Practical ACTION

THE POWER OF DATA

Assessing operational energy use in camps to inform the design of alternative renewable energy

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Practical Action: Transforming lives, inspiring change

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About Practical Action

We are an international development organization putting ingenious ideas to work so people in poverty can change their world.

We help people find solutions to some of the world's toughest problems. Challenges made worse by catastrophic climate change and persistent gender inequality. We work with communities to develop ingenious, lasting and locally owned solutions for agriculture, water and waste management, climate resilience and clean energy. And we share what works with others, so answers that start small can grow big.

We're a global change-making group. The group consists of a UK registered charity with community projects in Africa, Asia, and Latin America, an independent development publishing company and a technical consulting service. We combine these specialisms to multiply our impact and help shape a world that works better for everyone.

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THE POWER OF DATA

Assessing operational energy use in camps to inform the design of alternative renewable energy

Introduction: the energy data imperative for informing renewable energy options

In the absence of more reliable data from a greater number of agencies, any estimates of energy costs associated with complex humanitarian situations – or of the potential to effect savings – will be highly flawed (Grafham and Lahn, 2018).

The Moving Energy Initiative (MEI) estimated a potential saving of US$ 517m annually for the humanitarian sector if improvements were made to current energy provision and transportation (Grafham and Lahn, 2018a). Despite institutional commitments to energy efficiency and use of clean energy, many agencies are only able to pursue these objectives for their headquarters, while their field operations, where most energy is used, lag severely behind (Grafham and Lahn, 2018). In emergency response, institutional and operational energy needs are often addressed by means of oversized, costly, polluting diesel generators. Load requirements are not easy to predict in a constantly changing crisis environment but these short-term energy solutions are being employed far longer within camp environments than is efficient and effective in meeting long-term energy needs.

With the average lifetime of a refugee camp being 17 years, there is a responsibility on the humanitarian sector to create an enabling environment that supports the transition of emergency-deployed energy systems to cleaner, more efficient systems in protracted contexts. Currently the challenge in realizing this is that energy consumption in camps is not systematically monitored to benchmark current and future energy requirements; and there are limited behavioural incentives for this. Quality control and reliability of energy provision are limited by an absence of or unclear contractual obligations for energy operations and maintenance. Inflexible procurement policies and annual funding cycles make it challenging to secure long-term investment in new energy infrastructure.

Short-term energy solutions are being employed in camps far longer than is efficient and effective

Recognizing the need for change, Outcome 4 in the UNHCR *Global Strategy for Sustainable Energy* calls for 'energy-efficient technologies and renewable energy to meet the electricity needs of communities'. The strategy advocates use of hybrid or fully renewable mini-grids, integration with national grids, or decentralized energy solutions over diesel generators, depending on their appropriateness within the local context. It also promotes a culture of energy efficiency and energy metering at all institutions (UNHCR, 2019).

In order to deliver on these ambitions, clear, standardized, and relevant camp energy monitoring data is needed to inform and build confidence in alternative, renewable energy strategies. This case study details the energy assessment that was done on the set-up and energy use of the existing diesel powered mini-grid system in Nyabiheke refugee camp. The objective of this first stage of work was to provide a baseline of the current energy model in Nyabiheke in order to be able to comparatively demonstrate the viability of alternative renewable energy sources that would mitigate the use of diesel generators, reduce both the expenditure and greenhouse gas emissions of the existing system, and introduce electricity access to camp facilities currently without power (e.g. schools and water, sanitation, and hygiene (WASH) facilities).

In order to deliver on these ambitions, clear, standardized, and relevant camp energy monitoring data is needed.

Energy assessment in Nyabiheke refugee camp

Nyabiheke refugee camp, also known as Gatsibo refugee camp, is located in Gatsibo district in the eastern province about 130km from Kigali, Rwanda as shown in Figure 1. It hosts close to 15,000 Congolese refugees in over 3,000 households. The camp is located in a rural, remote location and spans an area of approximately 5 hectares. For administrative purposes, the area is divided into eight 'quarters', each of which has households, businesses, and common facilities such as halls, places of worship, and WASH facilities (toilets, showers, and water dispensing stations, etc.). Most institutions are centrally located in the camp with the inhabitants and their service infrastructure distributed across the surrounding quarters. Currently the camp is not connected to the Rwandan National Electricity Grid although the MINEMA (Ministry in Charge of Emergency Management) office, located at the camp periphery, is connected and there could be an extension of the grid in the future.

Figure 1 Location of Nyabiheke (Gatsibo) Refugee Camp

A previous survey (Practical Action, 2020) done in 2018 as part of the Renewable Energy for Refugees (RE4R) programme [1] reported that institutional lighting and electricity in Nyabiheke refugee camp is primarily provided by two diesel generators (only one working at a time). However, sometimes these generators are not operational due to maintenance issues and this has an effect on the consistency of power supply. Moreover, the survey pointed out the unequitable access to electricity. Only a few camp facilities and offices are connected while other community facilities such as schools, churches, WASH facilities, and businesses lack access to the diesel mini-grid and depend on lanterns or solar home systems. A need for more access was identified, especially for community facilities and enterprises which could provide new opportunities for improving refugee livelihoods.

This case study was done as part of the RE4R Intervention IV: Solar power for institutions, community facilities, and enterprises, whose objective was to support market-based supply of electricity to institutions and community facilities while mitigating the continuing usage of diesel and providing new (and equitable) access to those currently without electricity. [2]

A need for more electricity access was identified, especially for community facilities and enterprises.

This energy assessment collected data on the set-up and electricity use of the existing diesel powered mini-grid system in Nyabiheke refugee camp. The assessment also looked at unmet needs (such as enterprises and community facilities that were not connected to the current grid). This information was then used to provide a baseline comparison to analyse the viability of alternative renewable technical designs, financial options, and business and ownership models for future electricity services in the camp.

Overview of the energy assessment

Figure 2 shows the overall approach undertaken during this study in Nyabiheke refugee camp. The core of the methodology involved electrical data logging. However, a variety of other data gathering tools were used alongside data logging and these included direct observation and frequent consultations with stakeholders in the camp. These discussions were aimed at gaining a holistic understanding of the electricity consumption on site as well as to gather information on the administrative governance/ownership structures, operational data, and the roles of stakeholders in the existing electricity generation and distribution system. The approach has been split into five phases and their respective activities are detailed in the following sections.

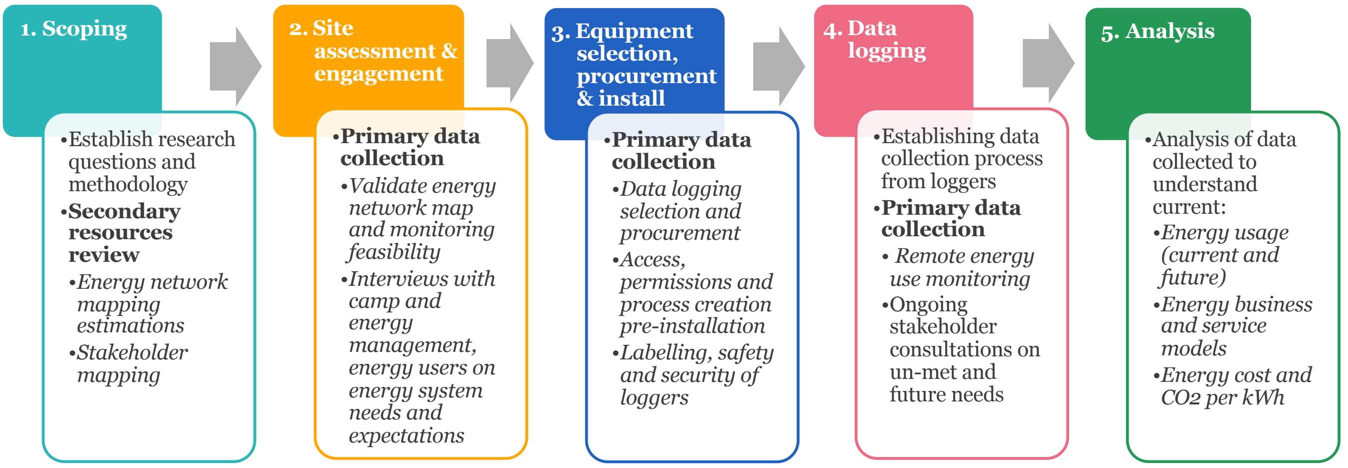


Figure 2 Nyabiheke energy assessment methodology

Phase 1: Scoping

Key research questions were established to help us work out what we need to monitor to create the desired output(s). Ultimately the feasibility study aims to find out, *'Can the current or future electricity demand be met with lower cost and/or environmental impact?'*

Before we could assess renewable energy options for Nyabiheke camp we needed to find out the current electricity situation to create a baseline for comparison as well as the future projections for electricity generation and consumption. Figure 3 outlines the research questions to provide this information and this case study focuses on providing the methodology and data collected to answer those questions. The fourth research question has yet to be completed and is discussed below.

During this scoping phase we used existing resources to create a basic electricity network map to estimate data monitoring requirements and to identify further primary research requirements to fill electricity data gaps across Phases 2–4. It was determined that data loggers were the most appropriate method of data collection to capture an accurate picture of electricity consumption within Nyabiheke (with its feasibility validated through the site assessment in Phase 2).

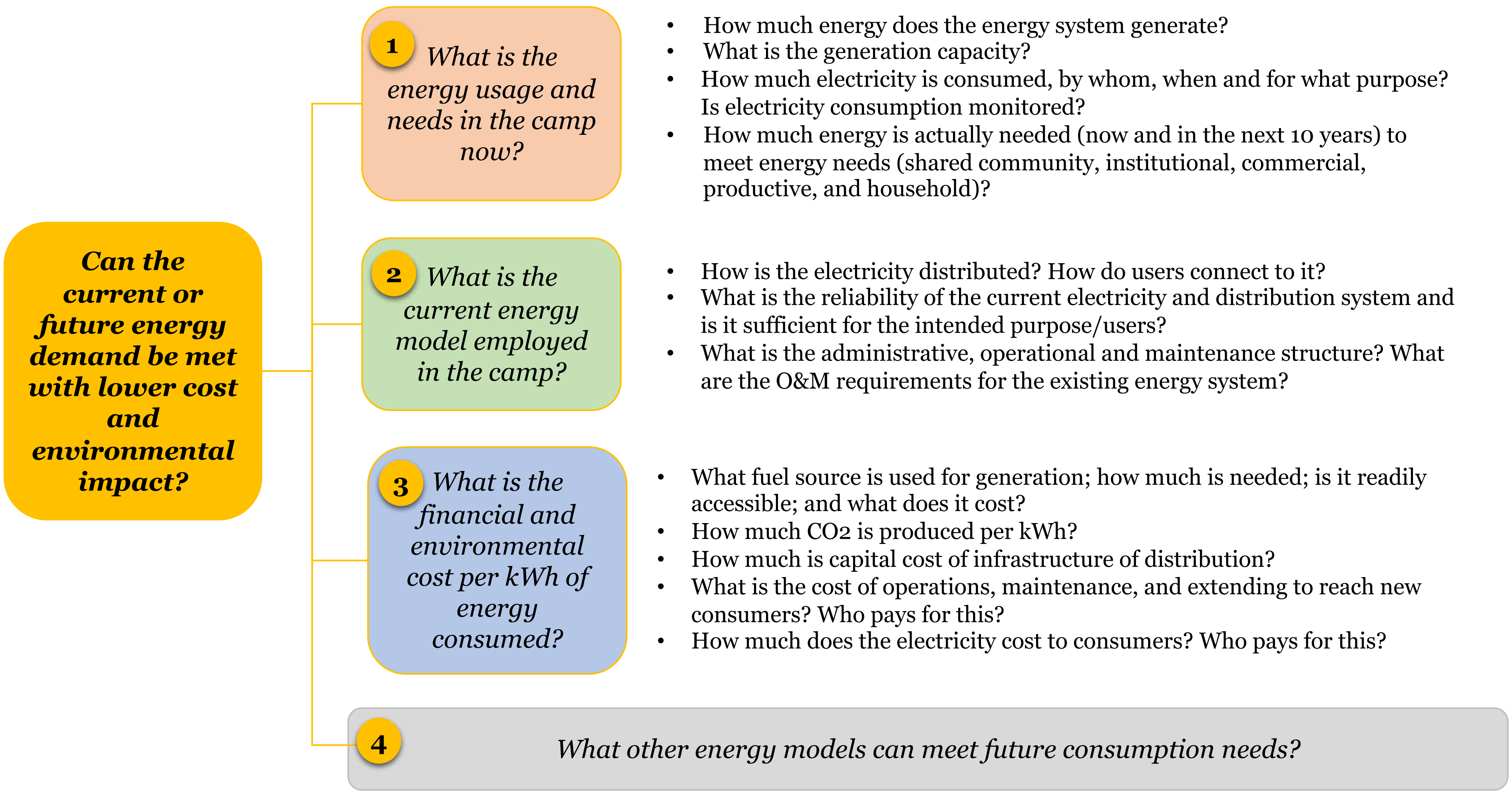


Figure 3 Energy feasibility study research questions

Phase 2: Site assessment and engagement

A rapid on-site assessment verified the current electricity model map and locations for data logging. The locations identified (Figure 4) covered almost the entire network and the only consumers that were not logged individually were too small (1–2 lamps). However, any loss of consumption data was mitigated by installing a logger at the feeder in the generator room to measure the total consumption of all connected users.

Figure 4 Data logging locations across the energy network

Project intentions and data logging requirements were shared to set expectations and gain approvals for monitoring from all relevant stakeholders. In Nyabiheke, the key stakeholders were UNHCR, MINEMA, Alight (formerly American Refugee Committee (ARC)), and consumers connected to electricity. The list of identified data logging locations with the required access was shared with onsite stakeholders to gain their approval and suggestions. The enterprises were also individually contacted to get their approval and provide information on the purpose and functioning of the data loggers. Everyone contacted in this regard was supportive and the only concern raised was about management of power outages during the installation. As such the installation was designed to minimize outages and was scheduled, coordinated, and communicated with Alight and the Health Centre.

Phase 3: Equipment selection, procurement, and installation

The meters had to be suitable for the monitoring needs, be available at an affordable price, and be easy to procure in Rwanda. Based on the initial site assessment, the Smart Mac series data logger was deemed the best suited device to meet monitoring needs at an affordable price and was easy to procure. Its main drawbacks were that it had a very small onboard memory such that frequent internet access was required to transfer recorded data to the supplier cloud server to free the logger's onboard memory. Fortunately, the advantage of these devices is their use of the MQTT data protocol which is especially suited for areas with limited internet connectivity. [3] A local technician was hired to assist with the installation of the meters. Electrical line diagrams were prepared to plan

The Smart Mac series data logger was the best suited device to meet monitoring needs at an affordable price

Data logging was completed over 12 weeks

the installation. The devices were installed in isolated enclosures as shown in Photo 1 to prevent unauthorized tampering and reduce vandalism risk.

Photo 1 Encased data loggers

Phase 4: Data logging

An onsite data collection routine was established with the Practical Action Field Officer at Nyabiheke to ensure that the data loggers were able to regularly upload their data before their memory was at capacity. Unfortunately, the transfer of data to the cloud server was not an automated process. The field coordinator had to go with a Wi-Fi router to each data logger (every 10 days) and a schedule was established for this. The data was then downloaded from the supplier cloud server which is remotely accessible. From a data security perspective, this supplier server was accessed with a username and password. This data was then downloaded and stored on a secure SharePoint. We did not consider other specific security requirements because no personal or sensitive data was collected to ensure that data may be shared more widely if required. The data logged above was periodically reviewed for quality assurance and analysed to form a usage profile. Data logging was completed over 12 weeks.

During the 12 weeks, stakeholder consultations and interviews were held with Alight, UNHCR, camp managers, high-consuming users, and NGOs (particularly those focused on projects requiring productive and community uses of electricity) to determine unmet and future electricity needs. The appliances that would be used for these consumers were identified and later analysed to form a future load profile.

Key assessment considerations	
	**Managing the scale of data logging.** It may not be feasible or necessary to log all user connections due to cost or time, especially if there are no existing metering systems monitoring consumption. The logging requirements can be reduced by: 1) ensuring the consumption measurement is required for project outcomes; 2) disregarding any connections with almost negligible consumption; and 3) identifying consumption profiles and behaviour in consumer usage groups to extrapolate potential consumption of similar consumers rather than monitoring each individual consumer (ensure a good mix of consumption data from the different types of consumers is captured to build confidence in extrapolation assumptions). In Nyabiheke, the number of users on the system was relatively small at 14 connections so data was logged directly from the larger electricity consumers and usage estimates extrapolated for other consumers.
	**Data storage challenges.** Small onboard memories of some data loggers can mean that data requires manual uploads every few days which can be a considerable commitment for field officers with small teams, multiple user connections, and large areas to cover. In addition, poor internet connectivity can make data challenging to upload at specified times resulting in data loss. Context and resourcing criteria need to be considered when selecting data loggers.
	**Maintaining logging continuity.** Aside from ensuring data loggers are protected against damage and tampering, contact information for site personnel should also be listed on the devices to enable consumers to contact them if required. If issues arise you could collect invalid information without your knowledge or have periods of time in which you will be unable to identify and rectify the issue if you are not collecting 'live' data but storing data for periodic downloads. In Nyabiheke, contact information for the Alight and Practical Action site personnel were listed on the devices to enable consumers to contact them if required.

Phase 5: Energy monitoring analysis and outputs

Current energy consumption

Electrical network diagram. An electrical network diagram was not available on site or with the installers of the grid and was created as part of the scoping study, as shown in Figure 5. This shows the main consumers and the locations of the installed data loggers.

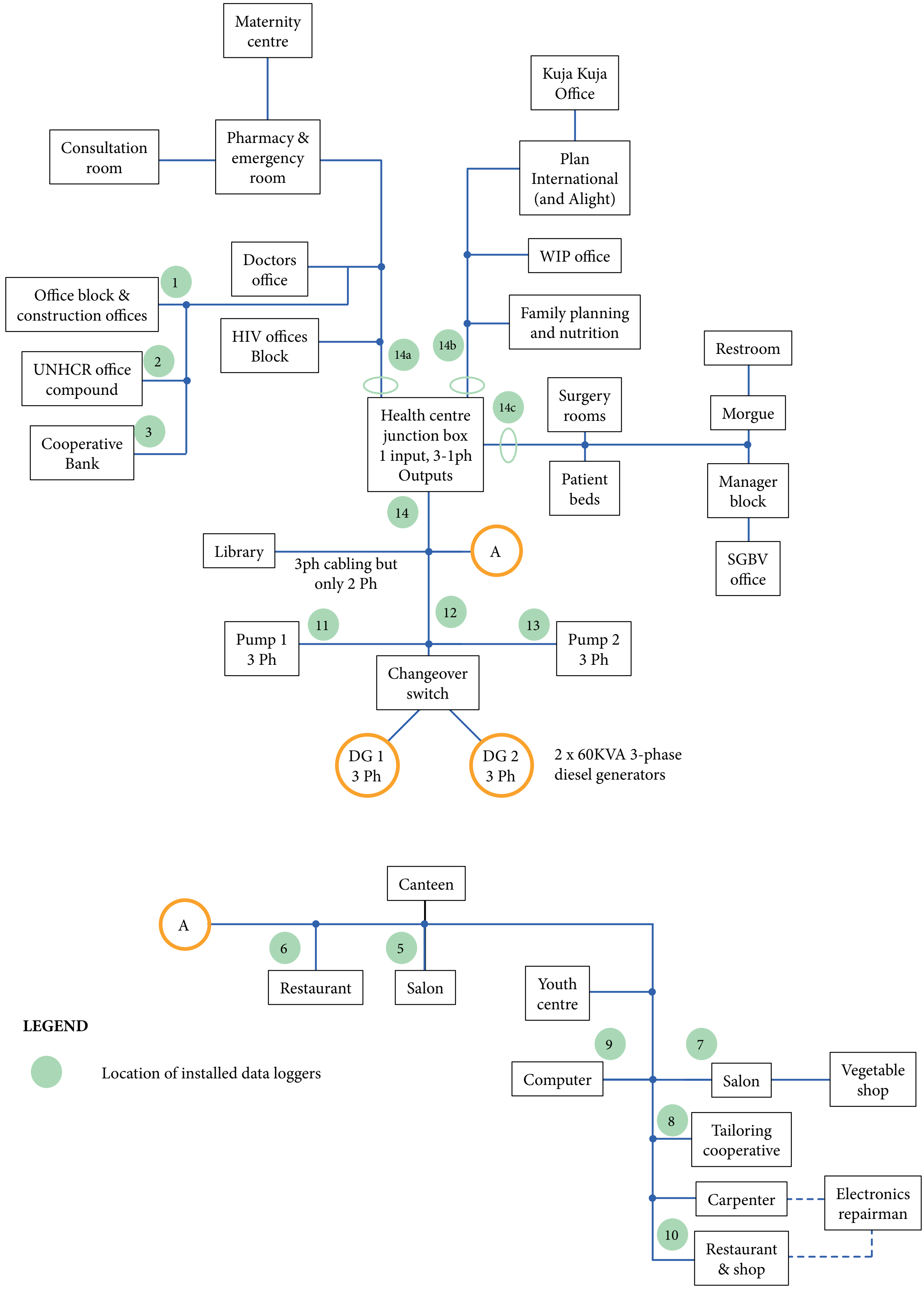


Figure 5 Nyabiheke energy network map

Camp electricity load profile. As mentioned above, the data collection was done for 12 weeks and recording gaps in the logged data were extrapolated for the sake of analysis.[4] It was assumed that there were no seasonal variations throughout the year. The data loggers 11, 12, and 13 are all connected at the generator room and together provide the complete electrical demand picture of the Nyabiheke camp. A generalized 24-h load profile for this existing demand in Nyabiheke is as shown in Figure 6. The average daily load is 10.7 kW with a total electricity consumption of 256 kWh per day.

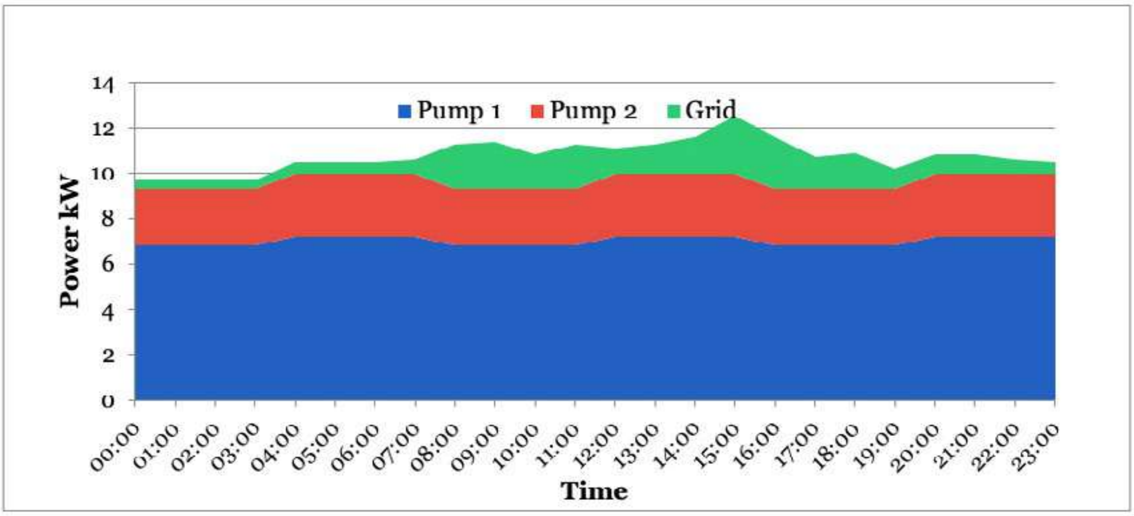


Figure 6 Nyabiheke current electricity 24-h load profile

There is huge inefficiency in the use of the current generators with the maximum instantaneous load about 20 per cent of each generator's individual capacity (60 KVA) which demonstrates that the generators are oversized for the current electricity demand in the camp. Continuous use of under-capacity generators leads to higher fuel costs to run the generators proportional to electricity use; increased technical issues with the generators; and impacts on their lifetimes (IRENA, 2019). At about 20 per cent load capacity, a 60 KVA generator operates at around 15 per cent efficiency compared to over 40 per cent efficiency if it were running at full load (Crainz et al., 2019).

The electricity load profile (Figure 6) shows the total load that can be split into pumping and non-pumping consumption:

- *Pumping load – the largest load is from the two water pumps consuming over 80 per cent of the total electricity.* The pumps runs close to 24 hours a day, every day. They have a fairly constant, unchanging, and stable load with total average consumption of 6.5 kW for Pump 1 and 2.5 KW for Pump 2. When running normally, Pump 1 consumes over 150 kWh per day and Pump 2 over 60 kWh per day.
- *Non-pumping load – the largest load is the health care centre followed by refugee enterprises such as hair salons.* The non-pumping load is quite variable, primarily due to varying health centre demand as well as the number of various users connected to the grid with differing usage profiles. Institutional offices consume very low levels of electricity (<0.5 kWh/day) primarily for lighting and charging phones and laptops. Enterprises have a larger daily demand (each between 2 and 6 kWh) using low power appliances.

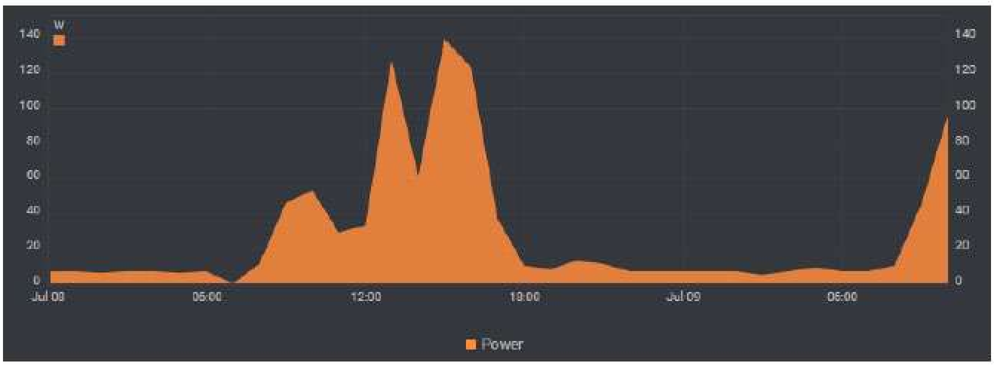
Continuous use of under-capacity generators leads to higher fuel costs

Within Nyabiheke there are four consumer electricity groups

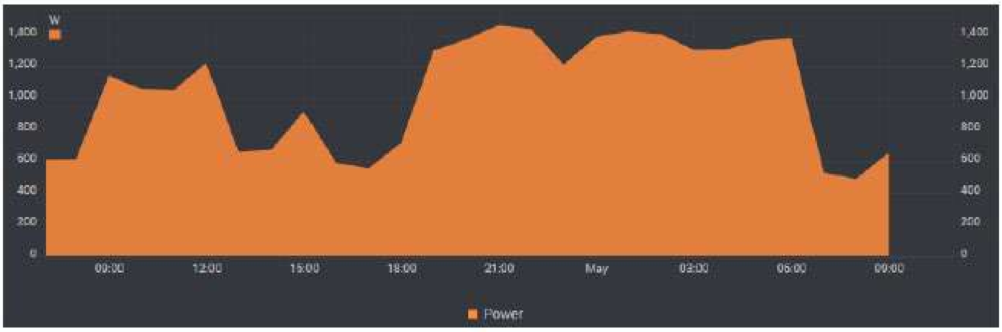
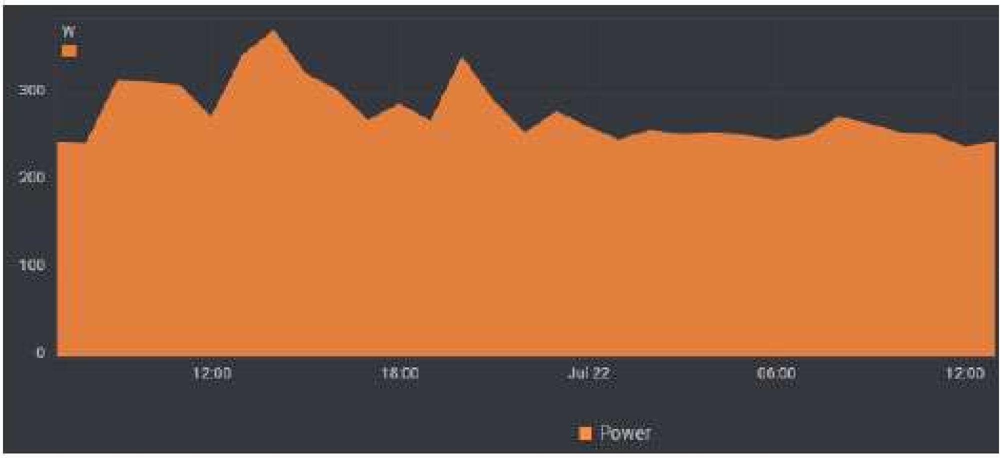
Consumers: Segmentation of usage patterns and efficiencies. Electricity is available 24/7 to the connected users as long as the generator and distribution systems are working. Within the camp there is currently no formal policy on usage limits for connected users and no load limiters or metering equipment installed to monitor or verify estimated usage. The only visible constraint is on new connections. No other users are currently allowed to connect to the network, even when they are willing and able to do so, and there is no clear technical or financial rationale provided for this, particularly when the existing diesel generators are operating at a fraction of their design capacity.

Within Nyabiheke there are four consumer electricity groups. Table 1 details the electricity consumption characteristics of these groups and provides electricity usage profiles logged in this assessment to exemplify how behaviour and function of a facility or consumer influences electricity usage. The different shape of the load profiles allows us to identify peak loads which the total capacity of the system needs to be able to meet. The peak and trough nature of the institutional and enterprise electricity use could be supported by, for example, solar generation, as the electricity generation mirrors the usage profile and hence less back-up power (or storage) would be needed. However, the water pump load is essentially constant over 24 hours so more storage and backup would be needed if using solar energy to ensure pumping continued outside of peak solar generation hours.

Table 1 Electricity consumers' segmentation in Nyabiheke refugee camp

Consumer type	Consumer energy profile
Institutional offices for organizations such as UNHCR, World Vision, ADRA, Alight, MINEMA, PLAN, WfP, H&I, Practical Action, Cooperative Bank	• Small offices occupied by one person with many field-staff who predominantly work outside the office. • Loads are typically from lighting (LEDs), power sockets for charging phones and laptops, and small electronics like card readers. • Occasional use of basic photography/lamination machines for a few hours when processing refugee travel documents.  *Figure 7* 24-hour electricity usage in the office block

(table continues overleaf)

Consumer type	Consumer energy profile
Shared community facilities which include water pumping stations, a computer lab, health centre, and youth centre	• The water pumping stations have two 3 phase water pumps which provide water to centralized locations which can be accessed by all people living and working in the camp. • The Youth Centre has: – loads that are mainly from lighting (though most lamps are not working); – music and sound systems that are used occasionally; – a computer lab with a dozen desktop PCs but discussions reveal that only a few PCs are ever used and no regular ICT training sessions are scheduled. • The Health Centre contains many offices such as doctors' offices, a laboratory, maternity ward, and waiting room. – loads primarily from lighting and a few medical and laboratory devices; – two fridges but not using electricity from the network; – diagnostics rooms containing 10 infrequently used machines (scales, microscope, blood testing systems, vial shakers, etc.)  *Figure 8* 24-hour electricity usage of the health centre
A few businesses run by refugees, who were granted electricity access as a one-off livelihoods improvement programme by Alight	• < 10 enterprises comprising hair salons, restaurants, small shops, a carpenter, and a tailoring cooperative that depend on energy to deliver their services and generate revenue. • Loads used include LED lamps, laptops, fridges, hair clippers, a clothes iron, music systems, and phone charging (generating revenue as a secondary service). • Single phase connections have been made available by Alight.  *Figure 9* 24-hour electricity usage of a restaurant
Informal 'illegal' connections	• While there is no official connection policy, a few nearby churches are sometimes connected to the network 'illegally'. Such connections are, however, temporary and swiftly disconnected upon being discovered.

Future grid layout and load estimation

The future load profile design was heavily influenced by an increase in connected businesses and productive use of energy (PUE) equipment such as a cassava leaf grinder, fridge freezers, computers, and other electronic equipment (each with a power requirement of 500–1,500 W). The future load profile also included several common facilities including halls, schools, churches, and WASH facilities which presently lack access to electricity. The additional load was estimated through the power requirement of the different appliances and validated by the power actually being used by similar businesses and facilities.

Since most of the projected productive use loads, such as the cassava leaf grinder, are intermittent loads, the electricity required by these consumers is not a direct extrapolation of their power over time. Instead, the actual likely running time of the various appliances/machines over an hour needs to be factored into the electricity usage calculation, which was done using a correction factor. These load profiles of the additional projected consumer types were combined with the existing load on site to create the future average load profile as shown in Figure 10. The future electrical load on site is estimated to be about 16.8 kW average consumption with a daily electricity consumption of 403 kWh (about 1.6 times the current electricity consumption).

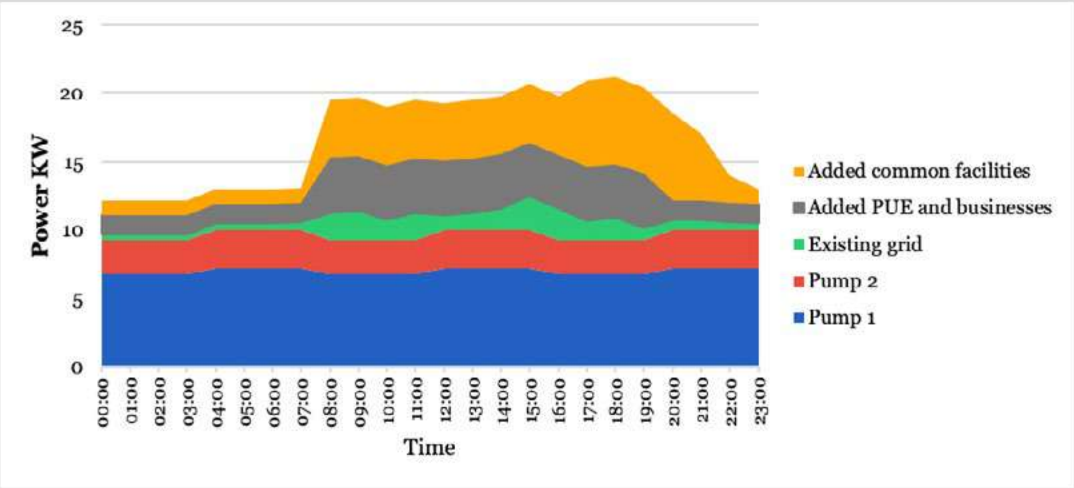


Figure 10 Proposed average daily load profile of the solar mini-grid

Current energy model

Electricity generation. Electricity is primarily generated by two 3 phase 60 KVA diesel generators (Photo 2) located outside the camp at the southern base of the hill on which the camp is located. These two AC generators operate at a frequency of 50 Hz and a nominal voltage of 230 V. The generators run alternatingly for 4 hours each, 24 hours a day, due to their current mode of operation. However, this operation strategy is quite inefficient and, in reality, regular maintenance would have been more effective. A changeover switch is used to select one generator or the other. Once the active generator is turned off there are a few seconds of complete black out before the other generator kicks in.

Photo 2 Nyabiheke camp generators

The generators are manually refuelled and no external fuel storage tank was found. This means that the diesel generators have to be refuelled very often due to the insufficient inbuilt storage capacity of the generators. The generators are also manually operated and do not have any automatic or remote start capability, communications device or supervisory controller. This is important because if the current generators are to be integrated with a renewable energy system, then they will have to be retrofitted with appropriate smart centralized control systems or replaced with generators capable of handling hybridization (that is a system with the ability to manage energy generation from two sources, both diesel and renewable).

Electricity distribution. The distribution grid spans a little over 1 km in length and provides single phase power supply to its connected users. It largely uses 4 x 25 mm2 copper cable mounted on wooden poles that are spaced about 40—50 m from each other depending on the location. While the grid extending into the camp is capable of 3 phase power transmission, only two phases are connected to the generators. [5] The grid has been extended over time in an 'organic' fashion. Much of the cabling, especially the service lines to consumers are connected incoherently making them difficult to follow. An electrical network diagram was not available on site or with the installers of the grid and had to be created as part of this study.

Energy asset ownership. The existing electricity generation and distribution network (as described above) is owned by UNHCR. The generators are part of UNHCR's asset inventory which are usually procured for the purpose of camp operations and are rarely sized to the specific demand. Some demand side equipment such as internal wiring of institutions and common facilities is also paid for and owned by UNHCR. However, in the case of enterprises, the internal wiring and appliances were paid for (and owned by) the enterprises themselves or partner financing institutions, such as Alight.

Operations and maintenance (O&M). Responsibility for the operation and maintenance of the entire electrical network lies with the NGO Alight operating in the camp. Alight comprises four pay-rolled permanent staff (three of whom are refugees) and is mandated to:

- manage the operating costs of the grid;
- purchase and transport fuel (UNHCR pays for this);
- maintain and service the generators; and
- manage the upkeep of the distribution network as well as respond to outages.

Alight manages various services for UNHCR which has an informal agreement with Alight to deliver on this O&M mandate. Apart from the four employees on the Alight payroll, there are no other contractual obligations in place nor have any maintenance or service contracts been agreed for the generators. All scheduled and unscheduled maintenance or service requests are made by Alight to UNHCR, who dispatch an in-house service team as required. Sometimes a third party technician (not employed by Alight) is informally called upon by Alight, when required, for servicing and repair of the system.

Alight estimates that 840 litres of diesel are used on average per week for the diesel generators only. Diesel usage is documented by the operators in an onsite log book. Alight uses trucks to transport approximately 42 jerry cans of fuel each week as shown in Photo 3. Larger transportation tanks were experimented with in the past, but were found difficult to handle, thereby settling on this method.

Alight estimates that 840 litres of diesel are used on average per week

Key concerns on the current O&M approach expressed by Alight were:

- *Safety and continuity issues of frequently transporting and storing diesel* in this manner particularly given poor road quality and inaccessibility risks during rainy seasons.
- *Lack of a routine maintenance plan and minimal preventive maintenance* measures consisting only of alternating the generators every 4 hours to prevent overheating.
- *The inability to manage all servicing requirements.* Alight is responsible for running other services in the camp such as healthcare, water, and sanitation; hence the overall running of the electrical network including managing faults, operations, and users is at times overwhelming.

Photo 3 Transportation of diesel jerry cans

Financial and environmental cost per kWh

When conducting the study, the main stakeholders, especially UNHCR and Alight, didn't know how much was spent on both capital and operating costs on the current diesel-based mini-grid in the camp. Table 2 shows the breakdown of the different costs. The total annual operating cost (diesel, transportation, and staffing costs) was estimated to be $53,160. This estimate is quite conservative as other running costs such as maintenance and replacement are not included because they are unknown and no records of this exist. The net cost of electricity production in the current scheme of operations was estimated to be RWF 532 ($0.57)/kWh. This is based on the total operational cost of $53,160 per year and the average daily consumption of 256 kWh/day (93,732 kWh/year). This net cost of electricity is over double the Rwanda national grid tariff (approx. $0.24/kWh).

(table 2 is overleaf)

Table 2 Financial and environment costs of current energy system in Nyabiheke refugee camp

Item	Estimated cost	Notes
Investment and O&M costs		
CAPEX	**RWF 900,000–19,000,000 ($10,000–20,000)**	This was not documented from the outset. The generators are part of UNHCR's asset inventory which are usually procured for the purpose of camp operations and are rarely sized to the specific demand.
Annual OPEX	**RWF 49,838,000 ($53,160)**	This includes the cost of diesel consumed by generators, cost of diesel transportation, and cost of service personnel with the breakdown provided below.
Generator diesel	47,655,000	At the time of this study, the cost of diesel was RWF 1,091. UNHCR does not receive any preferential pricing despite the large volume of fuel purchased. Diesel is paid for by UNHCR at each weekly refuelling run. The remaining incidental costs are paid by Alight but reimbursed by UNHCR.
Transport diesel	364,000	
Staff time/ Maintenance	1,819,000	Besides diesel expenditure there is no set budget or tracking for other maintenance costs. When maintenance is not carried out by an in-house UNHCR team, Alight pays for these services. These infrequent costs are bundled with other onsite reimbursements and hence the maintenance costs are not separately available.
Net cost of electricity production		
kWh cost	**RWF 532 ($0.57)/kWh**	kWh cost is estimated based on OPEX alone and does not include a cost for recouping CAPEX as these were unknown. These costs are borne by UNHCR.
Cost to energy user		
Tariffs by user type	**$0**	Electricity is free to all the connected users. UNHCR is the cost bearer for the entire electricity generation and distribution system. As owners of the electricity system, UNHCR policy does not allow them to collect money from refugees. Partner institutions' costs are largely reimbursed by UNHCR and hence UNHCR does not monitor usage or issue bills to users.
CO_2 emissions		
Annual CO_2	**117 tonnes**	The CO_2 emissions just for the electricity generation based on the diesel usage of 43,680 litres/year and the CO_2 emission of diesel as 2.68 kg/litre.

How this data is useful in designing alternative renewable energy options

The next step of the energy assessment in Nyabiheke will be to complete a comparative analysis of alternative energy systems for the camp against the current energy approach. The electricity usage data will allow decision-makers to identify the optimum energy scenario for the camp by allowing the comparison of critical parameters – CAPEX cost, OPEX cost, CO2 emissions, and lifetime of assets – for different energy system technologies and business models. [6] The data collected in such an assessment is very important in the following ways:

Technical design. To design a technically viable mini-grid system, the renewable energy resource availability and the current and future electricity load profile (Figures 6 and 10 for Nyabiheke) are needed. In order for this alternative generation system to service the given load profile, a vast number of sizing options for the various components such as solar, diesel, and storage are available. A platform like HOMER [7] allows for sizing of these components based on the locally available resources, design load profiles, system constraints, and optimisation cases: for example, lowest cost of energy, 100 per cent renewable energy share, lowest capital cost, high renewable energy share (70–90 per cent).

Segmenting the electricity usage in the camps into consumer groups is key, especially for an electricity system like Nyabiheke where the grid has been expanded in a very organic fashion. Knowing the proportion of electricity that each consumer group uses and when they use this electricity will help determine suitability of the different generation components and whether any energy efficiency measures could be employed in a particular consumer group.

The output of the technical design will be the potential capacity of the alternative energy system and this is not only important in determining the cost and economic feasibility, but it also determines the licensing and regulation process that has to be followed before implementation. For example, at the time of doing the assessment, the licensing and regulatory policy in Rwanda exempted mini-grids with a capacity of less than 50 KW from going through the 6 months' regulatory process. Considering the capacity of the system designed, the actual expected future load, and the regulations will all have implications for the project duration and economic feasibility.

Business and ownership models. Data about the current energy model of an electricity system like the one in Nyabiheke pinpoints inefficiencies in how the current systems are sized, procured, owned, operated, and maintained. When designing a mini-grid, it is important to think about what business and ownership will be employed for this new system considering the local context. For example, in Nyabiheke, Alight expressed that since they are responsible for managing other services in the camp, managing the diesel system was quite overwhelming and they would have preferred a model where a private developer builds, owns, and operates the mini-grid. This would mean that the developer would have the capacity and expertise to operate and maintain the electricity system more efficiently. In other contexts, however, a utility model, public–private partnership or hybrid model might work better depending on the local needs, country energy policies, and stakeholders involved.

A key factor that will influence the model choice is who will be paying for the capital and operating cost of the new system and whether refugees will also have to pay for the electricity they use. If the model is like the one in Nyabiheke where the users do not pay for the energy they use, then the implications of moving from this free model to one where refugees would have to pay have to be considered. Along with this, consideration has to be given to the actual tariffs that will be charged, how they compare to the current cost and national grid tariff, and how they relate to the willingness and ability of the different consumers to pay these tariffs.

Financial and environmental design and saving. A financial model has to be developed to evaluate the commercial requirements and economic feasibility of operating the alternative systems designed. Using income statements and cash flow analysis based on the different costs and revenues associated with each of the system designs, the estimated cost of electricity and end user tariffs can be calculated. The cost of electricity per kWh will be used to compare current system cost against the alternative systems designed. In Nyabiheke, the cost of the current system is $0.57/kWh, which is about double the Rwanda national grid tariff (approx. $0.24/kWh). Based on discussions with private mini-grid developers in Rwanda, the price per kWh of electricity from a renewable/hybrid mini-grid ranges from $0.53–0.82/kWh (Castalia and Ecoligo, 2017). These figures can be used to benchmark against the cost of the new designed systems to calculate the savings that come with implementing them. For example, an alternative mini-grid system whose price of electricity is over $0.57/kWh wouldn't provide any cost savings for Nyabiheke, while the national grid would provide over 50 per cent savings on the current cost. The same methodology and benchmarking can be used for environmental savings. The current CO_2 footprint can be compared with the footprint of alternative systems to determine potential CO_2 savings if these are implemented. Baranda & Sandwell (2020) explores this further by providing different economic and environmental decision

A key factor that will influence the model choice is operating cost

metrics for determining the cost effectiveness and environmental savings of implementing a mini-grid in displacement settings.

When doing the technical design, financial analysis, and choosing the ownership and business model, it is key to consider data collected from the stakeholders (administrative, operations, maintenance, consumers, donors, and local and national government). What do they think about the current system? What changes are priority to them in meeting their current and future energy need? What business and ownership model do they think will work? Do their policies allow for this? This data is helpful in determining the optimization criteria for the new system being designed depending on what the priorities are; for example, lowest cost of energy, highest renewable energy penetration. This data is also useful in determining what the roles and responsibilities of the different stakeholders could be in alternative business and ownership models.

Key considerations and recommendations

Every refugee camp will function within a different energy system with its own needs, opportunities, constraints, and behaviours.

The operational and institutional energy set-up and use in each camp will be very different. Along with this, the unmet and future needs, the renewable energy resource, the stakeholders, the model, and the possibilities and policies when it comes to implementation of an alternative system will also vary. Nevertheless, in each context a methodological approach to understanding each camp's specific energy system is needed to create a renewable energy solution that works over the long term.

The type of assessment methodology will vary depending on the context and what the priorities are for building/replacing a mini-grid system.

When planning for such an assessment, it is key to think about what you need to know, what you want to use the information for, and what information is critical vs. helpful. Both a lighter/estimation approach and a more rigorous approach have different advantages and disadvantages. A more rigorous approach was used in Nyabiheke which was suitable because of the way the grid had been extended to consumers and because it enabled disaggregation of energy data into consumer energy profiles, which provided further insight to properly assess the current system. However, it was time-consuming and required technical expertise to set up and analyse. Lighter approaches such as conducting interviews, doing surveys or estimating the electricity load profiles through appliances might be more suitable.

Stakeholder buy-in is imperative to get energy assessment data.

It is important to involve stakeholders right from the start not only to coordinate data collection, gain approvals, and set expectations, but also to get an insight into what they think could be improved in the current system and what their priorities are for an alternative energy system. Given that most of these stakeholders manage or use electricity from the system, they can identify what the met and unmet needs are, what the inefficiencies of the current system are, and what they think would work better in the context.

Going forward we recommend that guidance, tailored for the reality of the field practitioner, be created for energy feasibility studies.

Such assessment and analysis should not be an ad hoc donor exercise but an integrated and embedded part of a systematic drive to improve energy solutions for camp settings across humanitarian operations. Such guidance will be needed to start building the institutional capacity to deliver on UNHCR's *Global Strategy for Sustainable Energy*. This can build on the work currently done by the GPA, the UNDP 7 step process and the MEI Powering Ahead Toolkit (Grafham and Lahn, 2018b).

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Notes

1 https://practicalaction.org/our-work/projects/energy-for-refugees/#:~:text=Working%20in%20partnership%20with%20UNHCR,schools%2C%20health%20clinics%20and%20businesses%2C

2 For the full energy assessment report please contact Practical Action.

3 MQTT is a machine-to-machine (M2M)/'Internet of Things' connectivity protocol. It was designed as an extremely lightweight messaging transport which makes it easier for data to be transferred in remote locations where network bandwidth is at a premium.

4 Raw electrical data can be found at <https://data.humdata.org/dataset/nyabiheke-diesel-based-minigrid-data>.

5 The phase refers to the way power is distributed. Three-phase power transmission systems have at least three wires/conductors carrying current from the generator to the consumer. Connecting only two phases to a 3-phase system can cause an imbalance in the system and affect the connected appliances (especially for big loads). The loads in Nyabiheke are fairly simple and robust hence no usage issues were identified despite reduced line voltage values.

6 The results of the technical design, financial analysis, and comparison of alternative ownership and business model for Nyabiheke will be available in a subsequent publication.

7 This is the state-of-the-art tool used for mini-grid and hybrid system design. https://www.homerenergy.com/products/index.html

The Power of Data:

Assessing operational energy use in camps to inform the design of alternative renewable energy

This case study documents an energy data monitoring exercise performed as part of a wider feasibility study for renewable energy provision in Nyabiheke Camp, Rwanda. It is part of the Renewable Energy for Refugees (RE4R) project which aims to build the case for delivering renewable energy investments in humanitarian settings, working directly with refugees and host communities.

Big change starts small

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