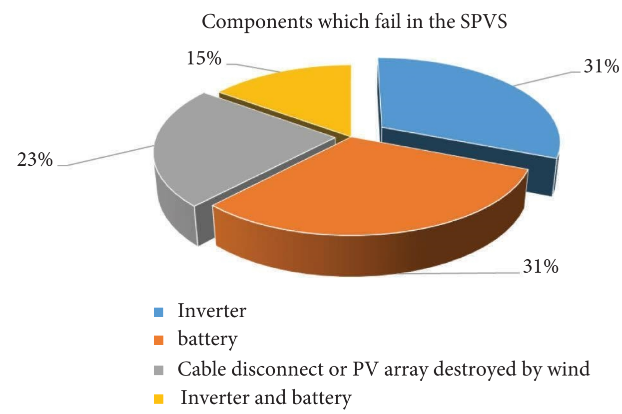


Figure 8: Component that fail in the SPVS in the households.

The system in Table 1 was installed to power the load as presented in Table 2.

The total load to be powered by the installed SPVS in Table 1 was 954 W, with an estimated daily energy demand of 3528 Wh. In the resizing of the components of the system, i.e., PV generator, battery bank capacity, charge controller, and inverter, the following parameters where considered: system efficiency was set at 80 %, peak sun hours in the locality were 4.5 hours, nominal battery voltage was 12 V, battery charging efficiency as taken as 80 %, day of autonomy for operation of the system was 1 day, depth of discharge of the battery was 70 %, the locally available inverter had an efficiency of 80 %, a load factor (PF) of 80 %, and a safety factor of 1.5 for the inverter. The resized system had component capacities as shown in Table 3.

Table 4 shows a comparison of the installed system and the redesigned system for the selected household. The installed SPVS was underestimated to provide the daily energy demands of the household.

From Table 4, some of the SPVS installed in the household in the municipality may be underdimensioned.

*4.1.8. Method of Installation of the PV Array.* Most of the SPVS (73 %) were simply placed on the rooftop with little or no anchoring support; 23 % were installed by placing on the rooftop with anchoring support. It is not yet a culture in the Bamenda municipality to install SPVS by integrating them as part of the roof. Figure 9 shows the share of the various method of installation of SPVS in the Bamenda Municipality. Figures 10 and 11 show the PV array installed in some of the households.

*4.1.9. Angle of Tilt of the PV Array.* All of the SPVS in the Bamenda Municipality had fixed solar panels, i.e., the PV array does not have any mechanisms for the track of the sun. From equations (1) and (2), the angle of inclination for fixed solar panels for Bamenda should range from 8.0° to 17.0° for optimum performance throughout the year. The results revealed that 31% of the SPVS installed were within required inclination norms. More than 69 % were tilted at angles greater than the recommended. Figure 12 shows the distribution of the various angle of tilt of the SPVS observed in the Bamenda Municipality.

*4.1.10. Orientation, Shading, and System Protective Devices of the Installed SPVS.* A majority (35 %) of the installed SPVS were installed to face the South direction. The remaining 65 % of installed SPVS were installed in directions order than south, that is, South East, North East, North, West, East,

Table 1: System capacity in a selected household.

| S/N | Component | Quantity | Unit capacity | Total capacity | Remarks |
|---|---|---|---|---|---|
| 1 | PV generator | 4 | 160 Wp | 640 Wp | $I_{max} = 7.96$ A<br>$V_{max} = 20.2$ A<br>$I_{sc} = 9.33$ A, $V_{oc} = 21.84$ V<br>The panels were monocrystalline connected in series |
| 2 | Battery | 3 | 150 Ah | 450 Ah | Each battery was rated 12 V, sealed gel lead acid battery |
| 3 | Charge controller | 1 | 40 A 12 V/24 V | 40 A 12 V/24 V | |
| 4 | Inverter | 1 | 2000 W | 2000 W | Pure sine wave |
| 5 | Surge protective device (SPD) | 1 | 2.2 kV | 2.2 kV | Protect the charge controller from surge voltage in case of a lightning storm |

Table 2: Load powered by the SPVS in Table 1.

| S/N | Appliance | Quantity | Unit power (W) | Power (W) | Time of operation (hour) | Energy (Wh) |
|---|---|---|---|---|---|---|
| 1 | Lamp | 30 | 5 | 150 | 8 | 1200 |
| 2 | Television system 1 | 1 | 36 | 36 | 16 | 576 |
| 3 | Blender | 1 | 400 | 400 | 0.16 | 67 |
| 4 | Decoder | 1 | 18 | 18 | 16 | 288 |
| 5 | Television system 2 | 1 | 350 | 350 | 4 | 1400 |
| | Total | | | **954** | | **3528** |

954 W is the total power of the load to be powered by the SPVS. 3528 Wh is the total daily energy demanded by the load.

North and South, and East and West. Figure 13 shows the distribution of the orientation of the installed SPVS. Shading is a factor which could affect the performance of an SPVS. Only 4 (18 %) of installed SPVS had objects which could cause shadows on the panels. However, accumulation of dust on the panels could be considered another form of shading which could affect the performance of the SPVS. Figure 14 shows an installed SPVS with huge accumulation of dust on the panel. Protective devices are very important for a healthy functioning of SPVS. The study revealed that only four (04) (18 %) installed SPVS have protective devices. The devices installed included AC and DC circuit breakers and AC and DC Surge Protective Devices. Figure 15 shows the SPVS with installed protective devices.

*4.2. Discussions.* Households in the Bamenda Municipality, like households in other parts of Cameroon are faced with the challenge of having access to a clean, affordable and reliable source of electricity. The households used a combination of electrical energy sources in order to have access to electricity. The use of multiple sources of electricity was a strong indication of the insufficiency of the national grid to supply reliable electrical energy even to urban area [11]. Electrical power demand in the households was mostly greater than 1 kW. The loads to be powered were mostly AC loads though there was a substantial mix of AC and DC loads. The nature of loads in the households has implications on the type and components of SPVS required. Most of the SPVS installed were very large and fall out of the classical definition of “solar home system.” Classical solar home system (SHS) may have array of up to 250 Wp [5, 15]. Most of the installed SPVS may be considered to be Solar Residential Systems (SRS), very few falls within the category of Solar Home System [5, 15, 27]. Fairly large SPVS were installed in the municipality. The installed systems partially powered the installed loads of the households. Thus, they served as alternative electrical energy sources to provide essential energy needs of the households. Though the installed PV array was fairly large, the battery bank for energy storage in most of the household was less than 200 Ah. Most of the loads were greater than 1 kW, this translated to about 4000 J/day of energy demand, if it is considered that basic access to electricity mean at least 4 hours of constant electricity supply per day [28, 29]. At 12 V, 200 Ah, the households will have about 2400 J/day (60 % of daily energy demand) from the battery. This is an indication that the systems were likely not properly dimensioned. Most of the SPVS were installed by less qualified technicians. About 23 % of the SPVS were installed either by a freelance Solar Energy Engineers or a solar energy company. There is therefore limited local expertise for the design and installation of solar PV technology in the municipality. Local qualified technicians are crucial for the design and installation of SPVS. Poor designed and installed system could negatively impact the local penetration of technology [4, 5]. The study revealed that SPVS installed within the Bamenda municipality did not record frequent failures even though the systems were installed by nonexperts. Failure recorded was most related to cable disconnect, batteries, and inverters. Failure in batteries and inverters could be as a result of poor dimensioning of the system. The dimensioning of the system for a randomly selected household revealed that the battery, inverter, charge controller, and the PV array were undersized (see Table 4). In a majority of the SPVS, the PV panels were simply placed on the rooftop without anchoring support. Rooftops and/or remote PV systems are not easily serviceable. PV systems must include associated power electronics to work properly with minimal maintenance requirements. Placing panels directly on the roofs without enough aeration will lead to high heat. The high heat and humidity will lead to faster degradation of the PV panels and materials which protect the cells [30–32]. It is therefore necessary to review the installation methods of SPVS in the Bamenda municipality in order to protect them from combine local heat and humid environment. Also,it is difficult to carry out maintenance activities, such as cleaning of panels of accummulated dust, for panels placed on rooftops. With cumulated dust of the panel, its productivity is reduced. The reasons for rooftop installation SPVS in the Bamenda Municipality may be to prevent theft of the PV panels.

Shading can cause a significant loss in power for PV systems, though bypass diodes are built into the module output wiring to direct current around the module should a string be shaded. This reduces the unshaded module from feeding the shaded modules and hence prevents excessive power loss in the panel [33, 34]. Although the study revealed that most of the SPVS were installed such that there was little or no shading on the panels, they were however, exposed to the accumulation of dust. The accumulation of dust on the panel presents another form of shading on the entire panel and therefore leads to power loss in the module. The SPVS installed in the Bamenda Municipality had fixed solar panels. In fixed panel PV systems, the angle of tilt and orientation are parameters which affect the performance of the system. The study revealed that a majority of the SPVS installed on the Bamenda Municipality had angle of tilt greater than the

Table 3: Capacity of resized components.

| S/N | Component | Unit capacity | Total capacity | N° | Remarks |
|---|---|---|---|---|---|
| 1 | PV generator | 160 Wp | 980 | 6.125 | $I_{max} = 7.96$ A $V_{max} = 20.2$ V<br>$I_{sc} = 8.56$ A, $V_{oc} = 24.2$ V<br>The panels were monocrystalline connected in series |
| 2 | Battery | 150 Ah | 525 Ah | 3.5 | Each battery was rated 12 V, sealed gel lead acid battery |
| 3 | Charge controller | 79.5 A<br>12 V/24 V | 79.5 A 12 V/24 V | 1 | |
| 4 | Inverter | 2236 W | 2236 W | 1 | Pure sine wave |
| 5 | Surge protective device (SPD) | 2.2 kV | | | Protect the charge controller from surge voltage in case of a lightning storm |

Table 4: Comparison of an installed SPVS and a redesign system.

| Component of the SPVS | Installed capacity | Redesigned capacity | Remarks |
|---|---|---|---|
| PV array | 640 Wp | 980 Wp | Undersized |
| Battery bank | 450 Ah | 525 Ah | Undersized |
| Charge controller | 40 A, 12 V/24 V | 80 A, 12 V/24 V | Undersized |
| Inverter | 2000 W | 2236 W | Undersized |

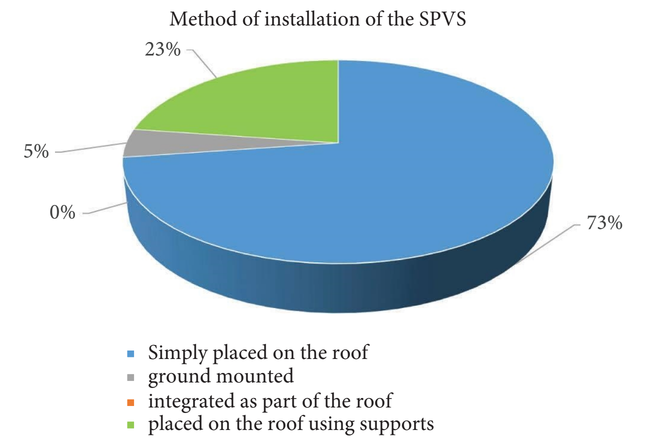


Figure 9: Methods of installation of the SPVS in the households.

Figure 10: PV array installed by simply placing on the roof with anchors.

Figure 11: PV array installed by simply placing on the roof without anchors.

calculated tilt range of 8° to 17°. More than 69 % of the installed SPVS had tilt angle between 21° and 50°. Such large angle of tilt affects the performance of the system [18]. Most of the installed SPVS in the Bamenda Municipality were oriented in the inappropriate directions. Such poor orientation could be attributed to the ignorance of the nonexperts

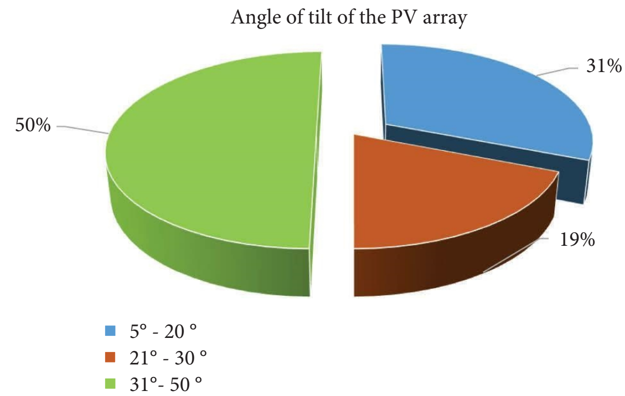


Figure 12: Angle of tilt of SPVS in the Bamenda Municipality.

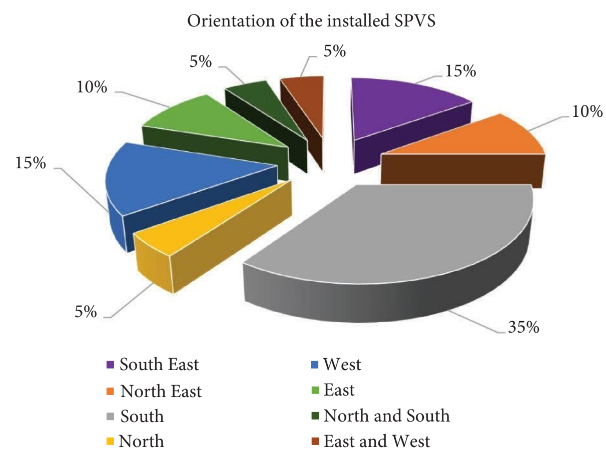


Figure 13: Orientation of the installed SPVS in the Bamenda Municipality.


Figure 14: SPVS with dust accumulation on the PV panels (a) and shading from nearby trees (b).

who installed the systems. Protective devices ensure safety, reliability, and prevent damage from overcurrent, overvoltage, lightning, and other hazards in SPVS installations [35]. Very few of the installed SPVS in the Bamenda Municipality had protective devices installed. The absence of these protective devices does not guarantee the reliability of the SPVS and safety of both the user and the system [36]. The absence of protective devices in the SPVS system, alongside


Figure 15: Some of the protective devices in installed in the SPVS.

inappropriate dimensioning of the SPVS indicates the need for capacity building and certification of technician involved in SPVS installation in the municipality [37].

## 5. Conclusions

The aim of this study was to carry out a technical evaluation of SPVS installed within the Bamenda Municipality. The study revealed that households in the Bamenda Municipality used a combination of different electrical power sources, such as PV only, PV and grid separated with segmented loads, hybrid systems, PV and Grid with the same loads, PV, and Diesel generator, PV, Grid, and Diesel Generator, to meet their electrical energy challenges.

Installed load capacities in the households were either DC or AC loads which ranged from 300 W to 10 kW, and very few households had installed loads less than 1 kW. The size of the solar PV array installed by the households varied from 200 W to 3210 W, no household has a PV array less than 100 Wp. Therefore, most of the household install SPVS were out of the range of the Classical Solar Home System of up to 250 Wp. The installed SPVS could power only part of installed load capacity of households.

A majority of the SPVS were installed by freelance technician who are not regulated, this place some uncertainties on the quality of installation of the SPVS.

Technical failures in the SPVS were mostly related to the inverter, battery, or simply disconnection of some connecting cables. The capacity of some of the SPVS installed in the households was undersized.

Most of the SPVS (73%) were simply placed on the rooftop with little or no anchoring support. Such method of installation put the system at risk of failure.

A majority of the SPVS was tilted at angle out of the range for the required angle of tilt for the municipality; also, a majority of the SPVS was installed in direction order than south, the required direction of orientation for SPVS in the municipality. Inappropriate angle of tilt and direction of orientation of the installed SPVS have consequences of the performance of the system.

This study reveals the need for capacity building and certification in the design and installation of SPVS in the municipality and the need for policy and regulation of the solar PV sector in order to ensure quality installation of SPVS for greater penetration of the technology in Cameroon and other countries of Africa.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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