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Electrical Power Demand Assessment of a Rural Community and the Forecast of Demand Growth for Rural Electrification in Ghana

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Abstract – *Electricity demand aggregation and demand forecast are prerequisites for establishing any electrical power project, especially for an off-grid power system. Some rural places in Ghana require the use of renewable resources for power generation, thus, must be carefully planned to avoid oversized or undersized systems. This research was carried out to aggregate the power demand of Buoya community in Ghana and a five-year forecast modeled in MATLAB using an inverse matrix method was made. Load aggregated through survey and appliance end-use method was used to calculate the demand for the community for a possible future bio-power electrical system. Different power supply scenarios were modeled for possible adoption to ensure a cost-effective supply of bio-power to the community. In the first year of implementation, a daily capacity of 45.37 kW was realised with an energy demand of 373.55 kWh. This is expected to grow to 72.1 kW with the energy demand of 718.6 kWh in five years. This growth is estimated at 70% over the period due to the lifestyle changes of the people. In the interim, as the community's productive use of power is low coupled with lower demand factor, this research proposes a plan of periodic daily power supply to cut down on fuel resources and cost of power. A scenario of 3-hour morning supply, a 2-hour mid-day supply, and a 4-hour evening supply plan is recommended for the first year of power system implementation before a full daily supply plan can be rolled out later. This finding is seen as applicable to most rural places that lack grid power supply and yet abound in renewable energy resources.*

Keywords – *Forecast, inverse matrix, load aggregation, power demand, rural electrification.*

1. INTRODUCTION

Ghana, as a developing country in Sub-Saharan Africa with an emerging economy is faced with several challenges hampering the rapid growth expected by this level of development. Among such is the lack of access to modern forms of energy, especially electrical power, which tends to renege on the efforts of policies and measures designed and implemented to lift citizens out of poverty. Notwithstanding the general low electricity access rate in Sub-Saharan Africa and other developing countries around the world, successive governments have made tremendous efforts in the increase of electricity accessibility rate in the country [1]. Currently, the country has an overall electricity access rate of over 80% with the urban areas boasting of more than 90% coverage. Rural communities, however, have lower electricity access rate of less than 65%. This unfortunate situation emanates from the fact that these communities which are mostly of lower population densities are quite far from major transmission lines that is the high and medium tension networks. Furthermore, these communities are difficult to access due to poor road infrastructure and difficult terrain such as islands [2], mountainous and forest nature. These hindrances make the extension of the national grid to such communities difficult and unprofitable [3] for the power producers since such efforts would result in financial loss in their operations.

Electrical energy use in Ghana just as in any part of the world provides domestic, social and industrial enhancements to life. Electrical energy is used to operate basic domestic electrical appliances such as television sets (TV), radio, fan, clothes iron and for heating and cooling applications. A myriad of industrial operations in production lines and services are adequately supported by electrical energy in Ghana, giving impetus to the growth of the economy and raising the standard of living thereby helping to reduce poverty.

Grid extension to supply electricity to consumers which has been the practice in Ghana is found to be difficult when it comes to rural and remote communities [4]. These places are characterized by low population densities coupled with high rate of poverty [5], [6]. This result in a low load factor and makes it difficult to utilize electricity effectively and productively. For such reasons, extending the grid is less feasible and unprofitable [1], resulting in the reluctance of both public and independent power producers (IPPs) undertaking rural electrification by grid extension. Distributed Renewable systems are found severally to minimize these effects [7]. Solar and wind systems which are the most developed RE systems have been employed in many other countries, achieving tremendous successes in rural and remote electrification to provide affordable, reliable and clean energy [5] to people in rural/remote places. These successes however are contestable when it comes to Ghana's rural communities. There has been little intervention and success in the use of these 'advanced' renewable energy resources for providing rural electrification. Reasons for

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this include the inherent challenges of inadequacy to meet demand and unavailability due to the nature of resource supply such as intermittency of wind and sunlight for PV and wind turbine systems respectively.

Most of these projects and interventions break down and are abandoned as the challenges of their maintenance and outputs show up [8]. These 'alien' interventions seem not to be giving the expected results in the communities and as such community spirit is lowered and interest waned, all as a result of the unreliability of the solar and wind resources [9] and the complexities of their maintenance.

Distributed power system has been identified by several researchers to be reliable and the resources available in such communities, [10] [11] to make the systems reliable. To supply adequate and reliable power for remote and rural communities such as Buoya; a typical rural community in Ghana, there is a need for assessment of the demand to improve rural electrification in the country. Most rural communities are never electrified and thus lack any time series data that can be used to model some of the known forecasting approaches. More specifically, it is necessary to establish the power demand of the community and forecast the demand growth to design a reliable system to satisfy the load using simple but dependable approaches. This will enable the deployment of renewable energy power projects to such areas to solve power deficit issues prevalent in the RE supply industry. Such will give impetus and confidence to project developers and financiers to execute projects without fear and much risk, ensuring sustainability and reliability of the projects [4]. Most renewable energy projects have a lifespan of 15 to 25 years. Inaccurate forecast of the demand and projected growth normally result in oversizing of systems and consequently in higher Cost of Energy (CoE) or under sizing creating nuisance demand deficits [12] making these projects unattractive.

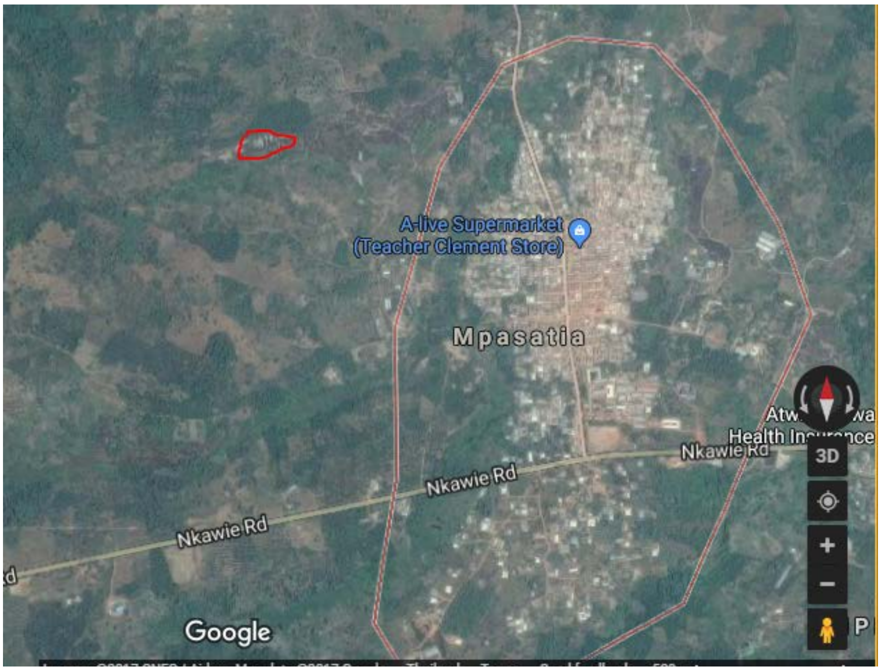

Fig. 1. Satellite map of the study area (marked in red).
Source: ***https://www.google.com/maps/place/Effiduase,+Ghana/ [20]***

2. METHODOLOGY

The community of Buoya was selected for this load assessment. Buoya is predominantly a farming community in the Sekyere East District of the Ashanti Region of Ghana. The total population is estimated at 729, and the age distribution is mostly concentrated in the third quartile because of the migration of the youth into larger communities and cities in search of greener pastures [6]. The coordinates are latitude 6.6631^0 N and longitude 1.8440^{0}W and rises 85m above sea level. The location map of Buoya is shown in Figure 1, and the study area is in the midst of thick forest with distances of more than 75 and 220 km from the district capital, Efiduase and Regional capital, Kumasi respectively. Access into the community is by a dirt road which once a while is graded to ease traveling.

A survey method was adopted to gather socio-economic data from the selected community. Buoya has never been electrified by grid or any distributed or stand-alone electrification system. Electric power consumption patterns from already electrified communities of Akrofrom and Katapei were used to support assumptions made in the aggregation of the load for Buoya. These other communities were chosen due to their demographic similarities, such as being in the same region, being at some distance away from the nearest larger city, and people of the same tribe and weather conditions. The survey method was chosen because of its simplicity, having a straight forward load aggregation approach and for its reliability in capturing satisfactorily the customer's demand behavior. This survey result information was used in imputing data for modeling community demand and growth of power using appliance end-use approach and the inverse matrix method of load forecasting. All households in Buoya were selected for the data collection, but fifteen (15) households each from the comparing communities were sampled at random for data collection. The items in the research questionnaire were thus designed to collect data on appliance possession and possible usage as well as the ratings to determine power consumption. The socio-economic indicators of power consumption considered included type of customer, monthly income, current electrical appliances owned, current electricity expenses, ability to pay for the electricity from the bio-power system in the future, and future electrical appliances acquisition projection. The results from these already electrified communities were used to identify the weighting factors that affect the load-dependent variables. An inverse matrix model [13] was used to forecast the growth of load in Buoya community for five years of the implementation of the bio-power electrical system.

Research field assistants who were Electrical/Electronic students of Kumasi Technical University, (KsTU) were employed to administer the questionnaire in the local language for better understanding. They were also mandated to inspect devices available to record the power requirement accurately in cases where respondents could not give the right response. An estimate measurement was carried out to ascertain the space area of the houses. This enabled estimates of the amount of illumination required for the provision of lighting needs of the dwelling units, which was compared to that in the already electrified communities.

2.1 Scenario Model and Assumptions for Load Aggregation

Three electricity supply option scenarios were created using information from data gathered from the survey as the basis. The first is a 24-hour electricity supply of community's load demand, named as s-1. In this scenario, the electrical appliances found in possession of residents and those willing to be acquired before or just after power is connected are aggregated to form the demand of electric energy for power use. These were found according to the categories of load points identified and how they are/will be used. The second scenario is three daily periodic use of power according to the supply power option considered. That is 2-hour morning utilization (05-07am), 2-hour mid-day use (12:30-14:30pm) and 4-hour evening use (18:30-22:30pm), named as s-2. These assumptions were based on popular load profiles from literature and experience which were found to be peak periods of daily power use as well as respondents desired time of use. The third is a 3-hour morning (05-08am) and 4-hour evening use (18:30-22: 30 pm), s-3. In each case, residents' behavior of appliance use was solicited using items structured in the questionnaire for the selected community and the comparing communities. Individual peculiar usage characteristics were not considered, but the total category of load point behavior was considered and generalized. Thus, all classes of consumers were deemed to have a common usage pattern and behavior pertaining to particular appliance usage. This is considered to offset the situation of both under and overestimation.

2.2 Load Aggregation Factors

The aggregation factors were solicited from survey and literature to assist in forecasting the demand growth of load for the community. Each dependent or independent factor having different weighting scale were modeled and used to predict the demand growth. Since Buoya has never been electrified and thus no power profile data exist, the other already connected communities (*i.e.* Akrofrom and Katapei) were used to calculate the power dependent variables and their weighting factors to be used in the inverse matrix model to forecast the future growth of power for the community. These communities have similar demographic characteristics and thus comparing and applying parameter variables can be reliable.

Several factors have been found to impact electricity usage including: population growth and density, adult literacy rate, average per capita income, nature of the community and development of modern infrastructure in and around the community [14], nature of dwelling, socio-demographic characteristics as well as climate and energy use charges which are external factors [15]. In many rural settings, especially developing ones, the obvious parameters may not include the intricate factors that may affect other developed and urban areas. Notwithstanding, the survey and literature confirm the impacts of population, adult literacy rate, communication and distance from large cities as obvious parameters that are considered for modeling in this research.

The population of the community determines the installed capacity as well as the energy demand of residential, social and commercial needs. The higher the population, the greater the demand and usage of power [14]. This reality is indicated in the high-power consumption of urban centers. This underpins the variations in per capita electricity consumption between developed and developing countries as well as urban and rural communities [16]. Customers acquire more electrical appliances as their income status increase and usually use more appliances for extended periods. A community that frequents nearby larger communities ends up acquiring the lifestyle of the urban community, which includes high electrical power usage. As the community is closer to the larger community, there is more interaction between them and causes lifestyle changes. Moreover, there is less rural-urban migration in such a situation. Residents of such rural communities are more comfortable staying in their communities, and only going to urban centers to conduct business and then return. Thus, these factors are considered and computed as a function of the load and future projection.

2.2.1 Categorization of load

For proper characterization of electric load of a community and balanced analysis and forecast, it is essential to segment the load into categories. Depending on the nature of the setting of the energy facility, research has found residential, commercial, social industrial and agricultural, as some of the areas of load categorization [15]. The study area has never been electrified by grid or any conventional means and thus, no official load data exist. Nonetheless, the demand is aggregated and calculated based on the comparison to the other two comparing communities to give a baseload upon which a projection and a forecast are modeled. To aid the expedient aggregation of the load and analysis for this research, the load was categorized into domestic, commercial and social demands.

2.2.2 Domestic/residential loads

The domestic category, which covers the power for operating domestic appliances is subdivided into three levels of usage- low, medium and high consumers. The questionnaire was structured to give empirical support for these classifications as respondents gave inputs. Four items sought to find the income level, ability to pay, space occupied, appliances owned, and amount spent on lighting (and other power demands) were averaged to give these classifications. This classification will help reduce the error in the estimation of load and the assumptions made. These classes of consumers are envisaged to factor in all consumption of both economic status and population. The number of appliances used is sectionalized according to the classification to make aggregation more accurate. These levels were expected to aid the forecast of growth that will be able to cater for broader scenarios.

2.2.3 Social loads

These loads served the entire community's needs. The units considered and prevalent in most rural communities in Ghana include street lighting, school and library, water pumping stations and durbar. grounds /social center. Except for the water pump, all appliances were similar to that of the residential category. Residential appliances included light bulbs, electric fans, and TV sets. Though water pumping was not available in Katapei, Akrofrom had pipe-born water; residents of Buoya expressed the desire to have it since the current source of drinking water is considered not potable enough. Most social events like durbar, funerals and birthday parties in all communities prepare for power with generator sets, yet members expressed a desire to have a common power source at the durbar grounds.

2.2.4 Commercial loads

These loads operated by individuals for businesses were found also to be similar to the others. The units in this category were found to include barber shops, ladies' beauty salons, grocery shops, grain mill shops, drinking pubs and dispensary shops. The demand spans 24 hours but is mainly concentrated in the morning and evening. Most of the residents of the rural communities spend less time at home in the morning and are mostly not available during the daytime. They leave home for work on the farm and other businesses that take almost the entire daylight hours.

2.3. Demand Aggregation

2.3.1 Characteristics of loads identified

Despite the unavailability of electrical power in the community, residents have some appliances that are either kept for future power needs or to use with other conventional means such as generator sets or battery power. The comparing communities are already connected, and thus residents are using appliances with the available power. Unlike the grid-connected Akrofrom, Katapei is solar powered and residents are advised not to use high powered appliances such as heating and heavy motorized ones. With the characteristics and behavior of the already connected communities, that have similar demographic characteristics as Buoya, a good estimate can be assertained at with the aggregation and forecast. A careful recording of all identified appliances' ratings is done for the aggregation and forecast. The power rating is recorded, or the voltage and current are used to compute the power of the appliance. The reported time and duration of use are also solicited from respondents in all sampled communities to estimate the pattern of use and energy consumption of a particular appliance.

2.4. Load Projection/Forecast

The survey revealed factors that determine the electrical energy requirement for residential, social and commercial applications of the community. The residential loads were found to be affected, though no equally weighted by household population (P_h) [17], educational attainment or adult literacy rate (E), and the income level of members of the household (I_{av}), all at a specified time *t*. All these directly affected the growth of demand. An inverse matrix function of the load demand (D_R) gives the relation;

$$D_R = f\left(P_{h(t)}, I_{av(t)}, E_{(t)}\right) \tag{1}$$

where, P_h is the household population, I_{av} is the average income of household heads, and E is educational attainment or the adult literacy rate all at a specified time (t).

Another variable that was found to impact the demand is the type of occupation [17] but could not be quantified and thus not included in the function. Social and commercial loads were found to be affected by the same time-dependent variables as in the D_R including another constant and time-independent variable, distance from the nearest town/city (D_{dc}) which in this case is taken as the district capital city for uniformity. The social and commercial demands are thus computed using Equations 2 and 3,

$$D_S = f\left(P_{C(t)}, I_{av(t)}, E_{(t)}, D_{dc}\right) \tag{2}$$

$$D_C = f\left(P_{C(t)}, I_{av(t)}, E_{(t)}, D_{dc}\right) \tag{3}$$

where P_C is the population of the community and D_{dc} is the distance of the community from the district capital.

The total demand of the community at a particular time, *t* ($D_{T(t)}$) is, therefore, be computed as a function of the sum of the individual load categories. That is:

$$D_{T(t)} = f\left(D_{R(t)} + D_{S(t)} + D_{C(t)}\right) \quad (4)$$

Thus,

$$D_{T(t)} = f\left(P_{h(t)}, E_{L(t)}, I_{av(t)}, D_{dc}\right) \quad (5)$$

Weighing determinants (h) are assigned to variables since they do not equally impact the demand [13]. Thus, D_R, D_S, D_C, and D_{dc} are assigned h_1, h_2, h_3, and h_4 respectively. Equation 6 is then used to evaluate the impacts of these parameters for determining the overall load demand.

$$h = D_{e(t)} \times P_{inv} \begin{bmatrix} P_{C(t)} \\ I_{av(t)} \\ E_{L(t)} \\ D_{dc} \end{bmatrix} \quad (6)$$

The total load is expressed regarding the variables and their weighing determinants in a matrix form and the determinants found in its inverse form which uses pseudo inverse matrix (P_{inv}). The estimated load of the Buoya community, using the results of the survey and the variable or parameters identified is modeled using the Equation 7.

$$D_{e(t)} = [h] \times \begin{bmatrix} P_{C(t)} \\ I_{av(t)} \\ E_{L(t)} \\ D_{dc} \end{bmatrix} \quad (7)$$

3. RESULTS AND ANALYSIS

3.1 Demography of the study areas

The demographic characteristics of the studied community of Buoya and the other two sampled communities whose electrification data were used to model are illustrated in Table 1.

3.2 Demand Aggregation

3.2.1 Characteristics of loads identified

The survey results showed residents of Buoya were in possession of electrical appliances even though most of them were not used at the time due to lack of power, but for the comparing communities, they were in use. Table 2 shows the appliances identified in Buoya, Akrofrom and Katapei communities. For Buoya, most of the appliances were previously used by same persons in other electrified communities before relocating to Buoya or were gifts received from friends and relatives except radio sets and or sound systems which were personally purchased and currently being used with battery power. Television sets were sometimes used with a car battery for watching football matches, entertainment shows and national events, but other appliances were largely unused. From observation, residents do not engage in much industrial/commercial activities that may be power demanding; causing a limited amount of end uses to be recorded. Like many small scales, artisanal works in Ghana, carpenters, masons and metal workers did not express the desire to use power tools that may require the use of electricity. The few businesses in Katapei were operating from the individual homes and hardly used much electric power except for operating radios and small appliances on the premises.

Table 1. Characteristics of the study area and the sample communities.

Characteristics	Community		
	Buoya	Akrofrom	Katapei
Population	729	850	880
Coordinates	Longitude-1.345 Latitude -6.790	Longitude -1.45 Latitude 6.8384	Longitude.-2.004 Latitude. 6.158
Nearest city	Efiduase	Kumasi	Tepa
District	Efiduase	Afigya Kwabre	Asutifi North
Electrification	None	Grid	Solar PV
Main Occupation (farming)	Cocoa, oil palm, citrus, staples	Cocoa, oil palm, citrus, staples	Cocoa, oil palm, mining, staples

Table 2. Electrical appliances identified in the study areas.

Appliance	Identified rating (Watt)	No. in Buoya per hh	Penetration (%)		Average daily usage duration-electrified
			Akrofrom (Grid-electrified)	Katapei	
Lighting bulb	40-60	7	100	100	12hrs
Sound system/radio	80	67	100	100	7*
Television	90-150	3	76	67	8
Electric Fan	50	6	91	82	6
Refrigerator	90-150	2	78	61	24
Water pump	800-1500	-	1	2	5**
***Electric iron	1000-1500	2	21	19	1

*duration of use varied widely and this figure may be an estimated average
**this was an automatic pump with an 'on' duration that could not be tracked.
***this appliance was mostly shared by most of the residents

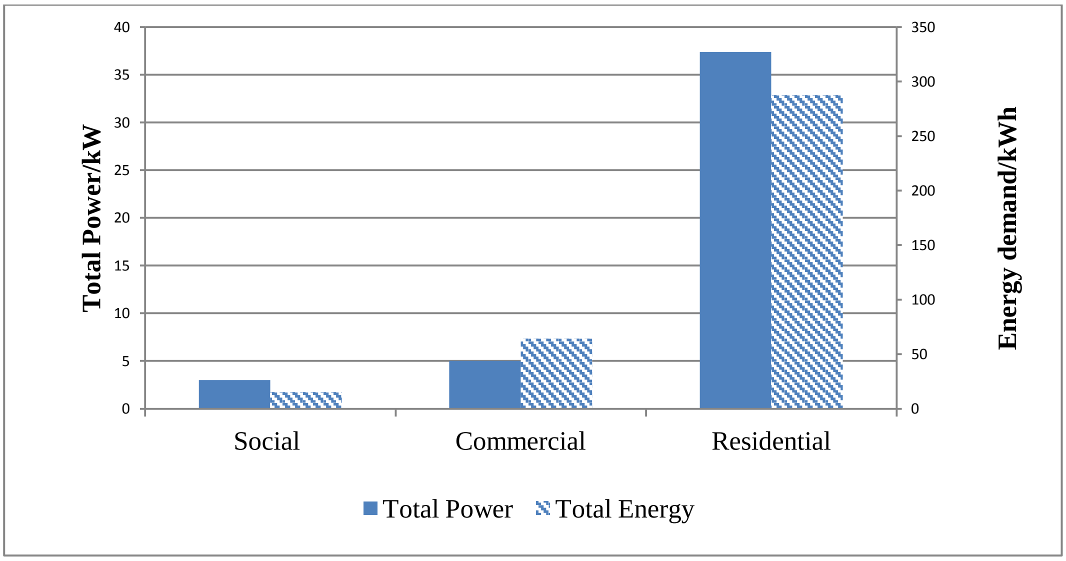

Fig. 2. Power installed and energy demand of study community by category.

3.3 Load Categorization

Based on the appliances identified in Akrofrom and Katapei, as well as the few identified in Buoya, a general aggregate was made as a likely load for the community of Buoya using the appliance end use method. Table 3 shows the installed load of the various appliances based on the individual load point's consideration. Since this is considered to be the beginning of supply of power to the community and to ensure minimal initial capital cost, not all appliances found and/or likely to be used were included in the estimation. For example, except for ladies hair dryers, no heating appliances were considered even though electric iron and immersion heaters were identified in Akrofrom and Katapei. Figure 2 shows the category of load demand expected at the study area of Buoya.

Despite appliances having different power ratings, the average of a particular appliance was used to aggregate the load and the power demand. Furthermore, the variation in time and period of use was considered using the already electrified communities' pattern which was found to be similar to respondents expressed interest in time of use. Thus, the general assumption that a particular appliance had the 'same' pattern of use is considered for uniformity in aggregation. Except compact fluorescent bulbs identified, no power efficient appliances were seen to be adopted in the electrified communities. Customers were not aware of such devices as a means of cutting down on energy consumption though residents of Katapei were told not to use heating appliances to minimize consumption. There were no educational measures on the use of energy efficient appliances in the electrified communities.

Table 3. Identified loads and categories of load points in Buoya.

Category	Appliance	kWh	kW	%kWh	% kW
SOCIAL LOADS	Fan	3.25	0.65		
	Light Bulbs	5.384	0.72		
	Other (Exp. Modules)	0.4	0.2		
	Sound System	5.8	1.12		
Total Social Loads		15.43	2.99	4.2	6.6
COMMERCIAL LOADS	Fan	2.475	0.33		
	hair dryers	38.4	2.4		
	Light Bulbs	1.068	0.276		
	Other	9.075	1.225		
	Refrigerator	10.8	0.45		
	Sound system/ Radio set	2.095	0.26		
	TV/computer	0.6	0.08		
Total Commercial Loads		64.513	5.021	17.6	11.1
RESIDENTIAL LOADS	Fan	53.13	9.66		
	Light bulbs	47.16	9.43		
	M phone charger	7.31	1.13		
	Sound system	109.8	7.79		
	TV (CRT)	70.2	9.36		
Total Residential loads		287.6	37.36	78.3	82.3
TOTAL COMMUNITY LOADS		367.5	45.37		

Table 4. Total installed capacities and load demand of appliances for Buoya community for scenarios.

Appliance	Total hourly installed capacity and daily demand					
	s-1		s-2		s-3	
	kW	kWh	kW	kWh	kW	kWh
Fan	10.64	58.86	10.64	42.16	10.71	42.16
Dryer	2.40	38.40	2.40	14.4	2.4	9.6
Lighting bulb	10.43	53.61	10.43	50.01	10.43	49.62
M. phones charger	1.13	7.31	1.13	6.75	1.13	5.81
*other	1.43	9.48	1.43	6.95	1.22	4.09
Refrigerator	3.42	82.08	3.42	27.0	3.42	20.42
Sound system/radio	6.20	46.42	5.40	28.70	5.40	28.15
Television	9.74	71.40	9.74	42.72	9.44	47.12
Total	45.37	367.56	44.59	218.69	44.15	206.97

*comprised isolated items used such as water pump, lab experimental modules and barbers clippers.

Based on the successful categorization of the community's load, a total aggregate was made and two other scenarios created based on the most popular pattern of use of appliances gathered from the already electrified communities as well as the preferred periods of use from Buoya. Table 3 summarizes the profile of appliances load for the three scenarios

The table suggests that television and refrigerators account for more than 40% of daily consumption of energy (*i.e.* 153.42 kWh) due to their extended period of daily usage. Lighting and fans together account for more than 45% of installed capacity (*i.e.* 27.07 of 45.37 kW) in all scenarios considered due to the number installed. Two ladies hair dryers considered in the profile accounted for approximately 5% of total installed capacity, demanding energy of 10.4, 6.6 and 4.6 kWh in s-1, s-2, and s-3 respectively daily. This suggests that the inclusion of more heating appliances in the aggregation will result in a large installed capacity that will make a modest rural electrification project unattractive for financing and installation. Notwithstanding, some of these loads are considered in the commercial category which will improve the ability to pay for revenue mobilization for the system.

The hourly appliance penetration and the total load profiles are shown in Figures 3 and 4 for a full day supply of power scenario, s-1. Peak demand is seen to occur between 20 and 21 hours of more than 350 kWh. A morning peak demand reaching almost 300 kWh is observed between 06-07 hours in the day.

From the load profiles in Figures 3 and 4, it can be seen that the demand is skewed towards the residential categories, taking more than 80% of the energy. This is largely due to the kind of occupation that the inhabitants engage in; that is farming. This may seem not to favor the productive use of electricity (PUE), but benefits of this initial utilization will result in significant development of the community which will eventually open up more industrial and commercial application for economic growth.

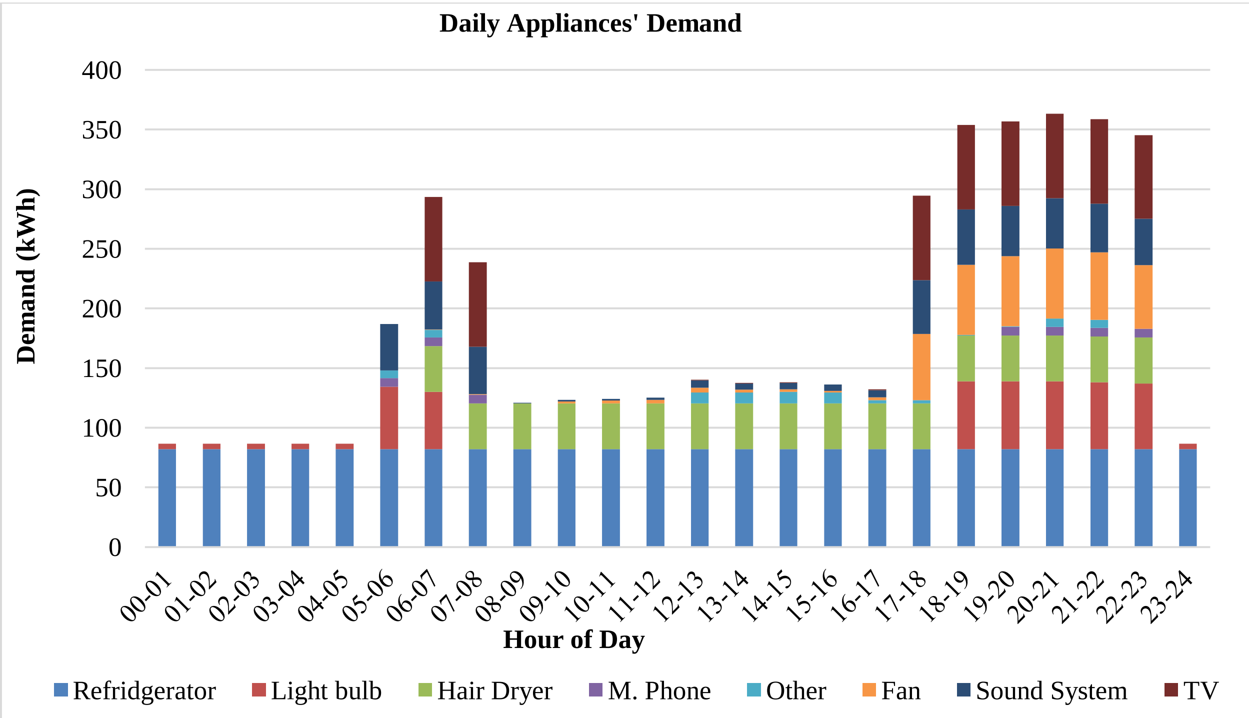

Fig. 3. Daily hourly appliance penetration load profile, s-1.

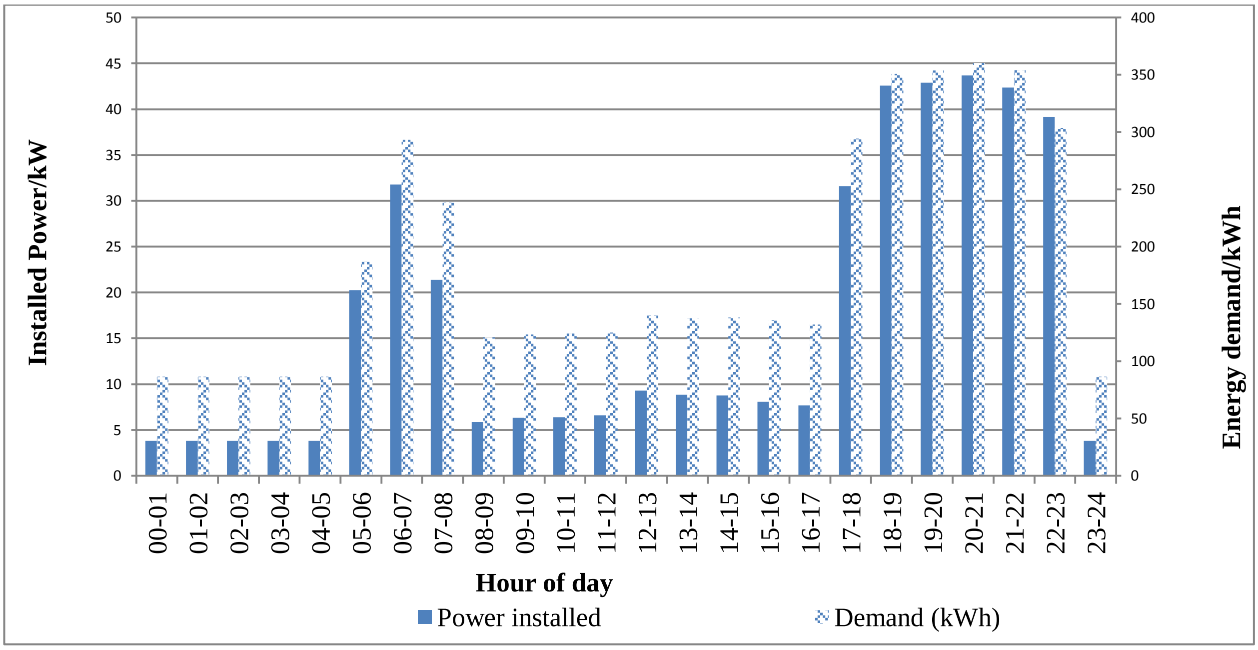

Fig. 4. Estimated daily load profile for 24-hours for Buoya community (s-1).

Load profiles of s-2 and s-3 are shown in Figures 5 and 6. The difference in installed capacity among the scenarios is insignificant, but the energy demand varies largely due to the difference in time of use. This will enable a decision to be made on how to optimize the cost of electricity (CoE) in tradeoffs scenarios. In times of a limited supply of fuel to run the bio-power system, the adoption of the scenarios can come in handy. For instance, in situations of short supply of fuel, s-3 can be adopted in the system will be expected to satisfy a daily demand of 206 kWh instead of more than 350 kWh for a 24-hour supply plan. Likewise, in a medium supply of fuel, s-2 can be adopted..

3.4. Load Aggregation Factors

The survey revealed factors that determine the electrical energy requirement for residential, social and commercial applications of the community. Due to the less intricate nature of rural power demand, several factors that have been suggested by research such as weather [18]; and occupation type [15] of customers could not be included. Only factors revealed by the survey of the studied communities.

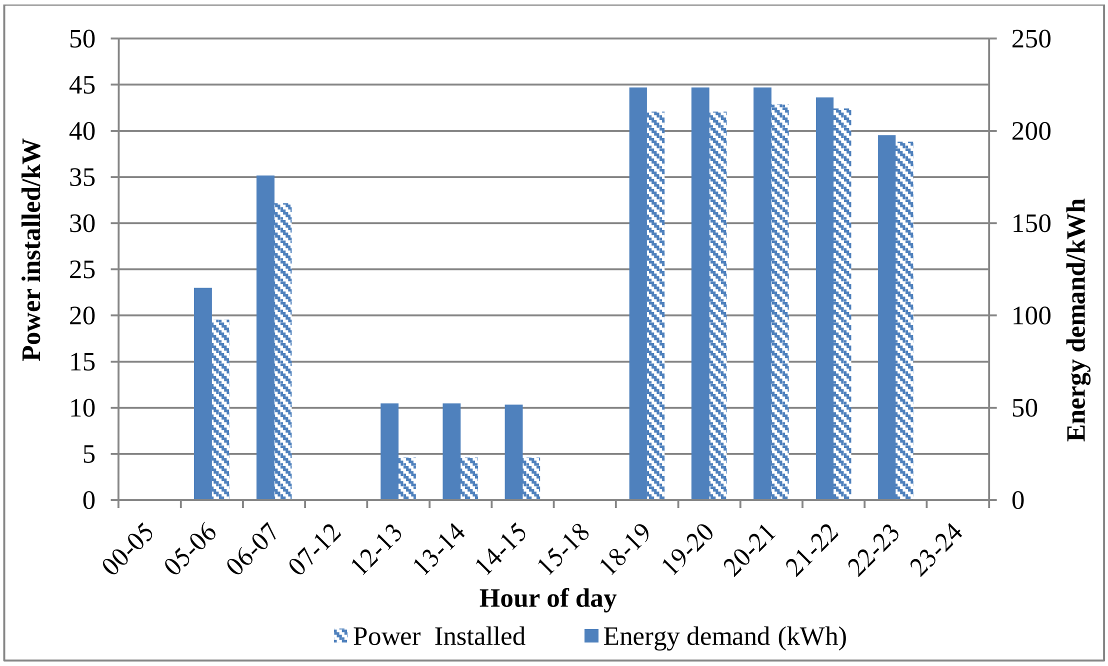

Fig. 5. Estimated daily load profile for '3-period' for Buoya community (s-2).

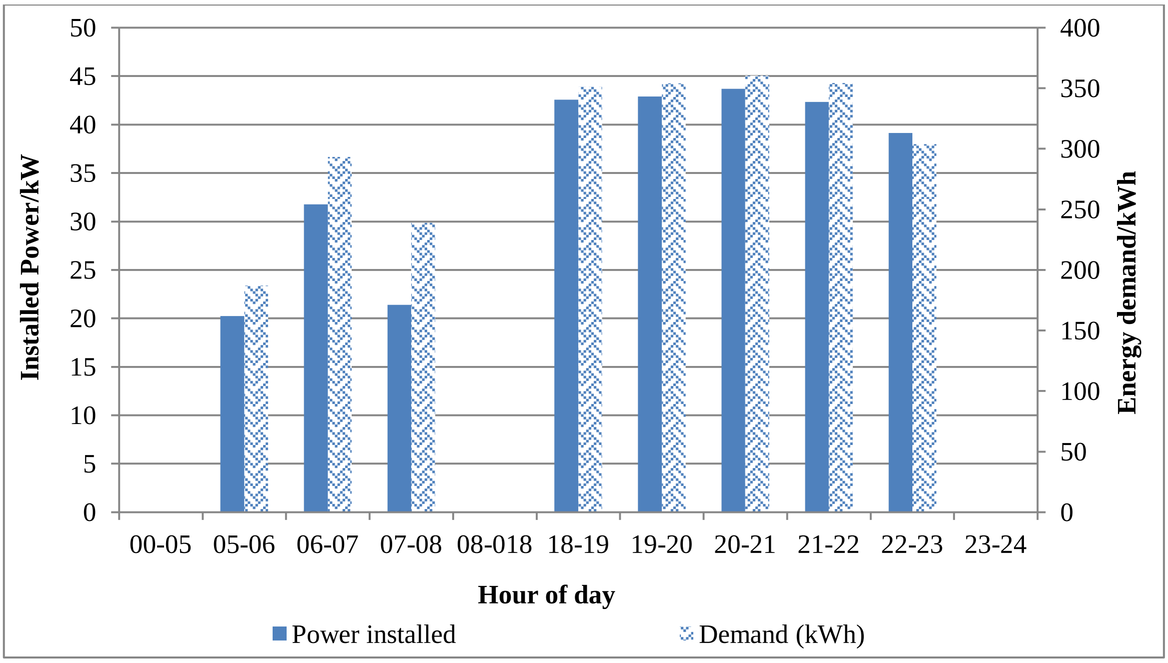

Fig. 6. Estimated load profile for s-3 (AM and PM loads).

As such, the residential loads were found to be affected, though no equally weighted by household population (P_h) or community population (P_C), educational attainment/adult literacy (E_L), and the income level of members of the household (I_{av}), all at a specified time *t*.

The population of the community (P_C) was determined from the survey and found to be 729 and using the average projected yearly population growth rate of 2.65, 2.57, 2.53 and 2.49% [19] over the projected years as indicated in Table 6, the estimated increase in population was calculated. The average income was based on the respondents' response on monthly income as stated. Income was for only the head of household even though other members' income will significantly affect energy demand. Low-income earners had an average of USD 28.55, average income earners of (USD 67.34), and high earners had USD 126.63 of monthly income. The total average thus was USD 74.17. This was projected over the years where at the end, it comes to USD 79.66 per month. Literacy rate as indicated by the Ghana Statistical Service is 15.3% yearly, and the survey recorded 406 adult literates. This number is thus projected over the years resulting in 573. The distance of 75 km from the district capital which is time independent is used in the model.

The impact of the parameters determining the load, *i.e.* P_C, I_{av}, E_L, and D_{dc} had their weighting factors calculated using the inverse matrix model in equation (3) in MATLAB. The codes were written taking the base aggregated load of 45.37 kW and the demand of 373.55 kWh. The P_C based on the national growth rate as indicated on Table 5 and E were calculated from the Ghana Statistical Service; I_{av} was calculated based on the results of the survey and D_{dc} was taken from the district geographical map. Tables 4 and 5 show the calculated output values of the weighting factors, *h*, and the forecast parameters.

Table 5. Power demand parameters for forecast modeling.

Parameter	2019	2020	2021	2022	2023
$P_{C(t)}$	729	2.65% (748)	2.57% (768)	2.53% (787)	2.49% (807)
$I_{av(t)}$(USD)[1]/month	73.40	74.72	76.07	77.44	78.83
$E_{L(t)}$(%) 15.3	406	531	545	559	573
D_{dc}(km)	75	75	75	75	75

[1]Currency converting rate: USD 1 = GhȻ 5.27

Table 6. Determining/weighting factors for power forecast parameters.

Years	h_1(Pc)	h_2(I_{av})	h_3(E_L)	h_4(D_{dc})
2019	0.0388	0.0206	0.0216	0.0400
2020	0.0381	0.0201	0.0270	0.0038
2021	0.0452	0.0236	0.0321	0.0044
2012	0.0486	0.0252	0.0345	0.0046
2013	0.0502	0.0259	0.0357	0.0046

3.5 Load Projection/Forecast using End-use and Inverse Matrix

All parameters considered directly affected the growth of demand. Social and Commercial loads were found to be affected by all residential load factors as well as distance from the district capital of the various communities. Equations 1, 2 and 3 were used to model the forecast of demand growth of the categories of the load; *i.e.* residential, social and commercial respectively. These were then used to model the forecast of the load for the next five years which results in a maximum installed capacity of 72.1 kW and power demand of 718.6 kWh as shown in Table 7.

From Table 7 and Figure 7, the demand increases rapidly up to the second year, and the rate of increase slowed up to 2023. In this case, customers are expected to acquire more appliances and use them longer to satisfy their needs. The parameters are expected to have a positive impact on the quantum of load where the power installed will increase by almost 50% and the energy demand by more than 70%.

This increase is expected to be due to lifestyle changes and improvement of social and commercial activities that would demand more use of power. The quantum of increase and the percentage increase in power and energy demand are shown in Figures 8 and 9.

Table 7. Forecast of daily power demand of Buoya for five years.

Project years	Installed Power	kW increase	%kW increase	Energy Demand(kWh)	kWh increase	%kWh increase (kW)
2019	45.373	0	0	373.55	0	0
2020	51.024	5.651	12.45	482.89	109.35	29.27
2021	62.022	10.99	21.55	610.10	127.20	26.34
2022	68.155	6.133	9.89	682.07	71.97	11.80
2023	72.088	3.933	5.77	718.64	36.56	05.36

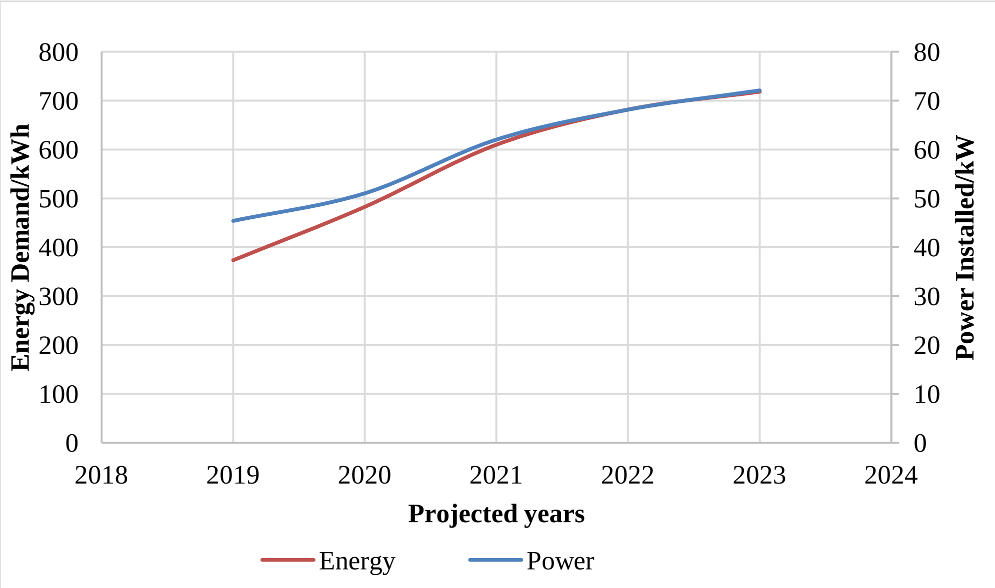

Fig. 7. Forecast of daily power and energy demand growth at Buoya

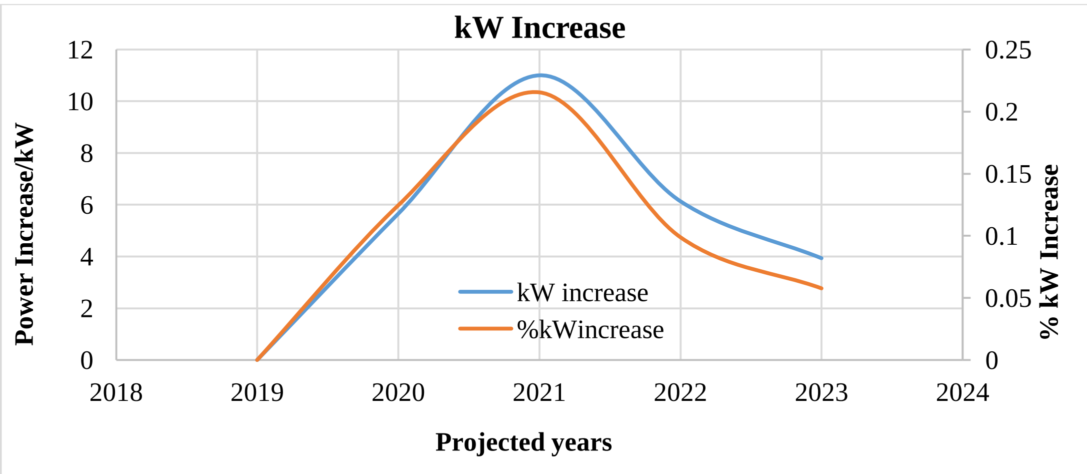

Fig 8. Amount and percentage increase in power for the forecast.

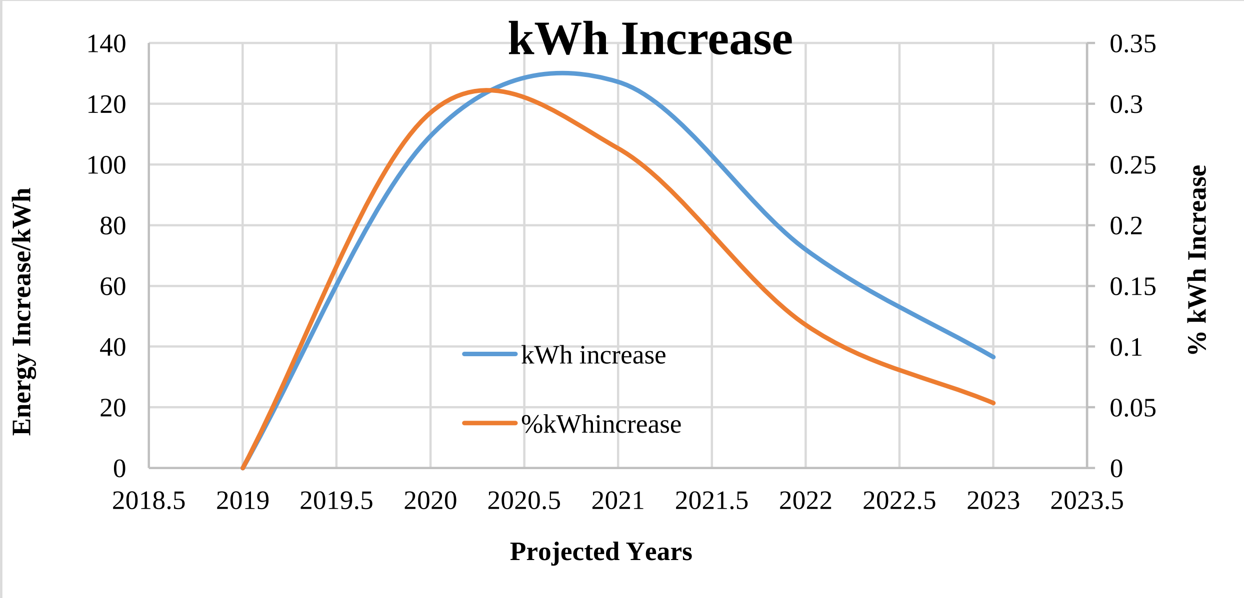

Fig. 9. Amount and percentage increase in Energy demand for the forecast.

4. CONCLUSION

For the implementation of any power system, careful load aggregation and forecast can prevent under and oversizing which may result in power deficits and high energy and system cost. To supply electrical power for Buoya community in Ghana with biomass option of renewable energy, a comprehensive aggregation has been done through the end-use method, and a five-year forecast of load and demand modeled using an inverse matrix method. The data was gathered through a survey in the communities and compared and substantiated to be by credible literature. A total installed capacity of 45.37 kW is expected to be installed once power is supplied and will grow to 72.1 kW in five years. Maximum daily energy demand of 373.6 kWh which is projected to grow to 718.6 kWh over the five years is expected. The inverse matrix method used for the modeling factored into the calculation of important parameters such as population, adult literacy rate, average income and distance from the district capital. The comparing communities were used to ensure assumptions were in line with practice and that the aggregation and forecast would be reliable for the implementation of the bio-power system. For the beginning of the implementation, a scenario where daily periodic power supply (s-2) is recommended for the full grounding of the system after which the 24-hour supply option (s-1) can be fully rolled out.

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