Load Profile Validation for Design of Sustainable Optimal Hybrid Renewable Energy Systems

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***Abstract*: This study focuses on the validation of load profile and energy usage of Itie-Ikpe, a rural community located in the southern part of Nigeria, for the purpose of designing sustainable optimal hybrid renewable energy systems. A two-year monthly estimated load profile data was obtained from an energy distribution company, monthly averages and overall annual daily load demand of 557.59 kWh/d were determined using mathematical method while a field survey was conducted to obtain the actual load demand figure 562.25 kWh/d for the study community with a difference of 4.66 kWh/d. The two independent results were comparatively analyzed with the field survey result higher than the estimated value obtained from the energy distribution company by 0.84%. Findings also showed that the error margin or difference was relatively negligible with little or no significant effect on the design of the optimal hybrid renewable energy system. Therefore, the daily load demand figure from the field survey result validated the average daily load demand value determined from the obtained estimates. This validation is a crucial step in designing an optimal hybrid renewable energy system for energy sustainability of the study community, as the modeling and selection of systems components of the hybrid renewable energy system depends on the knowledge of accurate average daily load demand in order to avoid design of ineffective energy systems whose performances might not be optimal.**

***Keywords*: Load Profile Validation, Hybrid Renewable Energy Systems, Energy Sustainability.**

I. INTRODUCTION

A. *Background of Study*

Load demand is very central and vital to the design of an optimal hybrid renewable energy system (HRES). Optimal sizing and selection of system components revolves around daily load demand. Inaccuracy in the determination of this vital system input parameter will surely lead to under-design or over-design of energy system with either inadequate capacity resulting into a scenario of capacity shortage and unmet load or higher cost of implementation of the energy system due to over-design, either way is not sustainable. Designing of energy systems with accurate load demand is very crucial and of great significance. Hence, the importance of validation of this important system input parameter cannot be over-emphasized. Load profile validation can be carried out in many ways according to literatures. In this research, two methods were mentioned while one of the two methods was applied and used. The first method is by conducting a field survey and validating the results by comparing it with an existing record of the load demand figures obtained from a regulatory agency or an energy distribution company while the second method is the other way round, by obtaining the load estimates from a government agency or electricity distribution company and validating the results from the estimates obtained by comparing it with the field survey results.

To design an effective optimal HRES for energy sustainability, usage of an accurate and validated load demand data is imperative in order to eliminate the design of ineffective HRES, poor system performance and avoidable higher cost of systems. Therefore, validation of the load demand figure of a study community of Itie-Ikpe for design of sustainable optimal HRES is what this research was set out to achieve.

B. *Study Community*

The study community is Itie-Ikpe, a community located in Ikpe Clan, Ini Local Government Area (LGA) of Akwa Ibom State, southern part of Nigeria with a population of about 860 people. It is surrounded by other communities of Ibiono Ewura, Nkana, Ikpe-Ikot Nkon, Obotme, Odoro Ikpe,Amuvi, Akani obio, Akpunabo, Atani, Ebem Obom, Ebam Ukot, Ekoi Ikot Udofe and Ibakesi. Ini LGA is bounded by Abia State to the north and to the south, by Obot Akara, Ikono and Ibiono Ibom Local Government Areas of Akwa Ibom State. Figures 1 and 2 show the geographical location while Table I displays the background information of the study community. The major occupations of residents of Itie-Ikpe community are trading, crafts making, farming, small and medium-scale enterprises like furniture and upholstery, auto-mechanics, barbing, tailoring, welding and milling. The estimated peak load demand of this community is expected to be about 44kW. Residents of this study community are presently connected to the national grid while making use of petrol and diesel fuel generators whenever there is no supply from the national grid which has its own attendant cost of acquisition, high prices of petrol and diesel fuel, high cost of operation and maintenance and emission of CO_2.

Table I: Background Information Of Itie-Ikpe Community

Particulars	Details
Country	Nigeria
State	Akwa Ibom
Local Government Area	Ini
Clan	Ikpe
Community	Itie-Ikpe
Latitude	5 22 41.8 N (5.37829)
Longitude	7 47 56.7 E (7.79909)
Elevation above sea level	21 m
Number of Households	102
Estimated Population	860
Main Socio-Economic activities	Farming, Small-scale Businesses and Crafts

Fig. 1: Itie-Ikpe geographical location 1

(Source: www.google.com/maps)

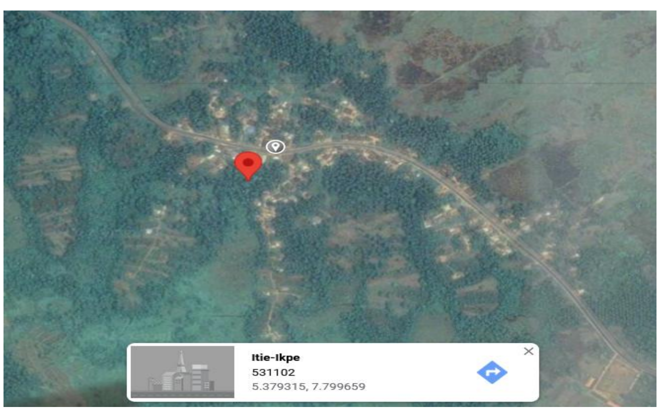

Fig. 2: Itie-Ikpe geographical location 2

(Source: www.google.com/maps)

II. LITERATURE REVIEW

A lot of research works has been done in the area of design of optimal hybrid renewable energy systems, with attention paid mostly on the techno-economic analysis rather than the validation of the daily load demand. Most of these works which include Kiros, *et al.* (2020), Kyaing, *et al.* (2019), Oladigbolu, *et al.* (2020), (Samir, 2021) and Vendoti, *et al.* (2020) were consulted in the course of this study, in order to gather reasonable information about load profile validation. (Samir, 2021) considered only residential loads in his techno-economic analysis of four different configurations of HRES for energy sustainability of Hurghada City in Egypt with a daily peak load of 218kW. The effects of community, agricultural and commercial loads on the design of the HRES were not put into consideration. Also confirmation of the validity of the residential load was not carried out. In the work of Oladigbolu, *et al.* (2020), an optimal hybrid renewable power system was designed for the deployment of electrical power to a typical remote community in the southern part of Nigeria. The work only focused on the estimated households and healthcare facility loads of the study community without considering the effects of both commercial and other community loads such as school, worship centers, hall and street lights on the power system. Also validation of the estimated households and healthcare facility loads was not done. Vendoti, *et al.* (2020) collected the average daily load data used in his work titled “Modeling and optimization of an off-grid hybrid renewable energy system for electrification in rural areas” from the locals through survey. However, no validation was done by comparing the survey results with any records from a government regulatory agency or electricity distribution body. In their attempt to find out the optimal design of mini-grid for rural electrification of a proposed village, Kyaing, *et al.* (2019) presented a load profile of a village to represent the estimated annual short-term load. However, load profile validation was not done.

Some of the research gaps identified in these works are non-validation of load demand figures, non-inclusion of both commercial and community loads in load profiling and usage of load demand value not related to study site. Designs of HRES that did not meet the non-validated daily load demand were also carried out by few authors. This paper attempted to fill most of these research gaps by validating the estimated daily load demand figures, inclusion of both commercial and community loads in load profiling and usage of load profile that is related to the study location.

III. METHODOLOGY

This research work involved the validation of the load profile and energy usage of Itie-Ikpe community for energy sustainability. An estimated two-year monthly load profile of the study community was obtained from an energy distributor – Port Harcourt Electricity Distribution (PHED) Company, Port Harcourt, Nigeria. The monthly averages were calculated together with the overall annual average, this gave us the estimated average daily load demand of the community. To validate the obtained estimated load demand value and obtain a realistic figure, a field survey was carried out. Ten samples were considered out of the 102 households. Both commercial and community loads were also considered for accuracy. The research methodology steps adopted and used are summarized in Figure 3. The details of the result of a field survey carried out are presented in the following section; this was used to validate the estimated data obtained from the energy distribution company. This validation is a crucial step in designing an optimal hybrid renewable energy system for energy sustainability of the study community, as the modeling and selection of systems components of the hybrid renewable energy system depends on the knowledge of accurate average daily load demand, serious attention ought to be paid to this. A deviation from this validation exercise may lead to the design of an ineffective energy system whose performance might not be optimal.

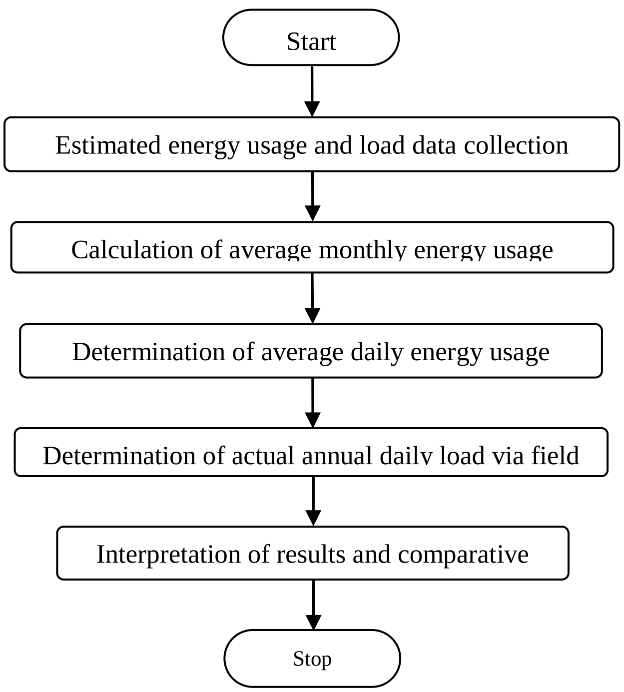

Fig. 3: Flow diagram of the research process

IV. RESULTS

The results of the field survey conducted are presented in the following subsections. These results are for the household, commercial and community loads.

A. Energy Usage and Load Profile of the Study Community

The load profile was obtained through a field survey conducted in the study community and the result was compared with the value determined from the estimates obtained from Port Harcourt Electricity Distribution (PHED) Company for validity confirmation. The name of the study community is Itie-Ikpe, Ikpe Clan, Ini Local Government Area of Akwa-Ibom State, southern part of Nigeria. The community does not experience summer and winter seasons under extreme situations and the electricity consumption does not vary almost the whole year except for July, August and September. In this study, the electric load demand of the study community is divided in to the following three major categories:

1) Households Load: This includes fan, lighting, mobile phone, television, radio, fridge, digital video player and baking appliances.

2) Commercial load: This consists of small business centers, stores, chemist shops, barbing salons, small shop, flour mill and welding shop.

3) Community load: This includes primary school, street lighting, health centre, worship centre and deferrable load (water supply and irrigation systems).

The total electric load obtained for the listed appliances were summed up to get the total daily load demand. Despite the present situation of people living below the poverty line, peak operation hours of the appliances have been proposed based on the current living condition of the study community and the current growth trend of the region. Oladigbolu, 2019) asserts that, to design an HRES for the electrification of a community, the establishment of information like the load profile of the community is an important parameter to be put into account. However, this research is saying a step should be moved further to validate the information. The initial point to put into consideration in calculating the load demand is to decide which appliance has to be used by the rural family households, accounting for the current and future situation of the study community as well as the country's power system framework.

B. Calculation of Primary Load

Primary load is the load that should be met by the energy system immediately. This includes lighting, radio, television, vaccine refrigeration, printer, computer, simple laboratory equipment etc. Here, the energy consumed in each household is considered to be the same and constant throughout the year. The load estimation for the study community was performed for 102 households with an average of eight family members per household. This shows a population number of 860. The rural economic situation of the country is below the poverty line, therefore, selection of low wattage appliances was assumed in this research for the affordability of the provided electric energy. The electricity load calculation was made according to the following approach. The daily energy consumption in kWh is the ratio of the product of three parameters (the power rating of appliance, the number of appliances and the hours of operation of appliance) and 1000.

1) Households Load: The electricity load demand in an individual household included a radio, fridge, four low energy bulbs, digital video recorder, fan, mobile phone, television and possibly air conditioner. Each household uses 1 unit of 70 W fan, 8 units of 12 W lighting bulb, 1 unit of 6 W mobile phone, 1 unit of 80 W television, 1 unit of 30 W radio, 1 unit of 150W fridge, 1 unit of digital video recorder and 0.5 unit of air conditioner, meaning that half the number of households use an A/C. The low energy bulbs are operational for 8 hours while the fan, lighting bulbs, mobile phone, television, radio, fridge, A/C, digital video recorder are operated for some hours as seen in Table II. The percentage load of each household appliance is also displayed, while Figure 4 shows the hourly load profile of each household. A radio of 15W which operates for 4 hours from 07:00 hours to 15:00 hours while a 14-inch television of 80W functions in each household on average basis, starting from 17:00 hours to 23:00 hours. The main target for the selection of the appliances in Table II is taking into consideration the low energy saving ideologies and these are the minimum facilities that could be owned by the study community. Therefore peak load demand of each household is around 0.8055 kW and the energy usage per household is around 3.5629kWh/d.

Average Daily Load Demand (kWh) for 1 household = {(70x6) + (96x12) + (6x6) + (80x7) + (30x4) + (150x8) + (373x0.2) + (0.5x0.6)}/1000 = 3.5629 kWh

Total Average Daily Load Demand (kWh) for 102 households = 3.5629 X 102 = 363.4158 kWh.

Table II: Household Daily Load Demand (102)

Appliance	Wattage	Quantity	Peak Load (Watts)	Estimated Daily Hours of Usage	Total Load (Wh/d)	Total Load (Wh/d)	Percentage (%)
Fan	70	1	70	6	420	42840	11.8
Light	12	8	96	12	1152	117504	32.3
Mobile Phone	6	1	6	6	36	3672	1.0
TV	80	1	80	7	560	57120	15.7
Radio	15	1	15	8	120	12240	3.4
Fridge	75	1	75	16	1200	122400	33.7
A/C	746	0.5	373	0.2	74.6	7609.2	2.1
Digital Video Player	0.5	1	0.5	0.6	0.3	30.6	0.0
Total Energy (KWh/d)	1004.5	14.5	715.5	55.8	3562.9	363415.8	100
Total Average Daily Load Demand (kWh/d) for 102 households					363415.8		

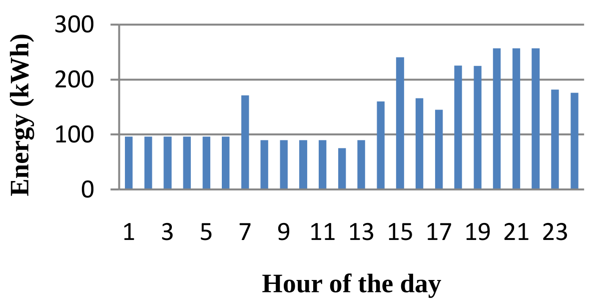

Fig. 4: Hourly households load profile

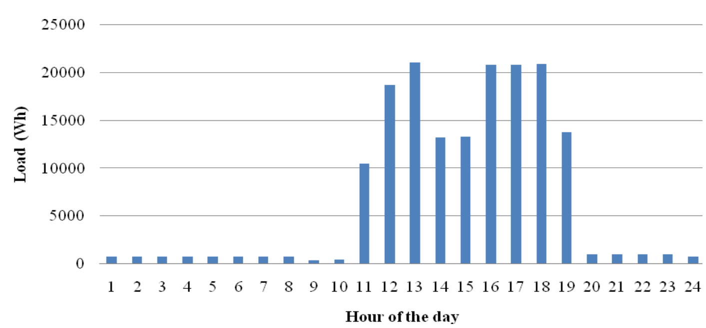

Fig. 5: Hourly commercial load profile

TABLE III: COMMERCIAL LOAD DEMAND

Customer	Load (Wh/d)	Quantity	Total Load (Wh/d)	Percentage (%)
Small Business Centre	3262	2	6524	3.94
Store	528	3	1584	0.96
Chemist Shop	1148	3	3444	2.08
Barbing Salon	2156	2	4312	2.6
Fashion Designer	1665	2	3330	2.01
Small Shop	320	12	3840	2.32
Flour Mill	53016	2	106032	64.04
Welding Shop	36516	1	36516	22.05
Total Load (Wh/day)			165582	100

TABLE IV: COMMUNITY LOAD DEMAND

Customer	Watt-hours /d	Quantity	Total Load (Wh/d) summer Nov-May	Total Load (Wh/d) winter high Jun-July	Total Load (Wh/y) winter low Aug-Oct	Percentage (%)
Hall	2360	1	2360	2360	2360	7.10
Street Light	1050	12	12600	12600	12600	37.90
Health Centre	6825	1	6825	6825	6825	20.53
Worship Centre	3370	2	6740	6740	6740	20.27
School	4726	1	4726	3150	3150	14.21
Total Energy (kWh/d)			33251	31675	31675	100

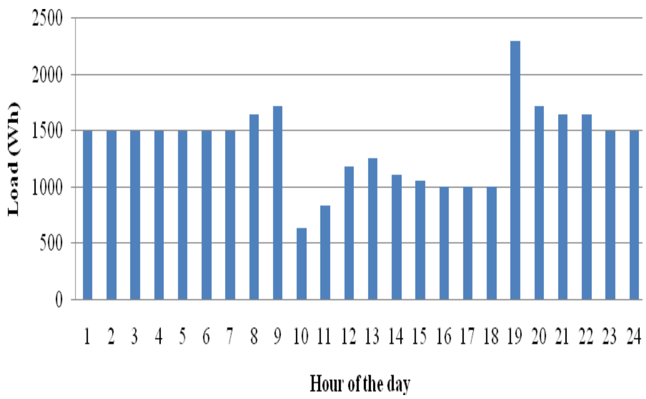

Fig. 6:Hourly community load profile

2) *Commercial load:* The commercial load demand of the study community included two small business centres with average daily energy consumption of 3.262 kWh/d each, three stores of 0.528 kWh daily energy usage each, three small chemist shops of 1.148 kWh/d each, two barbing salons of 2.156 kWh/d each, two fashion designer shops of 1.665 kWh/d energy usage each, twelve small shops with average daily energy usage of 0.320 kWh/d each, two flour mills of 53 kWh/d each and a welding workshop with average 36.5 kWh/d. The total loads of each commercial load component are shown in Table III alongside their percentages resulting in grand total of 165.582 kWh/d daily load demand. In Nigeria, in-house activities like preparing family food, cereal grinding, fetching of water and firewood are dominated by mothers and children. Diesel fuel-driven flour mills are currently popular, but the running cost is on the high side. Two flour mills were found in the study community of Itie Ikpe. These flour mills do not serve only Itie-Ikpe community but also the nearby villages that do not have electricity access. Each of the flour mill machines has power rating of 7.6 kW that operates for total 7 hours a day within 9:00 hours and 18:00 hours. Details of the community commercial load are shown in Table III and Figure 5 with the flour mill responsible for 64.04% of the total commercial load of the study community followed by the welding shop.

3) *Community load:* Table IV shows how the total community load of 31.675 kWh/d was arrived at. It is made up of a hall with 2.36 kWh/d average energy consumption, twelve units of street lights with total 12.6 kWh/d energy consumption, one health centre with 6.825 kWh/d, one worship centre with total 6.74 kWh/d energy usage and a primary school with 4.726 kWh/d energy consumption. Quality education for any community is essential for socio-economic development. At least, two family members are considered to be within school-going age bracket in each household of the families under this research. In the community primary school, there is no need for electricity for the class rooms since the sunlight can brighten the classes through the glass windows. Also, most of the energy consumption will be by the computers and printer at day times which is very small. The largest load of the school will be recorded in the evening times during evening classes. Each of the classrooms is installed with 2 units of 12W energy-saving bulbs and 3 units of 18W bulbs for the lighting of school surroundings. Health clinic engaged near to a group of communities in the basic service centre, which is equipped with provision of simple services and treatment of minor illnesses. The health centre works as health clinic, which will serve in stocking medicines and follow up of health conditions of the residents. The critical ailments that require special treatments are not attended to at the health centre rather they are referred to the nearby well equipped clinics or hospitals. The main possible appliances that draw electric power in the health centre are low-energy light bulbs, radio, television, computer, printer, laboratory microscope, and vaccine freezer. Details of the community load are shown in Table IV and Figure 6 with peak load occurring at 19:00 hours.

Table V shows the final result of the total load of the study community of Itie-Ikpe, this is put at 562.25 kWh/d.

Table V: Field Survey Results

Load Category	kWh/d
Household	363.416
Commercial	165.582
Community	33.251
Total Load Demand	562.249

C. *Comparative Analysis*

Table VI displays the estimated two-year monthly load of Itie-Ikpe Community as obtained from Port-Harcourt Electricity Distribution (PHED) Company. An average daily load was determined from the data obtained and put at 557.59 kWh/d with the largest load occurring in the month of January, followed closely by the months of February, November and December.

For confirmation of the validity of obtained estimated figure, a field survey exercise was carried out with the result standing at 562.25 kWh/d. Comparing the two independent results with the difference of 4.66 kWh/d, it was observed that the field survey result was 0.84% higher than the value determined from the estimates obtained from PHED Company. This difference is relatively negligible; it is within the allowable tolerance limit with little or no effect on the design of optimal hybrid renewable energy systems. Therefore, the field survey result validates the average daily load value determined from the two-year estimates obtained from PHED Company.

TABLE VI: ESTIMATED ANNUAL LOAD PROFILE OF ITIE IKPE COMMUNITY					
Month	2018 Monthly Energy (Kwh)	2019 Monthly Energy (Kwh)	Total Monthly Energy (Kwh)	Average Monthly Energy (Kwh)	Average Daily Energy (Kwh)
January	18983	18997	37980	18990	612.58065
February	16305	17242	33547	16773.5	599.05357
March	17470	15876	33346	16673	537.83871
April	16857.5	16284.5	33142	16571	552.36667
May	16380	16580	32960	16480	531.6129
June	16600	16150	32750	16375	545.83333
July	16554.5	15655.5	32210	16105	519.51613
August	16205	15585	31790	15895	512.74194
September	16237.5	16172.5	32410	16205	540.16667
October	17475	17075	34550	17275	557.25806
November	17762.5	18187.5	35950	17975	599.16667
December	18637.5	17508.1	36145.6	18072.8	582.99355
Annual Total	205467.5	201313.1	406780.6	203390.3	6691.1288
Average Load (kWh/d)	17122.292	16776.092	33898.383	16949.192	557.59407

Source: PHED (2021)

V. DISCUSSION

This research validates the load profile of Itie-Ikpe community for the purpose of designing a sustainable optimal hybrid renewable energy system for energy sustainability. Application and usage of a validated load demand in energy system designs is of great importance so as to avoid system poor performance and higher cost of system components. Table VII displays the load profile results obtained from an electricity distribution company and field survey with an error margin or difference of 4.66 kWh/d. The field survey result is 0.84% higher than the result obtained from the estimates.

TABLE VII: LOAD PROFILE OF ITIE-IKPE COMMUNITY

Source	Daily Load Demand (kWh/d)
Port Harcourt Electricity Distribution (PHED) Company	557.59
Field Survey Result	562.25

Comparing the results of this research study with some previous works done by some great researchers like (Samir, 2021) that did not put into consideration the effects of community, agricultural and commercial loads on his proposed energy system using the non-validated daily electricity load demand of 484.729 kWh/d. Unlike the load profile validation carried out under this research. Implementation of the proposed energy system design of (Samir, 2021) will either validate the load data or render it invalid which comes at a cost. Furthermore, the work of Oladigbolu, *et al.* (2020) focused on the estimated total households and healthcare facility load of 3,853 kWh/d for a community, without considering the effects of both commercial and other community loads such as school, worship centers, hall and street lights on the power system. Also, validation of the estimated daily load was not done as against the objective of this research which put into consideration, the effects of community and commercial loads on the design of optimal hybrid renewable energy systems. Reference Vendoti, *et al.* (2020) collected load data from the locals without validation, in his attempt to model and optimize an off-grid hybrid renewable energy system for electrification in rural area with a total estimated daily energy demand of 724.83 kWh/d. Under this study, a value of daily load demand was determined from the estimates obtained from an energy distribution company; a field survey was carried with full attention paid to other loads rather than only residential and validation was done through comparative analysis of the two results.

VI. CONCLUSIONS

From the results of this research, the error margin or difference between the field survey result for the load demand and the result gotten from the obtained estimates, was relatively negligible, with little or no significant effect on the design of an optimal hybrid renewable energy system. Therefore, it is concluded that the field survey result value of the daily load demand validated the average load demand value determined from the obtained estimates.

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