

Exploring the Feasibility of Solar Mini-Grids for Island Communities in Uganda: A Case of Koome and Damba Islands

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Abstract

This study assessed the feasibility of installing solar-diesel hybrid mini-grid systems on Koome Main and Damba Island (Uganda), to bridge the energy access gap in off-grid communities. Despite being economically active, these islands face significant challenges in accessing essential services such as healthcare, education and business infrastructure due to the lack of electricity. A mixed-methods approach including surveys, interviews, focus group discussions and technical modelling using STATA, Excel and Homer Pro was used to assess the technical, economic/financial feasibility as well as affordability aspects of the project. The results indicate that the installation of solar-diesel hybrid mini-grids of 650 - 950 kW and 300 - 470 kW for Koome and Damba islands respectively were feasible. The economic assessment shows favorable financial indicators, including internal rate of return (IRR) ranging between 14% - 19% and PBP between 4 - 7 years. In terms of affordability of electricity from mini-grids, a 50% subsidy would be necessary to make electricity affordable for domestic and institutional category spending between UGX10,000 - 30,000. Also, net present cost (NPC) between 1.58 million € and 2.24 million €, LCOE ranging between 0.24 - 0.27 €/kWh which was still less than 0.3 €/kWh for both islands was obtained, further highlighting attractiveness of the solar-diesel hybrid systems for Koome and Damba Islands.

Keywords

Decentralized Electrification, Solar-Diesel Hybrid Systems, Uganda

1. Introduction

The lack of access to electricity results in a multitude of consequences, which could significantly affect islands since in most cases these are cut off from basic services especially in developing countries like Uganda. Without access to electricity, economic growth is hindered, access to improved health care services is limited, welfare of households let alone overall development is stalled, leading to numerous negative impacts not limited poor health and sanitation, low illiteracy rates, poor livelihoods due to low-income generation opportunities to mention but a few [1]. It is estimated that around 670 million people will continue to lack access to electricity in 2030, with 9 out of 10 people expected to live in Sub-Saharan Africa (SSA) [2] [3].

Uganda currently has a population of close to 50 million people (Worldometer, 2025) and studies indicate that about 45% of the population has access to electricity (as of 2023), which is still low compared to some of the neighboring countries in the East African Block such as Kenya which boast of electricity access of up to 75% and Tanzania still recording overall electricity access of 46 % although urban electrification has been reported to reach at least 75% while access to electricity in the rural areas is at 36% [3] [4]. The situation in Uganda's rural areas is considered dire with around 75% of the population living in rural areas and reports indicating only around 22% have access to electricity [5] [6]. In that regard, rural areas are defined as areas of open land with few dwellings often distant from businesses [7]. The country's planning documents—such as Vision 2040, National Development Plan III and the Renewable Energy Policy of 2023—all highlight the central role electricity plays in development of the nation. Cognizant of the challenges associated with lack of access to electricity, the government considers mini-grids as one of the solutions as indicated in public documents such as the National Electrification Strategy, where the government foresees the development of over 2000 mini-grids to connect more than 230,000 households by 2030 [8] [9]. For islands and hard to reach areas, off grid systems powered by renewable resources such as solar, hydropower and biomass are indeed seen as viable options in ensuring that that citizens can have access to electricity [10] [11]. However, despite some success stories regarding the installation of mini-grids on islands and other locations not connected to the grid (e.g. Kisiizi hydropower station, Kanyegaramire, and Kyamugarura solar PV stations), the assessment of existing systems has revealed various issues which technical aspects such as system failures, load shedding and inadequate power supply due to interruptions related to the solar energy resource. In addition, missing productive use strategies to increase energy demand, inadequate access to capital or a lack of regulatory security of tenure have affected such systems [12] [13].

Hence, this paper provides a case study on the possibility of installing a solar-powered mini-grid in a non-electrified region in Uganda, particularly considering productive use within the area, installation and recurrent operational costs, willingness to pay, social as well as institutional requirements. The selected locations included

two islands in Koome sub-county: Koome Main and Damba Islands which were chosen due to various reasons: 1) the areas are more populated, 2) engage in various activities including those that require energy and 3) are not connected to any other power supply/grid system except for individual stand-alone solar or thermal/oil powered generator systems. On the other hand, these island communities experience major challenges concerning access to healthcare, education, social, economic and institutional services, largely due to the lack of access to electricity.

In this study, the authors attempt to answer the question: *What are the key technical, economic, and social factors determining the feasibility of installing a solar-powered mini-grid on Koome and Damba Island in Uganda?*

2. Literature Review

While Uganda has registered increased interest in installing solar, hybrid mini grids in various parts of country in the bid to contribute to increased electrification access, stakeholders have asserted that significant need for subsidies due to three broad gaps of affordability, investment and demand have affected sustainability of these systems [14]. Specifically, some of the influencing factors cited at various levels and scale of systems include, high upfront costs, system reliability, intermittent electricity supply, issues associated with market availability and scalability are some of the persist deterrents [12] [15].

In light of some of the issues identified, holistic feasibility studies, carrying out detailed feasibility studies become critical tools in preventing oversizing or under sizing, determining if systems are financially viable and are also socially acceptable. Some feasibility studies have categorized thematic areas of assessment to include:

Technical feasibility where, systems sizing and hybrid configurations are considered, reliability which also looks at the duration of autonomy when electricity is provided from other components other than PV *i.e.* batteries etc.

Economic/financial feasibility which incorporates; levelized cost of energy (LCOE), payback period (PBP), Net present value/cost (NPV or NPC), Internal rate of return (IRR), Capital Expenditure (CAPEX), Operational expenditure (OPEX) and financing structure where loan, equity and subsidy contributions are considered.

Affordability aspects; where tariff verse income, willingness to pay (WTP) for electricity and connection affordability are considered.

Demand assessment; includes, load profiles, consumer segmentation in various categories *i.e.* domestic, commercial, institutional and productive use uptake among others.

While aspects such as environmental and institutional may also be considered in the holistic feasibility assessment.

For some of the selected feasibility studies in Uganda and other areas in Sub-Saharan Africa, Asia, use of hybrid systems was cited to reduce fuel consumption while additionally increasing reliability. Other systems highlighted the reduction

in the country's carbon footprint by 436,035.6 kgCO₂ annually which was equivalent to a 0.01 % reduction from a solar-wind hybrid system in Sigulu Island [7] [16] [17]. Given that Mini grids are seen as a solution to electrification of remote areas and significant role these systems play in increasing electricity access, for decentralized areas like Koome islands where the national grid has not yet been connected, solar hybrid mini-grids could be a solution [18].

However, given the concerns associated with subsidization of these systems and the fact that islands like Kalangala, Ssigulu, Bugala and Kisiizi in Uganda have installed Mini grids, incorporating any lessons learned while assessing feasibility of mini-gids for Koome and neighbouring Damba Islands on Lake Victoria would be crucial [7] [19].

To inform the feasibility of the proposed systems, assessment criteria for reference was deemed crucial in this study the following criteria were considered; Affordability; which incorporated the cost of standard electricity consumption package associated with specified category *i.e.* domestic, institutional, commercial and productive use of energy. This factored in the WTP for the electricity produced, taking into consideration the demand annually.

Reliability of the system which considered the number of hours the system would continue to avail electricity without the solar PV input *i.e.* autonomy hours from the system and contribution from PV to meet the load. For the financial criteria, the IRR and PBP were considered for assessment. In this study, reference was made to existing guidelines for sizing and assessment of Mini grids to ensure key aspects are considered.

3. Methodology

3.1. Area of Study

The area of study of the research was Koome Main and Damba Island (see **Figure 1**). Both are located at Koome Island, which is an archipelago, consisting of 17 islands with 29 villages located along the equator in Lake Victoria on coordinates: Latitude: -0.0850; Longitude: 32.7500. Koome Island is located in the district of Mukono and is administered by Koome Subcounty. The island consists of 4 parishes named *Bugombe, Busanga, Lwomolo* and *Mubembe* as indicated in **Table 1** and each parish is largely run by a parish chief—a government employee who provides technical leadership to the Local Council Committee II. **Figure 1** shows the location of Koome and Damba islands.

Within each parish level is the village, which is the lowest political administrative unit and typically consists of at least 250 people and up to 70 households. Administratively, each village is led by a Local Council (LCI), chairperson and an executive committee. Demographically, the population of Koome Island consisted of at least 23,177 people in 2022. It should be noted that the population increases to about 38,500 people during good fishing seasons from February to September when transient populations increase the total population. **Table 1** provides a summary of the population [21] [22].



Source: [20].

Figure 1. Koome and Damba islands on Lake Victoria.

Table 1. Population of Koome islands.

| Parish | Estimate 2014 census | Estimate 2022 |
|---------|----------------------|---------------|
| Bugombe | 2147 | 2570 |
| Busanga | 7556 | 9043 |
| Lwomolo | 3484 | 4170 |
| Mubembe | 6178 | 7394 |
| Total | 19,365 | 23,177 |

Source: [21].

Although there are 17 small islands within Koome, just the main island of Koome and Damba Island were considered in this study due to reasons already mentioned. Koome Main forms the Bugome, at least 50% of the Lwomolo and 35% of the Busanga parishes, while Damba Island constitutes Mubembe parish.

According to the Rural Electrification Strategy and Plan 2013 - 2022, the Government of Uganda (GoU) intended to increase electricity access in rural areas of the country from 5% to 22%. Mini-grids were identified as one of the main options to be considered to achieve the increase in electrification. Island communities such as Koome Islands were identified for the installation of mini-grids powered by solar energy [5]. During field visits, some of the businesses and commercial establishments in both Koome Main and Damba Island use stand-alone solar systems mainly for lighting and phone charging. In Koome Main, a business owner had a stand-alone generator that used diesel to generate electricity used by a few businesses such as video halls, salons and popcorn machines in one of the trading centers. The power from this private generator was only used intermittently de-

pending on the availability of diesel, which had to be purchased from the mainland in Mukono and transported to the island. Meanwhile, some of the grain mill owners also used diesel generators to power their mills, which also operated intermittently.

A summary of the relevant baseline information for Koome and Damba Islands is included, based on pre-feasibility engagement with key stakeholders in Koome Main.

3.1.1. Education Sector

The entire Koome Subcounty had one Secondary School (*Koome Seed Secondary School*) and three public Primary Schools: Koome C/U Primary School, Damba Island Primary School and Buyana Primary School. However, it was found that not all pupils from the Primary Schools were able to continue their education at Koome Seed Secondary School, meaning that some of them opted to study in the mainland Schools or dropped out of School.

3.1.2. Health and Sanitation Sector

Like most of the islands within the Victoria Belt, Koome Island has three public health centers which included Koome Health Center III, Kansambwe Health Center II and Damba Island Health Center II. The sub-county had only three gravity water flow schemes that serve only three villages of Bugombe, Kibanga and Zingoola. The other two piped water sources donated by Water Mission Uganda served other islands of Kimmi and Myende landing site. Toilet coverage in Koome sub-county was at a measly 10% with public toilets installed in only three landing sites of Kimmi, Myende and Lwangamuto. It is worth noting that Koome Island is characterized by Sesse series soils and has a high-water table, making it difficult to install latrines in certain locations. Therefore, most households did not have their own latrine/toilet facilities, which influences poor sanitation practices where open defecation was practiced.

3.1.3. Transportation

Koome Subcounty was also struggling with transportation and the necessary road infrastructure. The canoe boats that transported fish to the markets were also used to transport people and their belongings to mainland areas such as Ggaba, Kasenyi, Ggerenge or Katosi. Although the Koome recently obtained a boat ambulance, costs for a trip were high (78 Euro) for the locals leaving the boat idle [23]. Transportation within the island is difficult, as there are few access roads and some places are completely inaccessible due to the poor road network.

3.2. Methods

This study employed a cross-sectional survey design, which is an observational design that analyses data from a population at a specific point in time [24] [25]. In this design, data was collected from a representative sample for Koome and Damba Island residents at a single point in time.

By using this design, the researchers obtained a snapshot of multifaceted un-

derstanding of the complexity of the real-life context for an off-grid solar hybrid system for Koome Main and Damba Islands [26].

Given the purpose of the study, a sequential mixed methods approach was used to generate data. This involved conducting interviews followed by a survey and focus group discussions, where information on area demographics, related to energy demand for different categories like households/residents, commercial, institutional and productive energy use and eventual willingness to pay as well as opinions, trends or beliefs were obtained. The group of stakeholders engaged included; residents/business owner of both Koome and Damba islands, Koome and Damba Sub-County leaders, Mukono District officials. Moreover, interviews were conducted with various key individuals to gain in-depth information and understanding of specific thematic areas such as the energy sector, trends, interest in mini-grids, and overall government plans. As such, interviews were conducted with officials from the Ministry of Energy and Mineral Development, as well as private sector actors involved in solar mini-grids, such as GIZ and the World-Wide Fund (WWF). Additionally, the researchers also adopted one of the most important methods *i.e.* observation, since it served as the basis for all other methods to analyze and interpret the information collected.

Information from the survey, interviews and focus group discussions was useful in estimating the energy consumption/demand for the different categories which included Households/residents, commercial, institutional and productive use for each of the islands.

Once the energy demand was obtained, HomerPro software which is considered a global standard for optimizing mini grid design in all sectors was used. The software simulates energy systems, showing various system configurations optimized by cost, and provides sensitivity analyses. Furthermore, with reference to various guidelines for conducting feasibility assessments for such systems, where key elements such as organizational, technical and financial aspects were assessed for a specific case study area, this study considered specific feasibility criteria [2] [17]. The following feasibility criteria were considered in the study:

Minimum Reliability: here, high reliability was considered critical for commercial adoption and eventual sustainability of system. As such a target of at least 90% uptime was considered, with the option hybrid systems (solar + storage + diesel backup) to overcome intermittent supply. As such, using Homer, having a renewable energy source penetration rate of at least 90% was considered to cater for this criterion

Affordability: For customers to afford electricity, tariffs should be competitive with existing diesel generators and affordability often requiring anchoring to productive users (like fish processing, grinding of grain like maize, diary products cooling to increase shelf life) to justify costs. In this study, affordability was considered as amount spent on purchase of electricity from the system being than 10% monthly income of customers [27].

Minimum IRR: an IRR of approximately 12% was considered achievable

given that other studies showed IRR of between 15% - 18% [7].

Maximum Payback Period (PBP): For projects designed around specific communities which is the case for this study, a payback period of less than 10 years to minimize risk was considered [28] [29].

Other aspects, such as the environmental, regulatory and legal valuation were not covered in this study for reasons of clarity. Ethical aspects were considered in all these methods and these included obtaining consent during survey, engaging respondents of age, and genuinely representing all data obtained.

3.2.1. Sampling and Data Collection

Demographically, reference was made to the national population and housing census of 2014, and projections were made for the population of Koome Sub-county in 2022 as shown in **Table 1**. Furthermore, reference was made to population sampling Equation (1).

$$N = Po / (1 + Po * e^2) \quad (1)$$

where: N is the sample size, Po is the population size, and e is the level of precision.

Considering 95% confidence level and precision $e = 0.05$ are assumed to compute the sample population with reference to Equation (1) for Equation below: Thus, the estimated sample size for both Koome and Damba Island population of 31,248 beneficiaries, was:

$$n = \frac{31248}{1 + 31248 * 0.05^2} = 395 \text{ participants}$$

The target respondents for the study were selected using a multistage sampling technique. In the first stage, each parish was selected, including Bugombe, Busanga, Lwomolo for Koome Island and Mubembe and part of Nsanja in Damba Island; secondly, at least 4 villages per parish were selected; and thirdly, households were randomly selected from a list of households compiled by the village headman and village chairmen. Furthermore, depending on seasons of the year, transient population to the islands ranged between 20% - 50% since nearly 50% of the population was youth, and a significant proportion of youth were reported to often leave the islands in search of better services on the mainland or on other islands, such as Kalangala, that were already connected to a mini-grid. Thus, using a factor of 0.35, the adjusted sample size to factor in the transient population was considered, refer to Equation (2).

$$N_1 = 395 * 0.35 + 395 = 533 \text{ participants} \quad (2)$$

As such, responses were received from a total of 537 participants at the quantitative phase of the study, representing about 1.7% of the overall population. This sample was considered representative given the characteristics of the Islands. To support data collection during the survey, questionnaires were developed and pre-tested with a representative sample of the Katosi landing site population before the survey was conducted in Koome and Damba Islands. Then, prior to conduct-

ing the quantitative survey, two focus group discussions were conducted to understand the composition and structure of the community, first with the community leaders in November 2021 and then in August 2022 with various community members from both islands.

3.2.2. Data Management and Analysis

Robust data management protocols were implemented to ensure data quality, efficiency and security. Real-time data quality checks were performed within the SurveyCTO platform to identify and correct errors or inconsistencies during data collection. Collected quantitative data was stored on the SurveyCTO server with regular backups to protect against data loss. Upon completion of data collection, the data was exported to the Statistical Package for Social Science (SPSS 27) for further analysis and cleaning.

After data was imported into SPSS, a rigorous cleaning process was conducted to identify and correct errors, inconsistencies, or missing values. Descriptive statistical techniques were used to analyze quantitative data using frequencies and percentages.

Qualitative data were transcribed, edited and analyzed using thematic analysis. This allowed for an in-depth exploration of the perceptions, experiences and challenges associated with off-grid solar systems for Koome Main and Damba Island. This approach involved a systematic process of identifying, analyzing and interpreting patterns within the data. Before beginning the data analysis process, the researchers made sense of the data by reading through the transcript several times. The textual data was then imported into ATLAS ti 9 for analysis. This software was used to generate codes, categorize and label the data based on its content. The codes were then grouped into themes that captured the core meanings and patterns. Both the qualitative and quantitative data sets were used in a complementary manner to provide a comprehensive understanding of the solar off-grid systems for Koome Main and Damba Island.

Projections of energy demand /load assessments were also performed. Key assumptions, such as population growth rates, were used to estimate energy consumption and, ultimately, demand for each consumer category. Formulas/equations were used to calculate energy consumption and demand, while consideration of other assumptions such as electricity penetration rate, technical losses associated with distribution of electricity in mini-grids, and safety factors that account for losses, inefficiencies, and temperature compensation for PV modules further informed the estimation of energy demand. Projections of future energy consumption and demand were carried out in Excel. Further evaluation of the technical-financial assessment of the proposed mini-grids to inform the sizing and design was then carried out using HomerPro software.

Data analysis was also conducted separately and the results were integrated during the data interpretation phase. This approach was chosen because it promotes complementarity and triangulation, allowing the researchers to validate one set of findings with the other and help to gain a complete picture of the proposed solar

hybrid off-grid systems for such communities [30] [31].

3.2.3. Input Data and Load Assessment

The meteorological data for Koome and Damba Islands was obtained from HOMER pro software having incorporated the coordinates for the respective islands and this was validated by linking to National Aeronautics and Space Administration (NASA) databases. The monthly average Global Horizontal Irradiance (GHI) was obtained, taking into consideration temperature, and wind speed for the respective islands using HOMER Pro software. In the software, mathematical models and algorithms simulate GHI, temperature, and wind speed levels, considering atmospheric and climatic parameters for locations where geographical coordinates, and elevation have been incorporated. Thus, for Koome island, an annual average GHI of 5.09 kWh/m²/day, while for Damba island an annual average of 5.22 kWh/m²/day. The average temperature and wind values were 23.94°C and 3.3 m/s for Koome Island, 22.93°C and 3.11 m/s for Damba.

Both islands maintained predominantly clear skies throughout the year, as indicated by the clearance index ranging from 0.46 - 0.55 for Koome and 0.49 - 0.57 for Damba Island, all below 1. The favorable GHI, clearance index, wind speed, and temperature data for both Islands suggests implementation of solar photovoltaic systems can be achieved.

3.2.4. Estimation of Energy Consumption

For both Koome and Damba island, use of electricity obtained from standalone units and diesel-powered generators was primarily for businesses/commercial entities, health centers, schools, and for powering low energy devices such as computers, lighting, radios, telephones, and other household applications. Other productive use of energy options which were identified included grinding machines used mainly to grind maize, need for refrigeration to boost preservation of fish, interest to process and preserve milk for a large-scale farmer in Damba Island. Thus, the estimated energy load for Koome and Damba islands was 1032 kWh/day and 452 kWh/day respectively. These values were estimated from collected data during the survey carried out and further discussed in results section.

3.2.5. System Architecture

In this study, investigation to assess the availability of solar as a renewable energy resource was carried out as indicated by the average GDI values for both Koome and Damba islands ranging from 5.09 - 5.22 kWh/m²/day. Furthermore, using a diesel generator as a back provision for when solar energy was not obtained *i.e.* in the evening hours was considered. From the survey, it was determined that at both Islands, diesel was already being used at a small scale by individuals mostly to avail energy to run grinding mills and also run businesses.

As such, in this study, the design incorporated diesel power generation as part of the hybrid system since a similar approach was considered for Kalangala Island which boasts of 1.6 MW hybrid solar-diesel power plant that has recorded successes [32]. Thereafter, estimation of the electricity load for both Islands was car-

ried out and this was informed by the survey information obtained. Using a range of input parameters and data available for solar as a renewable energy source, diesel for power generation, HOMER Pro software was employed to determine the optimal energy mix and generate the percentage of load to be served by solar and diesel-powered generator as sustainable and reliable hybrid systems for both Islands.

The system optimization in HOMER Pro was simulated for one year, using hourly intervals to ensure the load power demand for the respective islands *i.e.* 1032 kWh/day and 452 kWh/day was met at the lowest net present cost (NPC). Following the simulation in Homer Pro, multiple combinations of solar PV, diesel generator and battery storage were considered and the best combinations that registered the least NPC while incorporating other key parameters such as Levelized Cost of Energy (LCOE), Internal Rate of Return (IRR), and Return on Investment (ROI) highlighting how the systems performed economically and technically, capable of meeting the energy demand. For each of the systems considered, power generation through solar PV panels factoring in energy conversion from direct current (DC) to alternating current (AC) using a converter connected to the DC and AC buses, diesel generators, and battery energy storage. While the converter ensures efficient power transmission, the battery bank stores excess energy generated from solar, which can be utilized during periods of intermittency. **Figure 2** shows the system architecture.

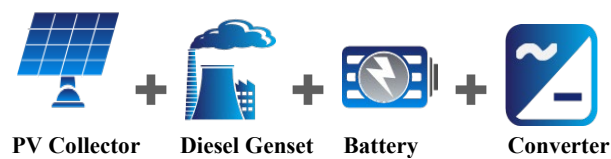


Figure 2. Solar Diesel hybrid mini grid architecture.

In summary, the procedure for developing the system architecture included:

- Selecting the study sites (Koome and Damba Islands).
- Gathering general research data including climate information for the chosen site and average prices of renewable energy components.
- Estimating the load demand of both islands based on the obtained load consumption data.
- Techno-economic analysis using Homer Pro to obtain suitable design which included components already highlighted.
- Key parameters of the system components were inputted in HOMER Pro prior to simulation.

HOMER Pro was used to generate various configurations for the system and select the optimal solutions based on the criteria of lowest NPC, LCOE, IRR and even PBP. Reference was made to key steps proposed in guideline for mini-grid sizing and design developed by GIZ [28]. The overall methodology adopted for the feasibility study for the Koome and Damba Islands as indicated by **Figure 3**.

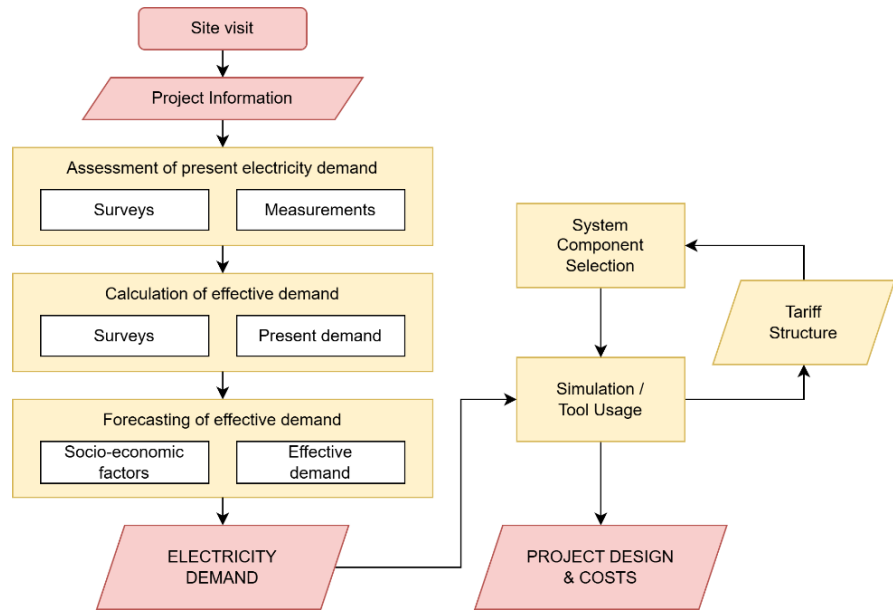


Figure 3. Procedure adopted for solar-diesel hybrid mini grid assessment.

3.2.6. Summary of Components Specifications

The key components of the systems designed for both islands included: PV arrays, diesel generator, a converter (inverter), and a battery storage system.

The Photo voltaic (PV) models selected for the system were Generic flat plate crystalline solar PV panels of 1kW power rating. An Autosize Genset diesel operated with 0.263 L/hr/kW, which automatically sizes self to meet load from Homer Pro database was used. Furthermore, a generic system converter with capacity of 1 kW and a 1 kWh generic lithium-ion battery were also used. Reference was made to the respective equations for NPC, IRR, LCOE and PBP already inbuilt in Homer Pro and indicated as equations 3, 4, 5, and 6.

$$C_{NPC} = \sum_{t=0}^N \frac{C_t}{(1+r)^t} \tag{3}$$

Where: C_t = Net cost flow in year t , r = discount rate or interest rate per period, N = total number of years.

$$o = \sum_{t=0}^N \frac{C_t}{(1+IRR)^t} \tag{4}$$

$$CRF = \frac{r(1+r)^N}{(1+r)^N - 1} \tag{5}$$

$$TAC = C_o * CRF + O + M$$

$$COE = \frac{TAC}{E_{Annual}}$$

$$\text{Payback Period (PBP)} = \text{Initial Investment} / \text{Net Cash Flow per period} \tag{6}$$

Where: C_o = Initial capital cost, CRF = Capital Recovery Factor, O = Annual operation cost, M = Annual maintenance costs, E_{Annual} = Annual energy produc-

tion (kWh).

Meanwhile, the following steps were taken to calculate the energy demand used to estimate the size of the hybrid systems:

- Energy demand data was collected through surveys. Specifically, data on appliances and equipment used by community members was of interest to determine the wattage of the appliances and their usage patterns.
- Thereafter, individual load demands were calculated for the respective appliances/equipment on a daily basis.
- The demand was then aggregated considering the number of users over monthly and annual periods and this was considered for respective categories *i.e.* domestic, commercial, institutional and productive use.
- Also, losses of the solar hybrid mini-grid system associated with components such as battery storage, inverters, were considered.
- To account for future projections based on population growth or increased electricity demand over time, an annual growth rate was factored into the demand calculation. This was derived from historical trends and projections in Mukono and Koome Sub-counties respectively.
- The solar mini-grid was then sized using Homer software

Accordingly, key assumptions were considered to support the energy demand estimation. These included

- A growth rate of 2.6% for the population of the parishes of *Lwomolo, Mubembe, Busanja Nsanja* and *Bugombe* representing the two islands of Koome Main and Damba Island.
- Potential consumers of electricity from the grid were categorized into 4 main categories including domestic, institutional, commercial and productive use.
- Based on trends in other neighboring island communities where the population is often transient, the household electricity penetration rate was assumed to be 50% (reference to Kalangala island).
- Growth in commercial/business and productive use was assumed to be 12%.
- Institutional growth was assumed to increase by at least 25% every 5 - 10 years. This was informed by historical trends within Koome Sub-County, considering institutions such as schools, health centers. The design period for the mini-grid was considered to be 20 years with a base year of 2022.

In addition, taking into consideration for timeline for additional studies for such systems, the actual initial installation of the mini-grid was projected to 2026. Given the key assumptions, the average monthly and annual energy consumption for each consumer category was calculated for the two islands. Equation (6) was used to calculate the energy consumption for each category.

$$Ec = P_{app} * T_{use} \quad (7)$$

Where: Ec is the Energy consumed, P_{app} is Power rating of appliance (watts), T_{use} is the duration of use per day (hours).

Thus, projections were made considering a duration of about 20 years with the base year of 2022. However, when recommending the initial installation to be con-

sidered, data for 2026 was referred to. This was considered based on the assumption that the actual commissioning of the plant could take place within 0 to 5 years after all relevant studies *i.e.* Environmental Social Impact Assessment (ESIA), land acquisition where necessary (especially for the mini-grid) and actual installation/construction were completed.

4. Results and Discussion

4.1. Socio-Demographics of Koome and Damba Island

A total of 537 respondents from the four parishes participated in the survey, 257 male and 280 females. Overall, the distribution of respondents per parish can be seen in **Figure 4**.

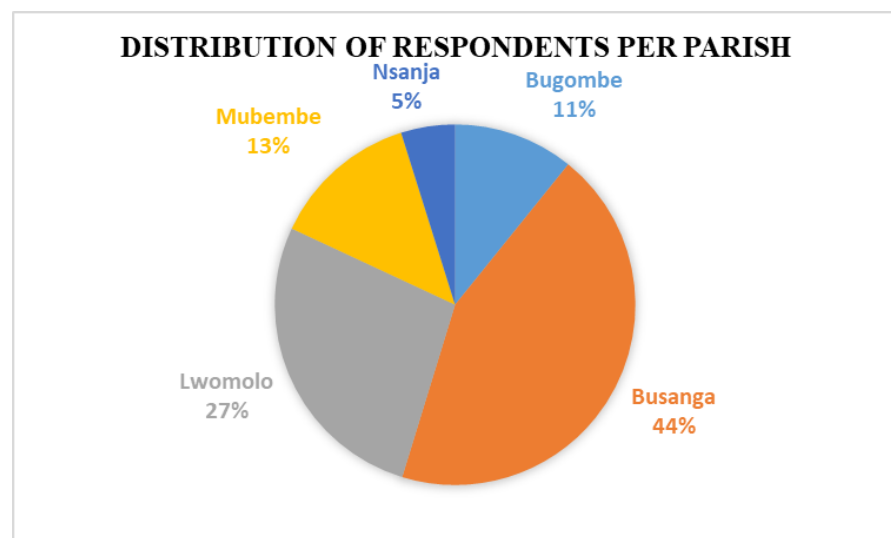


Figure 4. Shows distribution of respondents by parish.

An assessment of the demographic characteristics of the community revealed that at least 62% of the respondents have children of school age. Further, the average age of respondents in the study area is 35.6 years, with at least half of the population below the age of 35, which is the productive age group. The average household size is 4 persons, which is slightly lower than the national household size of 4.5 persons [21] [22]. In terms of marital status, at least 69% of the respondents were married, while 13% are single, 15% were separated and about 3% are widowed and divorced. In terms of educational attainment, 9.1% had no formal education, while at least 34% have secondary education (O and A levels) and 2.8% had university degree.

In general, at least 17% more women than men completed primary education, while 55% more men than women completed upper secondary education. There was no significant difference when looking at other categories of education. The results highlight the lack of infrastructure to support further education, as the entire Sub-County had only one public senior secondary school serving the islands. As such, most students were able to complete ordinary level secondary education,

while higher level education was a challenge for females who mostly dropped out since they had to shift to other neighboring islands or the mainland to study. Meanwhile, significant male dropout at the primary level had been linked to the interest of teenage boys to earn a living from the land by selling fish at an early age.

4.1.1. Energy Use

Regarding energy use, 67% of the respondents indicated that they used solar lamps for lighting especially for school going children to be able to read at night. Meanwhile, 11% of the respondents indicated that they used kerosene lamps and 6% used wax candles for lighting. In certain cases, torches powered by batteries, use of cell phone light/torches were used.

In the trading centers, lights were powered by a generator system, but only when the private power company has diesel from the mainland. **Figure 5** shows the representation of sources of energy for lighting by the respondents. At least 74% of the respondents indicated that used solar bulbs for lighting, followed by use of torches with batteries at 12%. Use of paraffine was also mentioned accounting for 2%. The dominant utilization of solar highlights the penetration of the technology and possibly affordability of such components like lights, which could be key factors influencing appetite and acceptance of solar systems.

Despite the insignificant use of paraffin for lighting, its use has been associated with health concerns such as cancer and increases in respiratory and cardiovascular mortality and is therefore not recommended [33]. In addition, the dull light of paraffin lit lamps forces people to sit close to the lamp, increasing the risk of health problems. This could be especially true for children, who could further be exposed to the risk of accidents caused by fire.

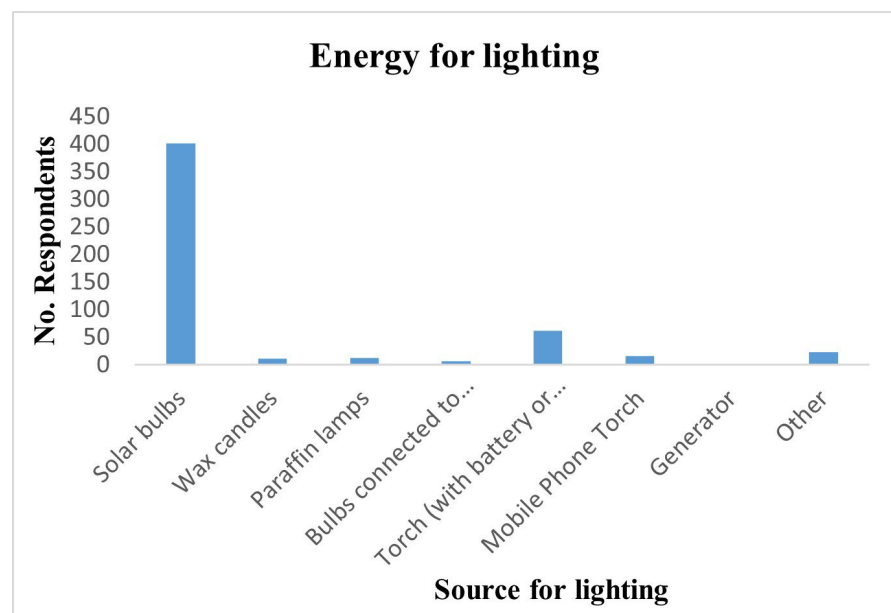


Figure 5. Energy sources for lighting.

4.1.2. Livelihood Activities

In terms of livelihood activities, 32% of the respondents were involved in fish business such as fishing, mongering and fish drying. The latter group, such as fish mongers and those involved in value addition, earned between UGX 100,000 - 299,900 per month (about €25.7 - 77.2). In addition, 75.4% of those involved in direct fishing earned up to UGX 500,000 (about € 128.7) per month. In general, women were mainly involved in the drying and marketing of fish, while men were fishermen. This gender trend is evident in many areas in Uganda, resulting in women earning less than men. In most cases, aspects such as patriarchy, religion, family, marriage, social and cultural practices play an important role in perpetuating gender inequalities in Uganda's formal and informal institutions.

Other activities included retail or wholesale trade, which accounted for 26% of respondents, while 16.3% of respondents were involved in agriculture (either livestock or crop production) and about 2.2% of respondents were formally employed. In addition, 18% of the respondents run pubs, restaurants or salons. In terms of monthly income, it was evident that at least 67% of the respondents earned between UGX100,000 - 1,000,000 as shown in **Figure 6**.

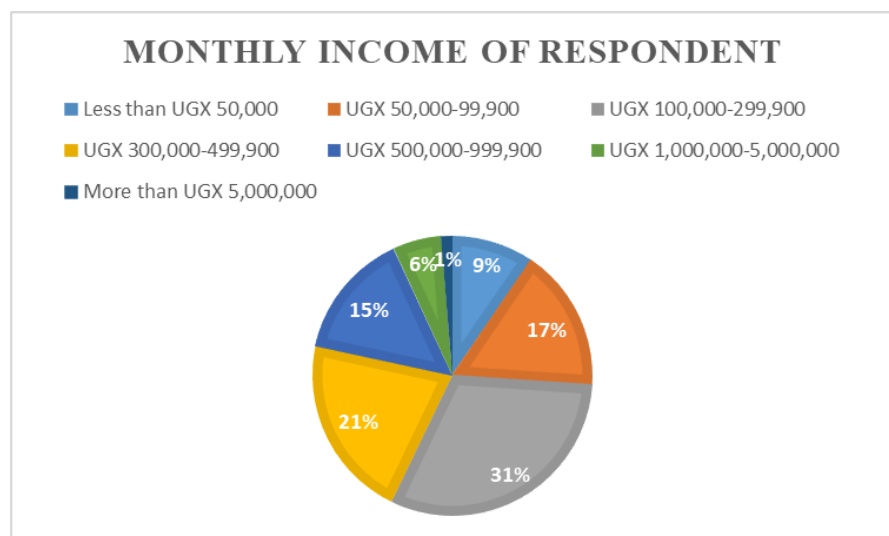


Figure 6. Monthly income ranges of respondents.

4.1.3. Energy Needs

Several focus group discussions revealed that the community was enthusiastic about the prospect of a solar mini-grid serving the islands of Koome and Damba. Community members emphasized that many households were already familiar with solar energy since they used small systems to charge phones and for lighting. They also noted that many businesses in the commercial centers used solar stand-alone systems or generators to power heavier equipment such as grinders or hair dryers in salons. Community members asserted that more economic activity would be stimulated in the islands if there was more regular and reliable source of energy, for instance from a solar diesel hybrid system referring to success stories of other islands like Kalangala. Furthermore, community members, leaders and

government officials were convinced that the presence of a reliable electricity system would stimulate economic growth for such communities. Other factors cited by stakeholders to further encourage the use of electricity from the proposed mini-grid are summarized in **Figure 7**.

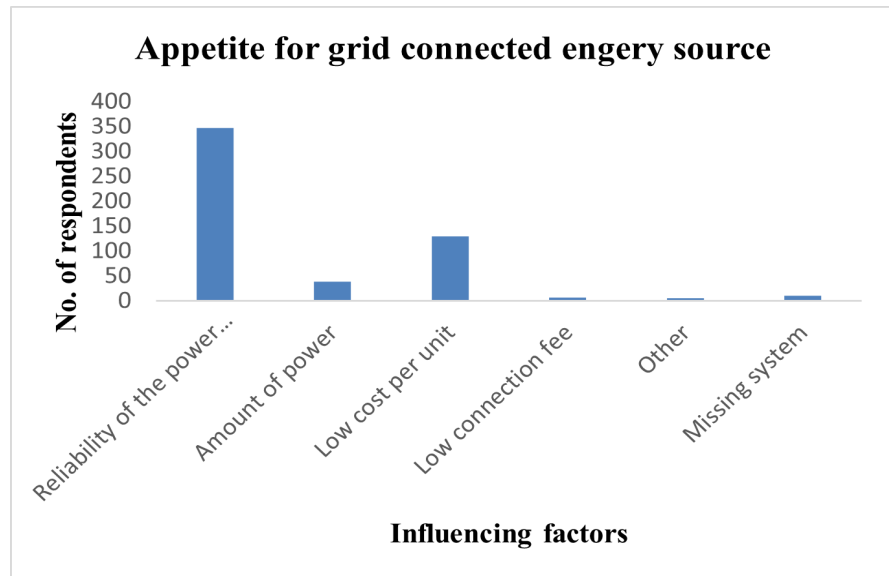


Figure 7. Appetite for solar mini grid connected energy source.

4.1.4. Energy Consumption and Demand Estimation

From the survey, population demographics highlighting socio, economic activities, and willingness to pay for energy were obtained and used to inform further estimation with reference to literature [17]. Energy consumption for the four categories was estimated based on the activities performed in each category.

Residential category

This category mainly included households and people living on the respective islands who owned property, e.g. house and/or land, as well as those who rented houses. From the survey, the main energy demand activities considered in this category included lighting, charging of mobile phones, use of appliances such as radios, televisions (TVs), flat irons and refrigerators. Information from neighboring islands such as Bugala-Kalangala was also included to provide a representative picture. Initially, the number of beneficiaries was calculated using a household size of 4, a population growth rate of 2.6% and an electricity penetration rate of 50%, hence the number of beneficiaries is summarized in **Table 2**.

Table 2. Beneficiaries after consideration of electricity penetration.

| Islands | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|--------------|------|------|------|------|------|------|------|------|------|
| Koome Main | 984 | 1064 | 1168 | 1296 | 1451 | 1643 | 1879 | 2172 | 2536 |
| Damba Island | 930 | 948 | 973 | 998 | 1024 | 1051 | 1078 | 1106 | 1135 |

Institutional category

In this category, institutions such as schools and health centers were mainly considered. The total number for each entity within the two islands was summarized in **Table 3**.

Table 3. Distribution of institution in the islands.

| Institutional entities | Koome Main | Damba Island |
|--------------------------|------------|--------------|
| Primary & nursery School | 4 | 1 |
| Secondary School | 1 | - |
| Health centre | 1 | 1 |

Commercial category

Under this category, retail/wholesale stores, restaurants/catering establishments, video/entertainment establishments (discotheques), bars and saloons, and specific appliances and equipment were considered. For example, for salons, refrigeration, lighting, phone charging, TV use, water heating, and hair dryer use were considered as some energy consuming activities, while similar activities except hair dryers were included for shops, restaurant/eatery, entertainment facilities, etc.

Given the trends in the islands where, during the months of February to September, the population was found to double since this duration consists of the peak fishing seasons, it was projected that the business entities within the islands would also grow since at least 50% of the population was involved in business entities *i.e.* fish value chain, retail shop, bars, restaurants among others.

Productive use category

The main inputs for the productive use category were identified as flour mills, fishing enterprises, and units such as farms that produce both crops and animal products in significant quantities, *i.e.* dairy products, beef, coffee, rice, among others. The main equipment and facilities considered were refrigeration and heating/pasteurization of milk from the dairy farm prior to cooling for transportation and eventual sale, refrigeration for fish processing businesses, electricity for grinding/milling grain mills, lighting and phone charging activities.

A growth rate of 12% was also assumed for this category. **Table 4** showed the estimated consumption per category.

Table 4. Estimate for consumption per consumer category.

| Category | Monthly Average consumption kWh | Annual Average Consumption kWh |
|--------------------------|---------------------------------|--------------------------------|
| Residential | 55 | 443 |
| Institutional | | |
| Secondary School | 737 | 8846 |
| Primary & Nursery School | 114 | 1366 |
| Health Centre | 539 | 6471 |
| Commercial | | |
| Saloon | 269 | 3227 |

Continued

| | | |
|-------------------------------|-----|--------|
| Restaurant/Eating joint | 224 | 2683 |
| Video hall | 31 | 374 |
| Retail Shop | 28 | 336 |
| Bars | 51 | 613 |
| Productive Use Options | | |
| Grinding mill-grain | 346 | 4153 |
| Diary plant | 948 | 11,379 |
| Processing fish-refrigeration | 134 | 1644 |

Specifically, the daily load for Koome and Damba islands was estimated to be 1032 kWh/day and 452 kWh/day respectively, following data collected and assessed from the surveys, focus group discussions and informant interviews held. Estimation of the load was carried out with reference to Equation (7). These values were used in Homer Pro software to simulate optimized systems for both islands. The best system consisted of solar PV(PV), diesel generator (DG), battery Storage (BS) and converter (CV) combination followed by system with PV, BS and converter as summarized in **Table 5**.

Table 5. Summary of best system options for Koome and Damba islands.

| Sn | Key aspects | Koome Island-Best System | Koome Island -2nd Best system | Damba Island best system | Damba Island-2nd best system |
|--------------------------------------|---------------------------------------|---|-------------------------------|--|---------------------------------------|
| 1 | System components/architecture | Specifications | | | |
| 2 | Flat plate PV | 420 kW-420 panels | 1067 kW | 159 kW | 365 kW |
| 3 | Lithium-Ion Battery capacity- | 1 kWh capacity-950 strings with 17.7 hours of autonomy | 1635 strings | 601 strings with 25.5 hours of autonomy | 1163 strings and 49 hours of autonomy |
| 4 | System converter | 132 kW | 146 kW | 45.1 kW | 82.1 kW |
| 5 | Autosize Genset | 230 kW | | 140 kW | |
| Initial parameters considered | | | | | |
| 6 | Nominal discount rate | 10% | 10% | 10% | 10% |
| 7 | Life time of system | 20 years | 20 years | 20 years | 20 years |
| 8 | Inflation rate | 10% | 10% | 10% | 10% |
| Other key parameters computed | | | | | |
| 9 | Fuel-Diesel | 1.33€/litre | 1.33€ | 1.33€ | 1.33€ |
| 19 | Average load considered | 1032 kWh/day | 1032 kWh/day | 452 kWh/day | 452 kWh/day |
| 11 | Total NPC | 2,246,595 € | 3,932,494€ | 1,580,107€ | 1,981,441€ |
| 12 | Total LCOE | 0.2982€ | 0.5224€ | 0.4789€ | 0.6010€ |
| 13 | Operating Costs | 25980.14€ | 16061.16€ | 38439.26€ | 20204.32€ |

Continued

| | | | | | |
|------------------------------|-----|------------|-------------|------------|------------|
| 14 | ROI | 15.5% | 4.7% | 19.8% | 8.4% |
| 15 | IRR | 19.2% | 6.8% | 24.8% | 11.7% |
| 16 | PBP | 5.13 years | 10.62 years | 3.69 years | 7.24 years |
| Renewable energy penetration | | 95.7% | 100% | 94.2% | 100% |

Results summarized show that the best system options for both Koome and Damba islands had similar architecture consisting of Solar PV, diesel generator, converter and battery (PV + DG + CV + BS). The initial parameters considered included a nominal discount rate of 10%, inflation rate of 10% and life of project of 20 years. For Koome Island, the best system had an NPC of 2.24 million €, LCOE of 0.298 €/kWh, IRR of 19%, PBP of 5 years clearly performing better than option 2, where only renewable energy source from solar PV was considered *i.e.* PV + CV + BS, which had a much higher NPC of close 4 million €, LCOE of 0.522 €/kWh, a PBP slightly above 10 years, much lower IRR of 6.8% even though 100% renewable energy penetration was considered. For Damba Island, a similar trend to Koome Island results could be traced although the PBP was much lower at about 4 years and the penetration for renewable energy at 94.2%.

From these results, considering a solar diesel hybrid system was preferable since also the feasibility assessment criteria were fulfilled *i.e.* availability of electricity/energy by at least 90% represented by the proportion of renewable penetration. Furthermore, IRR of at least 12% and PBP of less than 10 years registered by both systems.

The cost summary from respective components of the best option system is summarized in **Figure 8** and **Figure 9** respectively.

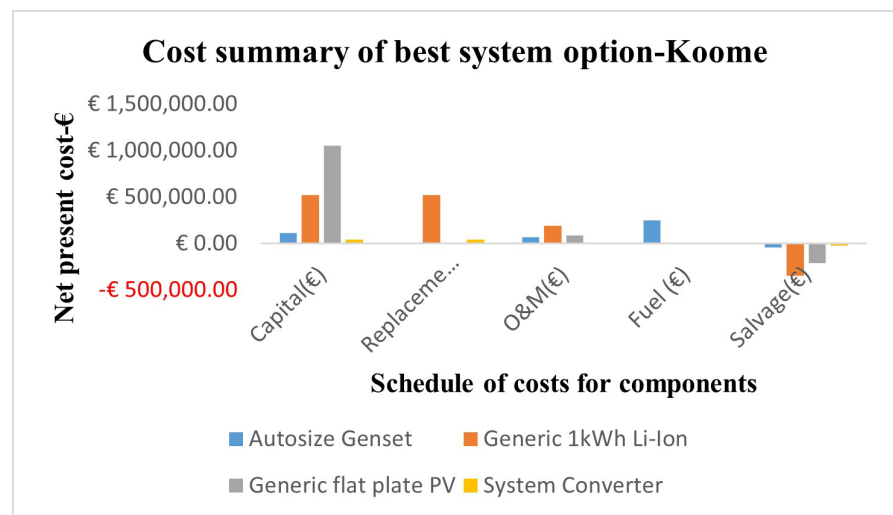


Figure 8. Cost summary for Koome Island.

Results showed that the PV flat plate panels contributed the most to the capital expenditure accounting for at least 1million € while replacement of Lithium-ion batteries at close to 522,000€ was the key contributor to replacement costs. O &

M costs for Lithium-Ion batteries were also significant, accounting for 190,000€ as seen in **Figure 8** for Koome Island.

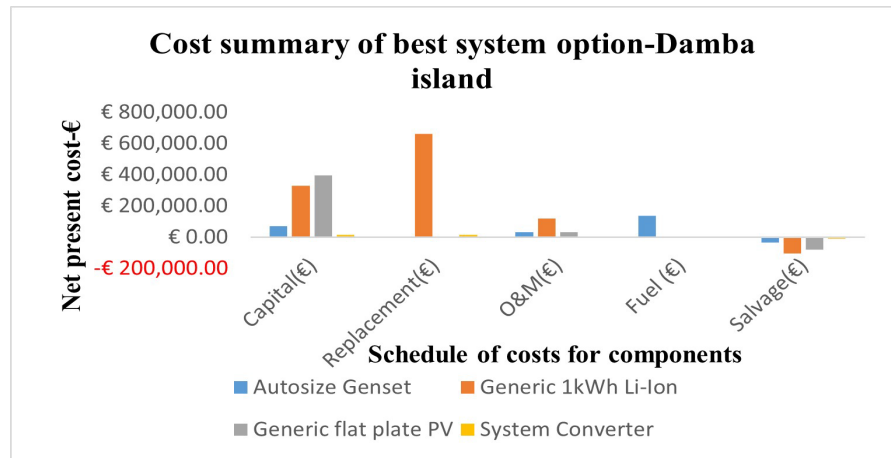


Figure 9. Cost summary for Damba Island.

For Damba Island, replacement costs for the Lithium-Ion batteries were quite high accounting for at least 600,000€ while the capital costs were mainly from purchase of the solar PV and the battery accounting for between 330,500 and 400,000€. The overall high replacement value could be associated with the low overall salvage value also shown in **Figure 9**. In terms of reliability, reference was made to the combination of the autonomy hours for the battery units factoring in 1 day of autonomy, equivalent to 24 hours and the composition of the renewable energy fraction.

Thus, from the results, for Koome Island, 17.7 hours of autonomy would be available from battery units and the renewable energy penetration was at least 95.7 %, implying that during the day at least 90% of electricity would be provided by the PV system while in the evening hours both the battery and diesel units would cater for the energy demand by availing averagely 50 MWh annually. **Figure 10** and **Figure 11**

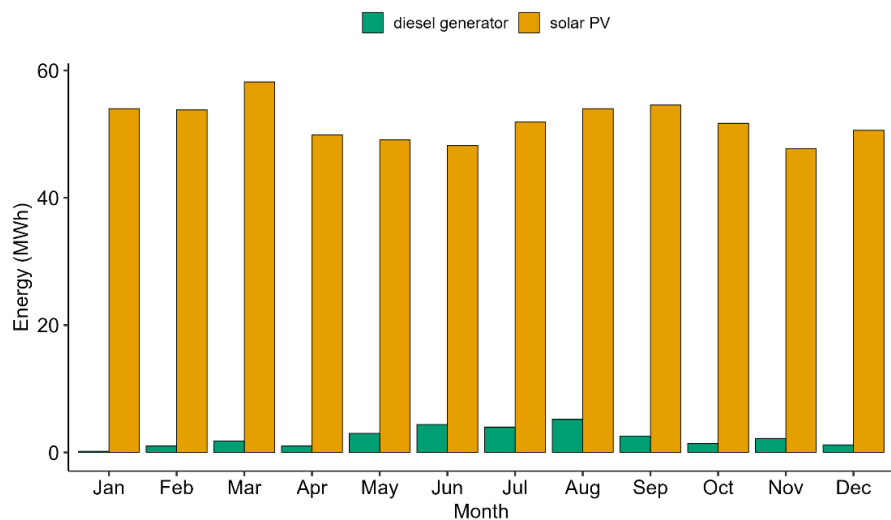


Figure 10. Show monthly energy contribution from system components to meet the demand for Koome Island.

shows the contribution from PV and diesel in meeting the energy demand throughout the year.

For Damba island, the duration of autonomy was 25.5 hours which was at least 1 day and the renewable energy penetration of at least 94%. Similar to Koome Island, diesel generator and energy stored in battery unit could be used in evening-night hours. An average amount of about 22 MWh/annually was provided by solar PV and diesel generator units as shown in **Figure 11**.

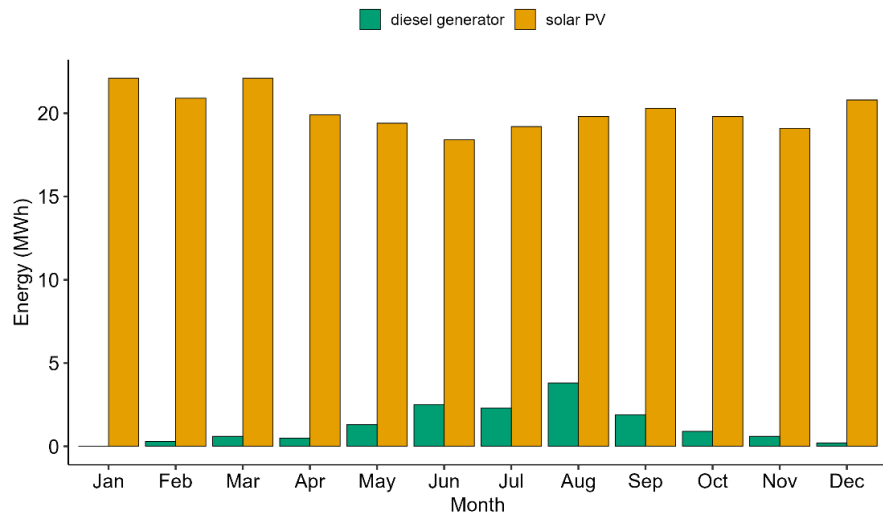


Figure 11. Show monthly energy contribution from system components to meet the demand for Damba Island.

The results also showed that for months like January and December during the dry season, diesel utilization was minimal especially for Koome Island system while notable use of diesel was traced between May and September-rainy season, especially for the Damba Island. In terms of affordability of power, reference was made to studies that highlighted that off grid tariffs are slightly higher than national grid end user tariff often availed by Electricity Regulatory Authority (ERA). Particularly for mini grids, consumers were willing to pay between 600 – 1200 UGX/kWh equivalent to 0.16 - 0.32 €/kWh for electricity cutting across various categories [15].

This was also confirmed by the response from the survey where different customers indicated amounts, they were willing to pay to have reliable electricity. Moreover, reference was also made to the monthly income of respondents to compute the affordability especially for the domestic customers. With at least 67% of respondents earning between UGX100,000 - 1000,000(refer to **Figure 8**), affordability of electricity was considered if 10% of the monthly income was used to cater for energy needs For other categories, willingness to pay amounts were still based of survey information and literature from other islands benefiting from mini-grids like Bugala island, operated by Kalangala Infrastructure Service [34]. **Table 6** shows the summary of results on affordability of the electricity that per category in line with meeting the energy demand on a monthly basis.

Table 6. Summary of Affordability of electricity for categories.

| Sn | Category | Cost of kWh from mini grid (UGX/kWh) | Willingness to pay (WTP) (UGX/month) | Computed amount to be paid (UGX/month) | Subsidies considered 50% (UGX/month) | Subsidized amount (€/month) |
|----|---|--------------------------------------|--------------------------------------|--|--------------------------------------|-----------------------------|
| 1 | Domestic(H/H) | 800 - 1200 | 10,000 - 30,000 | 44,000 - 66,000 | 22,000 - 33,000 | 5.83 - 8.75€ ¹ |
| 2 | Commercial | 900 - 1200 | 50,000 - 200,000 | 108,540 - 144,720 | 54,270 - 72,360 | 14.39 - 19.18€ |
| 3 | Productive use | 600 - 1000 | 200,000 - 700,000 | 285,600 - 476,000 | 142,800 - 238,000 | 37.86 - 63.10€ |
| 4 | Institutions; schools and Health centre | 700 - 1000 | 50,000 - 300,000 | 324,100 - 463,000 | 162,050 - 231,500 | 42.97 - 61.38€ |

As mentioned, the computed amount to be used per category to meet the energy demand monthly was obtained with reference the monthly electricity demand for each category as summarized in **Table 6** and the WTP amount for each category. Thus, reference was made to Equation (8).

$$Am = Ecat * WtPcat \quad (8)$$

where Am = Amount paid per month, Ecat energy demand per category/month and WtPcat amount that each category is willing to pay for a kWh.

For Domestic category = 55 kWh/month*800 UGX = UGX 44,000 = 55 kWh/month*1200 UGX = UGX 66,000.

A similar approach was used in computing the amounts to be paid per month for each of the categories. From the results indicated in **Table 6**, it is clear that monthly amount that would be paid by the domestic/H/H was higher by at least UGX 14,000 in reference to WTP threshold value of UGX 30,000/month. A similar stance could be seen for institutions, where the monthly amount due was UGX 24,000 more than the threshold value of UGX 300,000. Implying that for domestic and institutional categories, electricity sale to users on a monthly basis was not affordable. This was not surprising given that studies indicated that for solar mini grids, most private sector developers had asserted that they were not breaking even and this resulted in the current trends, where Government of Uganda (GoU) heavily subsidizes production of electricity from mini grids.

GoU subsidies for mini grids between 50% - 70% have been considered in addition to promoting adoption for productive use of energy measures [12] [14] [29]. Thus, in this study, a subsidy of 50% (to reduce upfront initial investment costs, connection fees, system performance verification, solar components and mini grids) was considered and this resulted in the affordability of electricity for both domestic/HH and institutional categories falling within the monthly thresholds of 10,000 - 30,000 (subsidized amount UGX 22,000 - 33,000) and 50,000 - 300,000 (subsidized amount UGX 162,050 - 231,500) respectively.

4.2. Sensitivity Analysis

The sensitivity analysis carried out factored in the assumptions initially stated of 50% penetration rate of electricity from the systems for households, 12% increase

¹Exchange rate considered 2022 last quarter; 1 Euro (€) = UGX 3771.52.

in energy demand for both commercial and productive use categories and 25% growth in the institutional category. As such, energy demand ramps up for each of the islands was estimated with Koome Island having an increased demand from 1032 to 1446 kWh/day and Damba ramping up from 452 to 842 kWh/day respectively.

Furthermore, reference to criteria for assessment of feasibility, which included reliability of power consisting at least 93.6% - 95% energy availed by renewable energy source, an IRR of at least 12%, PBP of less than 10 years was taken into account. In addition, following the trends in the solar energy subsector in Uganda and globally where the overall cost of system components continues to reduce and studies indicate that subsidies have been offered by government for mini-grids between 50% - 70%, the discount rate was also adjusted to 8% from 10%. The sensitivity analysis results showed that for Koome island, at least five (5) system options were feasible, while for Damba island, only three (3) system options were feasible still consisting of hybrid systems PV + DG + BS + CV as key components shown in **Table 7** and **Table 8**.

Table 7. Summary of optimized system options-sensitivity assessment Kome Island.

| Architecture | | | | Cost (€) | | | | System | Project economics | |
|--------------|---------|------|------|----------|--------|---------|--------|---------|-------------------|----------|
| PV (kW) | Gen(kW) | 1kWh | Conv | NPC | LCOE | O&M | CAPEX | Ren/F % | IRR (%) | PBP (yr) |
| 625 | 230 | 1320 | 212 | €3.16M | €0.245 | €28,365 | €2.47M | 93.9 | 13 | 6.7 |
| 620 | 230 | 1267 | 189 | €3.14M | €0.244 | €29,571 | €2.42M | 93 | 14 | 6.6 |
| 620 | 230 | 1267 | 189 | €3.14M | €0.244 | €29,571 | €2.42M | 93 | 14 | 6.6 |
| 614 | 230 | 1269 | 183 | €3.17M | €0.247 | €31,648 | €2.40M | 92.9 | 15 | 6.2 |
| 614 | 230 | 1269 | 183 | €3.17M | €0.247 | €31,648 | €2.40M | 92.9 | 15 | 6.2 |

The results summarized in the **Table 7** showed that for Koome Island, the **NPC** definitely increased to **3.14 million € from 2.24 million €**. However, economies of scale definitely played a role since the overall capacity of the system during the ramp up scenario was significantly bigger than in initial scenario (refer to the architecture-).

Furthermore, **LCOE** reduced from **0.29 €/kWh to 0.24 €/kWh**, the **IRR** also reduced from **19% to 15%** while the **PBP** increased by 1 year. This could be due to adjustment of the discount rate yet there were increments in the cost of purchasing key components such as PV panels, batteries etc.

Table 8. Summary of optimized system options-sensitivity assessment Damba Island.

| Architecture | | | | Cost (€) | | | | System | Project economics | |
|--------------|---------|------|------|----------|--------|---------|--------|---------|-------------------|----------|
| PV (kW) | Gen(kW) | 1kWh | Conv | NPC | LCOE | O&M | CAPEX | Ren/F % | IRR (%) | PBP (yr) |
| 324 | 140 | 1224 | 111 | €2.10M | €0.277 | €21,107 | €1.59M | 95.9 | 13 | 6.8 |
| 320 | 140 | 1217 | 113 | €2.11M | €0.279 | €22,131 | €1.57M | 95.7 | 14 | 6.4 |
| 322 | 140 | 1208 | 110 | €2.12M | €0.279 | €22,389 | €1.57M | 95.7 | 14 | 6.2 |

In reference to the 3 feasible system options for Damba Island (**Table 8**), a similar trend to Koome Island could be traced with reduced **IRR from 24.8% to 13%**, increased **PBP from 4 - approximately 7 years**, increased **NPC from 1.58 million € to 2.12 million €** and reduced **LCOE from 0.4789 €/kWh to 0.279 €/kWh** although the rate of renewable energy fraction increased from **94% to 95.7%** also highlighting the reliability of the systems optimized.

From the results, it would suffice to say economies of scale played a role since the capacities of components increased although overall NPC increase was by about 70% while the IRR still were above threshold set of 12% and PBP was still below 10 years for all optimized system options. Overall, the most feasible options for both Islands are solar-diesel hybrid systems with capacity ranging from 650 - 950 kW and 300 - 470 kW for Koome and Damba Islands respectively.

5. Conclusion and Recommendation

The purpose of the feasibility study was to investigate whether off-grid systems could be considered for island communities such as the Koome and Damba. The islands of Koome are cut off from the main grid and, yet they are bustling with economic activities, but require various services ranging from social, cultural, educational as well as sanitation/health. Following the COVID-19 pandemic that affected the country, a new normal was adopted for all sectors and yet communities like Koome, which are off the grid were still expected to cope, a reality that was daunting.

A holistic approach that combines technological innovation, financial inclusivity, local participation, environmental consciousness, and strong policy backing is essential in ensuring that off-grid solar hybrid mini-grids are sustainable and transformative for isolated communities. Hence, the authors adopted a cocktail of methods to support the feasibility assessment, and these included both qualitative and quantitative methods not limited to surveys, focus group discussions, conducting interviews, supported by the use of other tools such as STATA/Excel, Homer Pro for micro/mini grid system design, sizing and optimization.

The key findings of the study indicated that it was indeed feasible to establish two solar-diesel hybrid mini-grid systems for the Islands of Koome and Damba with capacities of **650 - 950 kW and 300 - 470 kW** respectively.

The systems which can be developed using a modular approach, would have an **NPC between 1.58 and 2.246 million €**. The systems were also considered reliable since autonomy hours ranging between **17.7 - 25.5 hours** approximately 1 day and having a renewable energy penetration of at least **94%** in addition to having diesel generator as part of the system components. In terms of electricity affordability from the system for the customers, a subsidy of **50%** would be necessary to ensure affordability of electricity for domestic and institutional categories. While, no subsidies were initially necessary in assessing affordability of electricity for the commercial and productive use categories although inclusion of the subsidies could further enhance electricity uptake for these categories.

Enhancing productive use options such as boosting fish preservation, agro-processing, value addition for dairy products would be critical. Sensitivity analysis results further confirmed that best system options would be solar-diesel hybrid systems for both Islands and this was depicted by the IRR values ranging from **13% - 15%** which was above 12% threshold considered, **PBP** ranging between **6.2 - 6.8 years**, still lower than 10 years and **LCOE** ranging between **0.24 - 0.27 €/kWh** which was still less than **0.3 €/kWh**.

Ethical Statement

Formal ethical approval was obtained from the Uganda National Council for Science and Technology and Uganda Christian University Research Ethics Committee. This was carried out in accordance with national requirements when conducting studies involving the collection of views from human participants, which require formal clearance and compliance with the Uganda Data Protection and Privacy Act, 2019 (Sections 24 - 28).

During the surveys, interviews, and all engagements, participants were also provided with a structured and translated informed consent forms that included the study objectives, assurance of confidentiality of data collected, request for voluntary participation, and that respondents' identities would not be revealed in the reporting of results. In addition, to encourage participation, the local language (Luganda) was used to elicit participant responses and translation was provided.

Funding Declaration

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Informed Consent

Consent to participate in the study and publish was obtained from participants at various levels of the study i.e. during survey and all stakeholder engagements as was required by the Research Ethics Committee for which approval was obtained under UCUREC-2022-290.

Publication Declaration

Consent to Publish declaration: "Not applicable".

Clinical Trial Declaration

Clinical Trial: "Not applicable".

Data Availability

Data sets generated during the study such as the findings from the survey, modelling data are available from the corresponding author on reasonable request.

Author Contribution: Summary of Author Contribution to Manuscript

Miria Frances Agunyo (MAF) contributed to all technical aspects and discussion of results sections (including methods, energy needs and consumption as well as all economic and technical analysis), detailed alignment of paper and review of manuscript.

Inken Hoeck (IH) contributed to discussion in introduction, abstract section, alignment of manuscript and review.

Elizabeth Balyejusa Kizito (EBK) and **Stephen Kyakulmbye (SK)** worked on the qualitative and quantitative analysis of results including aspects on survey. EK further contributed to discussion of results section including social demographic and livelihood aspects in the manuscript.

Elmar Steurer (ES) contributed to the economic and financial discussion, review of manuscript and alignment of sections on technical assessment.

Jeremy Waiswa (JW) contributed to methodology and data management analysis sections of the manuscript and also on discussion/results for Socio-demographics of Koome and Damba Islands.

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Conflicts of Interest

The authors have no conflicts of interest to declare. The article has never been submitted to another journal for publication.

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