Final report SLE-20186

January 2024

On the path to sustainable health electrification?

Uncovering power quality and reliability challenges at electrified health facilities in Sierra Leone.

Alexandra Wall
Olufolahan Osunmuyiwa
Genevieve Flaspohler
Margaret Odero
Jackson Goode
Noah Klugman
Matthew Podolsky

IGC

DIRECTED BY

LSE

UNIVERSITY OF OXFORD

FUNDED BY

UKaid from the British people

On the path to sustainable health electrification? Uncovering power quality and reliability challenges at electrified health facilities in Sierra Leone

Authors

Alexandra Wall (*n*Line), Olufolahan Osunmuyiwa (*n*Line), Genevieve Flaspohler (*n*Line), Margaret Odero (*n*Line), Jackson Goode (*n*Line), Noah Klugman (*n*Line), Matthew Podolsky (University of California, Berkeley)

Acknowledgements

We are thankful for the support Niccolo Meriggi provided including introductions with policymakers, funders, and implementers involved with healthcare electrification in Sierra Leone. We would also like to thank Paul Yillea for his insights on the energy and health landscape in Sierra Leone and for his support facilitating conversations with the Ministry of Health and Sanitation (MoHS). We are thankful for members of MoHS in their support of this project and the broader effort to improve healthcare electrification, including Mr. Maurice Koroma (Special Adviser to the Minister of Health and Sanitation on Program Quality) and Dr. Syliva Fasuluku (Western Rural District Medical Officer (DMO). Individuals who deserve a special thanks include Josephine Garnem, Joseph Skeff, and Dr. Katy Kuhrt. We sincerely wish to thank Albert Moiwa for his support throughout this project with the installation and maintenance of the GridWatch sensor fleet at each of the monitored health facilities. We would like to thank Lane Powell for her thoughtful review and feedback on this report. Finally, we would like to extend a special thank you to Karen Notsund and Catherine Wolfram for their guidance.

We are grateful for funding support from the International Growth Centre (contract no. C-0002455) and Crown Agents Ltd.

Table of Contents

Executive Summary

Poor electricity access, quality and reliability are major obstacles to the delivery of quality health service in sub-Saharan Africa (SSA). In the last decade and with the onset of the COVID-19 global pandemic, a wave of national and multinational electrification initiatives has emerged to address current electrification gaps in SSA’s healthcare sector. Despite these initiatives interlinking SDG 3 (“ensure healthy lives and promote well-being for all at all ages”) and SDG 7 (“ensure access to affordable, reliable, sustainable, and modern energy for all”), health electrification challenges persist and progress remains slow. Recently, researchers seeking to address current health electrification challenges have highlighted widespread anecdotes of chronically poor power quality and reliability (PQR) on thousands of electrified healthcare facilities in SSA. Poor PQR, encompassing frequent outages, voltage spikes and sags, and other power artifacts, severely hampers the promise of sustainable health electrification. Despite the importance of PQR, virtually all policy and investment proposals on health electrification remain devoid of concrete mechanisms to understand and address PQR challenges and their subsequent impacts on healthcare delivery.

Electricity quality and reliability have lacked the policy attention paid to electricity access in large part because of the absence of affordable methods for collecting PQR measurements at scale. Lacking high-resolution, longitudinal PQR this data, metrics like the number of electricity connections made and data collection using recall-based surveys—neither of which accurately captures on-the-ground realities of quality and reliability—remain the standard approach for measuring electrification progress towards SDG 7. One effect of counting the number of electricity connections as the metric of success is that new electricity investments are channeled towards rural and remote locations, while health facilities in urban areas—which this study shows often have abysmal PQR—are neglected.

Addressing PQR data gaps at health facilities is therefore an urgent problem. This project took steps towards addressing current PQR data gaps by leveraging GridWatch, nLine's novel remote-monitoring technology. We collected direct PQR measurements at 15 electrified public health facilities in Sierra Leone, a nation grappling with under-developed electricity infrastructure, one of the world's highest maternal mortality rates, and a 38% electrification rate for all health facilities. GridWatch sensors were plugged into wall outlets at health facilities in both urban and rural areas to collect real-time PQR measurements including power outages (frequency and duration) and voltage and frequency levels. Using machine-learning models grounded in power systems and statistics, sensor-collected measurements were transformed into PQR profiles and key performance indicators (KPIs) for each monitored health facility.

Using this data, we further explore four key concepts: (1) quality and reliability as essential elements of electricity access to ensure usability; (2) health facility type (e.g. hospital) as a determinant of reliability; (3) heterogeneity in PQR based on subregions within the bulk-grid network; and (4) stacking multiple energy sources as a form of energy resiliency for health facilities.

This report presents data collected over a two-month period, as well as an analysis of the state and variation of PQR at electrified health facilities powered by on- and off-grid energy solutions. We further describe the methodology we develop to enable future effective, scalable, and independent auditing of energy system performance.

Key findings include:

- ➢ There is wide variation in PQR for electrified health facilities: the average outage time ranges from less than one hour to as much as nine hours without power each day.
- ➢ Hospitals experience more stable voltage levels on average than non-hospitals. This is because off-grid hospitals are found to have stable voltage supplied by solar PV systems and generators compared to grid-connected non-hospitals in our sample. We do not find notable differences between hospitals and non-hospitals in the daily average frequency or duration of power outages.
- ➢ PQR is unequal across grid-connected health facilities in Freetown, based on the geographic location of a facility. The western region of Freetown experiences the overall highest reliability and quality, while the eastern region is supplied with much poorer grid power in terms of both outages and voltage stability.
- ➢ Having a sufficiently sized and functional solar PV system can help a health facility mitigate energy costs and PQR challenges associated with weak grid-supplied power.

In conclusion, we show that remote, real-time, longitudinal collection of PQR measurements provides valuable, independent auditing of electrification at healthcare facilities. Further, we demonstrate that formerly insurmountable PQR data gaps can be bridged quickly and efficiently, across 15 facilities in Sierra Leone. This work represents a proof of concept that could enable innovation in measuring the performance of energy systems at-scale in SSA and in setting regulatory standards for ensuring sustainable healthcare electrification.

Background and Context

This section provides an overview of healthcare electrification initiatives in SSA, with a focus on the critical impact that PQR has on healthcare delivery and the challenges that exist in collecting high-resolution PQR data. We then introduce the landscape of health electrification in Sierra Leone, the country context where we conducted an exploratory study into the energy access experience for electrified health facilities.

1. Energy Access for Healthcare Delivery

The last decade has seen a growing prioritisation of energy access beyond households and businesses to include a focus on energy for healthcare delivery. In 2011, the United Nations launched the Sustainable Energy for All Initiative (SEforALL) to "achieve universal access to clean and modern energy sources in households and community settings by 2030." SEforALL highlighted the urgency of electrifying public health services and prioritised healthcare facilities as a special focus within its energy access agenda. The importance of energy for healthcare delivery was further underscored by the Sustainable Development Goals 3 ("ensure healthy lives and promote well-being for all at all ages") and 7 ("ensure access to affordable, reliable, sustainable, and modern energy for all") at the COP21 Paris Climate Conference in 2015— an arena that offered new global commitments to clean healthcare electrification investments [6].

While SDGs 3 and 7 have helped drive policy and investment actions at the health-energy intersection in SSA, the COVID-19 pandemic became a tipping point, demonstrating the need for energy resilience to respond to public health emergencies. As stated by SEforALL's current CEO Damilola Ogunbiyi, "the ability for doctors and first responders to treat infected populations is based on the assumption that clinics, medical equipment and medicines are fully functioning with access to sufficient, uninterrupted, reliable electricity." [14]. Post-pandemic, the World Health Organization (WHO), World Bank (WB), the International Renewable Energy Agency (IRENA), and SEforALL published a landmark report on energizing health, which put healthcare electrification at the forefront of discussion within the SDG 3 and SDG 7 global communities of practice. New global initiatives are also emerging—such as the 2023 launch of the $47 million USD Power Africa-funded Health Electrification and Telecommunications Alliance (HETA)—to address energy challenges in SSA's health sector.

Outside of the policy and investment domains, there has been a resurgence in the academic discourse on the role of energy for health systems transformation in SSA. This has prompted research into the state of PQR of existing energy infrastructures at health facilities, and the impacts of this PQR on healthcare delivery. In SSA, poor PQR poses a concern equally as important as issues of low electricity access rates and consumption levels [2]. However, PQR evidence remains sparse as historically most health-electrification projects have focused on energy access (i.e. whether a facility is electrified or unelectrified) and how access should be implemented (i.e. looking at the type of facility, the services provided, and the patient load to inform energy system design and power supply). Working towards achieving SDG 7 in its holistic definition means not only addressing facilities without energy access but also addressing those that are already electrified but experience an unreliable supply.

1.1 The Importance of Access to Reliable, High-Quality Power for Health Facilities

Recent valuations of health electrification projects are beginning to emphasize PQR as fundamental to healthcare outcomes. This is because healthcare interventions are intricately linked to reliable electricity, without which the delivery of critical care becomes unattainable [4]. Concretely, electricity PQR impacts healthcare delivery in three ways [6]:

1. **Service readiness and availability** (i.e. does the facility have the capacity to respond to patients' health needs and provide services that require electricity). Health facilities without reliable energy are unprepared to deliver adequate health care due to, e.g. poor lighting, absence of refrigeration and sterilization services, inefficient use of electricity-dependent medical equipment, and the inability to attract trained staff.
2. **Quality of healthcare service provision** (i.e. reliable electricity improves quality of care). For example, WHO statistics show that infections from unsterilized equipment affect 1 in 5 postoperative patients in low- and middle-income countries [WHO 2012b].
3. **Management and finance** (i.e. reliable electricity improves health facility staff satisfaction and information management systems). Facilities with a reliable supply of power are able to provide a more comfortable living and working environment for staff, often leading to higher retention rates.

In response to this reality, "several organizations have since put forward frameworks to define energy access beyond just the number of connections" [16]. In 2015, the World Bank's Energy Sector Management Assistance Program (ESMAP) released a seminal technical report titled "Beyond Connections: Energy Access Redefined". This report argues that access should be seen as the usability of the energy supplied:

> **Energy access =** The ability of the end user to utilize energy supply that is usable for the desired energy services.

ESMAP's Multi-Tier Framework for Energy Access (MTF) further redefines the way energy access is measured and highlights various attributes that impact the usability of energy:

> **Access to energy supply** = The potential to use energy (or the usability) should the user desire to do so. The usability of energy improves with increasing levels of energy attributes, such as the quantity, quality, reliability and affordability, among others.

For energy access to hold meaning for end customers, it must extend beyond the scope of availability and be "adequate in quantity, available when needed, of good quality, reliable, convenient, affordable, legal, healthy, and safe" [1]. ESMAP defines power quality and reliability as:

> **Quality of energy supply =** An attribute of energy supply that implies correct level and stability of voltage (and frequency) in case of electricity.
>
> **Reliability of energy supply =** An attribute of energy supply that entails absence of unpredictable outages of energy supply. It is measured by the frequency and length of unpredictable outages.

The WHO recognizes that access to reliable energy transforms healthcare settings, enabling the provision of quality medical services after sunset, enhancing diagnostics, treatment, and surgical capabilities, and bolstering disease prevention and treatment efforts through adequate sterilization and refrigerated vaccine and medicine storage [1]. ESMAP's definitional expansion of access has also motivated broader assessments of PQR impacts on healthcare delivery. For instance, survey data collected in Ghana revealed "a positive association between the frequency of power outages and in-facility mortality, with the risk for mortality estimated to increase by 43% for each day the power was out for over 2 hours" [5].

Some research has also assessed the unequal nature of PQR for grid-connected customers in disadvantaged or marginalized communities, which translates to inequities in PQR for health facilities reliant on bulk-grid-supplied power. For example, researchers exploring spatial and temporal disparities in grid outages in Accra, Ghana found that "daily, the poorest housing quintile received an average of 7.5 hours of electricity while the richest received 17.5 hours even though 12 hours were pledged equally to all neighborhoods" by the distribution utility. Similarly, "researchers found data from Nairobi, Kenya to reveal 'low income' households received over twice the outage duration and frequency as 'high income' households" [16].

Other studies highlight the types of energy stacking performed by health facilities to provide resilience and remedy the impacts of PQR. For example, grid-connected facilities often have back-up fuel-based generators onsite or have a solar PV back-up system to address outages and quality of access from the bulk grid [7]. Under-electrified health facilities in off-grid settings, who "mostly only have power for a specific health service (e.g. for a vaccine fridge and/or lighting)", also often rely on a combination of solar and fuel-based generators. While energy stacking addressed the issue of *inadequate* access to electricity, issues of affordability often arose because "facilities may struggle to purchase fuel and/or maintain a generator" [1].

Despite the glaring impacts of PQR discussed above, global and national energy access programs have continued to measure electricity access primarily using metrics such as the number of connections added and to measure power reliability primarily using survey-based recall questions. This is problematic because neither method accurately measures PQR. Further, consistent definitions of "reliable power" do not yet exist and "accurate values of reliability from individual recall are notoriously poor, therefore limiting the insights available from survey-based studies" [16]. There is a clear need for innovative measurement approaches that track PQR in real time and provide operational evidence to support new energy investments.

> **"Even when health facilities [have] an electricity connection, there may [be] significant quality-of-supply issues for which data are not collected." [1]**

In the next section we discuss challenges around collecting high-resolution PQR data at scale.

1.2 Challenges Collecting High-Resolution PQR Data for Healthcare Electrification

Part of the challenge in assessing the state of electricity access beyond the binary metric of "electrified" or "not electrified" is due to technical and operational challenges and financial costs associated with collecting standardised PQR data in low-resource settings at scale. Smart metering roll-out is still very low in SSA, in part due to consumer-centric factors and but largely due to monetary costs. For example, in Nigeria a World Bank-funded program to procure customer and retail smart meters—critical for better monitoring and identifying technical issues on the distribution grid network—cost $120 million USD. It cost $20 million USD to equip Nigeria's electricity regulator with a data aggregation platform to then be able to access and receive adequate, real-time information about the distribution network's operational performance [21]. The high-cost of wide-scale PQR monitoring for grid distribution networks also applies to wide-scale monitoring across isolated mini-grids. This results in the current PQR data gap we see today: nationally representative summary statistics on energy access for health facilities is available for only a handful of countries in SSA, and if reliability data is collected, it is often self-reported data from surveys [10].

Outside of cost, wide-scale monitoring and reporting of PQR is inhibited by the lack of universally established standards within the SDG 7 and SDG 3 communities for PQR indicators. For example, in [4], "reliable electricity" for health facilities is defined as "power available during all regular service hours, with no outages exceeding 2 hours on a given day in the week prior to data collection." This example is problematic for two main reasons: while a threshold of two hours may seem like reliable power supply, in the context of healthcare delivery two hours without power can mean the difference between life and death for, for example, a patient on an oxygen concentrator. Further, existing definitions and standards for PQR for health facilities are often not differentiated according to the level of service provided at the facility; this ignores the reality that hospitals—often equipped with critical medical equipment and providing a wide array of healthcare services—may require higher levels of reliability and quality than, for example, a community health centre that provides basic services with limited electricity-powered equipment.

Lastly, few utilities—including solar mini-grid providers—actually measure and report service quality and reliability. Despite the responsibility of an energy provider to ensure adequate access to electricity to its customers in terms of quantity, quality, and reliability of supply [1], there is rarely a requirement from investors, donors, or regulators to report quality and reliability data. If or when this information is shared by energy-service providers, there is a clear conflict of interest with the accuracy of the self-reported data, which is often entered manually into CSV spreadsheets (as is the case with mini-grids monitored by UNOPS in Sierra Leone).

These measurement challenges have allowed binary measurements of energy access and PQR data collection through surveys to remain as the status quo.

This project sought to provide a solution to this PQR data gap by leveraging GridWatch, nLine's novel remote measurement approach that combines quickly deployable wall-outlet sensors with cloud algorithms to aggregate sensor data into key performance indicators (KPI) of energy system reliability and quality.

2. Country Context: Electricity Access and Healthcare Electrification in Sierra Leone

This project studies healthcare electrification in the context of Sierra Leone. Sierra Leone, a West African country with a population of approximately 8.9 million people [12], ranks 181 out of 191 countries in the United Nations' Human Development Index. Food security, health, and education challenges are exacerbated by limited electricity access nationwide. Only 26% of the total population has access to electricity, with rural access estimated as 6% [7]. This national energy disparity is mirrored in Sierra Leone's healthcare system, where health service delivery is directly hampered by a lack of reliable access to electricity at health facilities; Sierra Leone holds the unfortunate distinction of having one of the world's highest maternal mortality rates [11], in part due to the absence of resources—such as electricity—that contributes to the lack of access to high-quality maternal healthcare, such as the ability to treat postpartum hemorrhaging by blood transfusion.

In 2022, SEforALL conducted a critical market assessment of Sierra Leone's health sector to inform a roadmap for accelerating the deployment of renewable energy solutions to health facilities. This report revealed that 38% of health facilities lack any access to electricity [7]. For those healthcare facilities that do have some form of access to electricity, most continue to experience unreliable and inadequate access regardless of their combination of electricity sources [7].

26%
Population with access to electricity
Rural: 5%
Urban: 55%

~38%
Share of health facilities providing primary healthcare without electricity

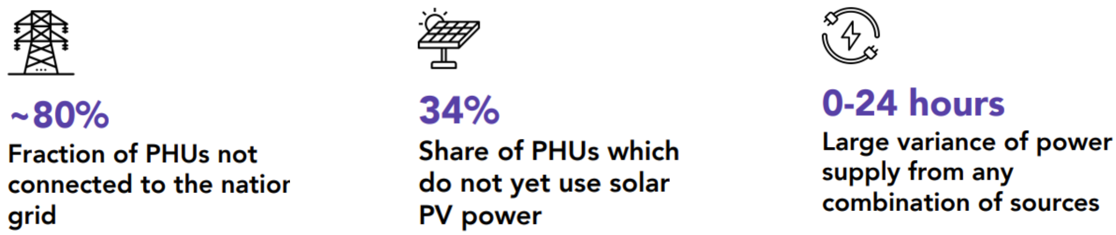


Figure 1: Electricity access and healthcare electrification rates in Sierra Leone. *Figures from SEforALL's report "Powering Social Infrastructure in Sierra Leone: Market Assessment and Roadmap for Health Facilities". ("PHUs" are primary healthcare level facilities).*

Based on SEforALL's market assessment, more than 1,000 health facilities in Sierra Leone either need new power solutions or a backup solution [7]. Recently new, decentralized, renewable energy systems have been deployed to rapidly electrify healthcare facilities where a connection to the central grid is unforeseeable within the next few years. For example, between 2017 and 2022, 94 solar mini-grids were installed in rural communities, with 54 of these mini-grids connected to community healthcare centres [13]. But problems with the reliability (frequent and/or long power outages) and quality (sub-optimal voltage levels) of these installed solar mini-grid systems remain common.

Project Description

This section explains the primary motivation and objectives for collecting localized PQR data at 15 public health facilities in Sierra Leone. We also outline the site-selection and data-collection methodologies used to generate localized PQR insights at each monitored health facility.

3. Motivation

Given the critical role electricity plays in the provision of healthcare delivery and the estimated 470 million people in SSA that are served by health facilities with unreliable electricity [3], billions of dollars will be spent electrifying health facilities through both grid and off-grid energy solutions. Rigorous and granular PQR data is needed by multiple stakeholders, including governments, regulators, utilities, project developers, developmental agencies, and financial investors, to design, monitor, and evaluate healthcare electrification investments.

While electricity "reliability is included in the text of both (SDG 7) and ESMAP's MTF, it is understudied in comparison to the wealth of research on energy access overall" [16]. This project aims to address the deficit of PQR data collected at electrified health facilities through an innovative model using real-time, standardised, remote monitoring. We pilot this approach in Sierra Leone, where 15 public health facilities are instrumented with nLine's GridWatch sensors to collect data on power outages (frequency and duration), voltage levels, and frequency. With support from IGC and Crown Agents, the nLine project team collected continuous PQR data at each health facility. *Note: At the time of publication of this report, the GridWatch sensors remain plugged in at all 15 health facilities. Remote monitoring will continue through July 2024, to ensure 12 months of continuous data collection to generate a one-year PQR profile for each facility.*

4. Project Objectives

This project seeks to inform the reliability and quality facets of the energy-access framework and is motivated by two primary objectives:

4.1 Bridging the Data Gap: Generating Power Quality and Reliability Profiles for Electrified Health Facilities

This project addresses the general lack of data on health facilities' electricity access. The project "provide(s) standardized data collection using harmonized indicators and methodologies" [3] that reflect current, more-nuanced definitions of electricity access by measuring and collecting data on the *reliability and quality of energy supply*. Our exploratory project in Sierra Leone sought to identify trends and patterns systematically across a sample of electrified health facilities, and to strengthen the availability of data for monitoring progress on the expansion of electricity access for health facilities.

4.2 Driving Innovation: Informing Power Quality and Reliability Standards for Healthcare Electrification

Innovative technologies like remote monitoring can generate valuable data to validate energy system performance [15]. In this project, PQR data is collected through digital remote monitoring and is used to calculate and monitor key performance indicators (KPIs). Through this ground-truth, independent verification of PQR and development of PQR profiles for facilities of different types (e.g. hospital versus non-hospital), the project team will contribute to defining PQR standards for electrified health facilities. By developing and testing a real-time, remote data-collection method for wide-scale monitoring of electrified facilities, this project ultimately seeks to drive innovation in the KPIs for electrification of health facilities across SSA.

5. Methodology and Approach

This section provides an overview of the site-selection strategy for the 15 public health facilities, our data-collection methodology, and data sources and analysis used by the nLine project team to draw insights on the experienced state of electrification for each facility.

5.1 Site-Selection Strategy

5.1.1 Overview

Beginning in April 2023, we deployed GridWatch sensors—outlet-level power monitors—to measure the real-time power quality of 11 health facilities across Western Urban and Western Rural districts in Sierra Leone, as well as one hospital in the Southern Province (Bonthe) and three hospitals in the Northern Province (Kambia, Masanga, and Kabala).

Figure 2: A map of Sierra Leone. *This map illustrates the four regional provinces: Northern Province, Eastern Province, Southern Province, and the Western Area Province.*
(source: https://www.worldatlas.com/maps/sierra-leone)

Of the 15 health facilities monitored in this study, six were pre-identified and selected by SEforALL, who, in partnership with FCDO and the Global Energy Alliance for People and Planet (GEAPP), conducted a “Market Assessment & Roadmap” to identify energy gaps in hospitals in Sierra Leone (both on- and off-grid) and opportunities to address these gaps with solar PV with storage solutions [7]. Crown Agents was contracted to electrify these six hospitals with renewable energy systems and partnered with nLine to conduct PQR monitoring at these six hospitals before and after solar PV system installation. *Note: PQR data and findings contained in this report do not reflect energy provided by the newly installed solar PV systems. These systems are expected to begin providing energy to the six hospitals in September 2023.*

Figure 3: Health Facility Locations. *This map shows the locations of the 15 public health facilities instrumented with GridWatch sensors. The magnified box shows health facilities located in Freetown.*

Within the Western Area Province, 8 public health facilities were selected for power monitoring in close collaboration with the Ministry of Health and Sanitation (MoHS), the Western Rural District Medical Officer, a colleague working with faith-based organizations Healey International Relief Foundation and Caritas Sierra Leone, and a colleague who is an OBGYN doctor at Princess Christian Maternity Hospital in Freetown. In Sierra Leone, roughly 92% of health facilities are owned and operated by the Government through the MoHS [7]. Consequently, we prioritised monitoring public health facilities within the sample, to reflect the outsized role that public facilities play in healthcare provision in Sierra Leone.

Funding provided by IGC and Crown Agents provided the monetary resources to instrument 15 health facilities.

5.1.2 Site Selection by Health Facility Types

To understand how PQR may vary in relation to the size of the health facility and the types of healthcare services provided, it was critical to ensure that the sample reflected a mix of health facility types (i.e. hospital versus non-hospital). Sierra Leone classifies health facilities in one of five categories, as outlined below.

Health Facility Categorization	Operating Structure	Number of Health Facilities in the Project Sample	Names of Health Facilities Instrumented with GridWatch Sensors
Teaching / Tertiary Hospital	Three out of 24 hospitals in Sierra Leone are teaching/tertiary hospitals	2	• Ola During Children's Hospital (ODCH) • Princess Christian Maternity Hospital (PCMH)
General Hospital	There are 24 public hospitals in Sierra Leone. Hospitals provide secondary referral care, with at least one hospital per district functioning as a Comprehensive Emergency Obstetric and Newborn Care (CEmONC) centre.	5	• Bonthe Government Hospital • Masanga Government Hospital • Kabala Government Hospital • Kambia Government Hospital • Lakka Government Hospital
Peripheral Health Unit – Level 3: Community Health Centres (CHCs)	Generally larger facilities meant to cover a catchment area (population) of 10,000-20,000 individuals	7	• Hastings • Hill Station • Kissy • Saint Joseph • Waterloo • Wellington • Wilberforce
Peripheral Health Unit – Level 2: Community Health Posts (CHPs)	Medium-sized facilities designed to serve a catchment area of 5,000-10,000 individuals	1	• Hamilton

Peripheral Health Unit – Level 1: Maternal and Child Health Posts (MCHPs)	MCHPs provide the first point of contact with the facility-based health system. They are usually located at the village level and serve populations of less than 5,000 individuals.	0	• Not applicable

Figure 4: Health facility types in Sierra Leone. *This table outlines the categorization used for health facilities in Sierra Leone and the list of 15 health facilities instrumented with GridWatch sensors. [7] [8]*

5.1.3 Site Selection by Energy Systems

Within the Western Area province, the project team wanted to understand the PQR of power provided by the distribution utility, the Electricity Distribution and Supply Authority (EDSA). Consequently, nLine partnered with the Western Rural District Medical Officer (DMO) to identify grid-connected health facilities within her district that were suitable for GridWatch sensor installation. In addition to broadly evaluating the PQR of grid-supplied power, we aimed to understand how homogeneous PQR is within the grid network (i.e. do some areas within the grid network experience better or worse PQR than others?). To that end, the Western Rural DMO and our close colleague at PCMH supported our team in identifying grid-connected health facilities across west, central, and east areas of Freetown in both Western Urban and Western Rural districts.

The 15 selected public health facilities are powered by a mix of power sources, as seen in the table below. *Note: Power sources are marked as present (✔) if the power source was functional and actively provided power to the health facility (or a subset of wall outlets in the health facility) at any point during the data collection period. For example, if a generator is located at a health facility but is broken or unused due to fuel costs, the health facility is recorded as NOT having energy supplied from a generator. Similarly, if solar panels are located at a health facility but were not providing energy to the facility during the data collection period, the facility is recorded as NOT having energy supplied from solar. Further, if solar panels only provided dedicated power to a vaccine fridge and/or several light bulbs and did not provide any power to wall outlets, then the health facility is recorded as NOT having energy supplied from solar. For the purpose of this project, "energy supply" is classified as providing power that can be used for various applications, beyond strictly lighting or refrigeration.*

Health Facility Type	Health Facility	Electricity Source		
		Solar	Generator	Grid
Teaching / Tertiary Hospital	Ola During Children's Hospital (ODCH)	✓	✓	✓

	Princess Christian Maternity Hospital (PCMH)	✗	✓	✓
General Hospital	Bonthe Government Hospital	✓	✓	✗
	Masanga Government Hospital	✓	✓	✗
	Kabala Government Hospital	✓	✓	✗
	Kambia Government Hospital	✓	✓	✗
	Lakka Government Hospital	✓	✓	✓
Peripheral Health Unit – Level 3: Community Health Centres (CHCs)	Hastings CHC	✓	✗	✓
	Hill Station CHC	✗	✗	✓
	Saint Joseph CHC	✗	✗	✓
	Waterloo CHC	✗	✗	✓
	Wellington CHC	✗	✗	✓
	Wilberforce CHC	✗	✗	✓
	Kissy CHC	✗	✗	✓
Peripheral Health Unit – Level 2: Community Health Posts (CHPs)	Hamilton CHP	✗	✗	✓

Figure 5: Available electricity sources for the 15 health facilities. *This table is adapted from SEforALL's report "Powering Social Infrastructure in Sierra Leone: Market Assessment and Roadmap for Health Facilities".*

5.2 Data-Collection Approach

5.2.1 Overview

To assess the quality and reliability of power supplied to the 15 health facilities, data were gathered from remote monitoring devices, in-person surveys, and ongoing qualitative, informal interviews with health facility staff. A local Project Manager was hired and trained to ensure correct protocols were used when obtaining informed consent from health facility staff, when conducting surveys and interviews, when plugging in GridWatch sensors at the health facilities, and when conducting any necessary sensor troubleshooting after installation.

5.2.2 GridWatch Sensors

Beginning in April 2023, GridWatch sensors were installed in 15 public health facilities through formal introductions from the Ministry of Health and Sanitation (MoHS) and Crown Agents. Sensor installation itself happened gradually over a 13-week period, beginning April 25 and ending July 20, 2023.

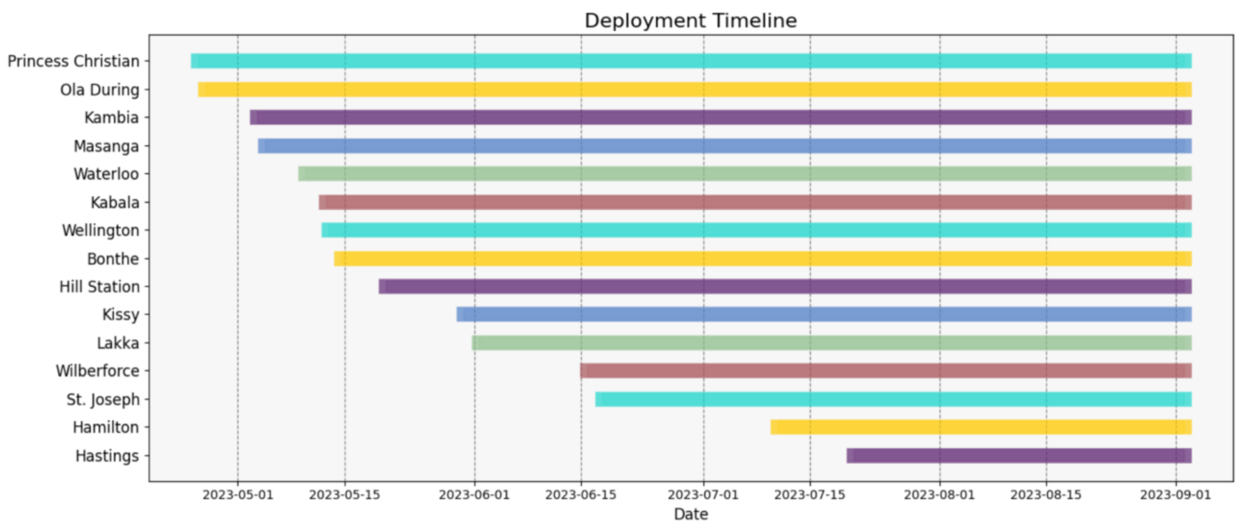


Figure 6: Data-collection timeline at each health facility. *GridWatch sensors were installed in health facilities in a phased approach given limited field team resources and the phased identification of the 8 Freetown facilities. This timeline illustrates the variation in deployment start dates.*

A minimum of three GridWatch sensors were installed in each health facility to ensure accurate detection of power outages and quantification of power quality [18]. The GridWatch sensors measure the voltage magnitude, AC frequency, power outages and power restorations time stamped to the millisecond, and the GPS-based location of the power outlet. Integrated global SIM cards capture data at two-minute intervals over the cellular network and a battery enables continuous data reporting throughout a power outage. If there are GSM network connectivity problems, data is queued and uploaded once connectivity is restored.

Figure 7: GridWatch sensors installed at Masanga Government Hospital. *Each sensor is plugged into an nLine-provided powerstrip to ensure limited electric sockets are not taken by the sensor.*

To detect outages and evaluate their extent, we identify simultaneous reports of individual sensors losing power close in space and time and perform additional analysis. Finally, data are aggregated to produce KPIs for PQR for each health facility. The following table summarizes nLine's standard PQR KPIs:

Key Performance Indicator (KPI)	Definition	Description (KPI type)	Unit	Example KPI Impacts on Health Facilities
Daily Hours of Outage	Average cumulative outage time experienced at a health facility	*Power reliability metric* for the duration of power outages	Hours per day	Long outages can result in loss of vaccines, blood, and reagents that require refrigeration
Daily Number of Outages	Average number of outages experienced at a health facility	*Power reliability metric* for the frequency of power outages	Number of power interruptions per day	A single outage can be the difference between life and death for patients who rely on oxygen concentrators or ventilators to breathe
Voltage Magnitude (average, median, minimum, and	Average voltage delivered to a health facility	*Power quality metric*	VRMS	Voltage surges can break sensitive equipment such as x-ray machines. Low

maximum)				voltage can also render appliances, such as fans and pumps, useless.

Figure 8: Health facility PQR KPIs produced by nLine. *GridWatch sensors measure power state and voltage every 2-minutes. These measurements are aggregated into PQR KPIs.*

The final KPIs are visualized using a web-based Grafana dashboard for near-real-time insight into PQR conditions in each health facility.

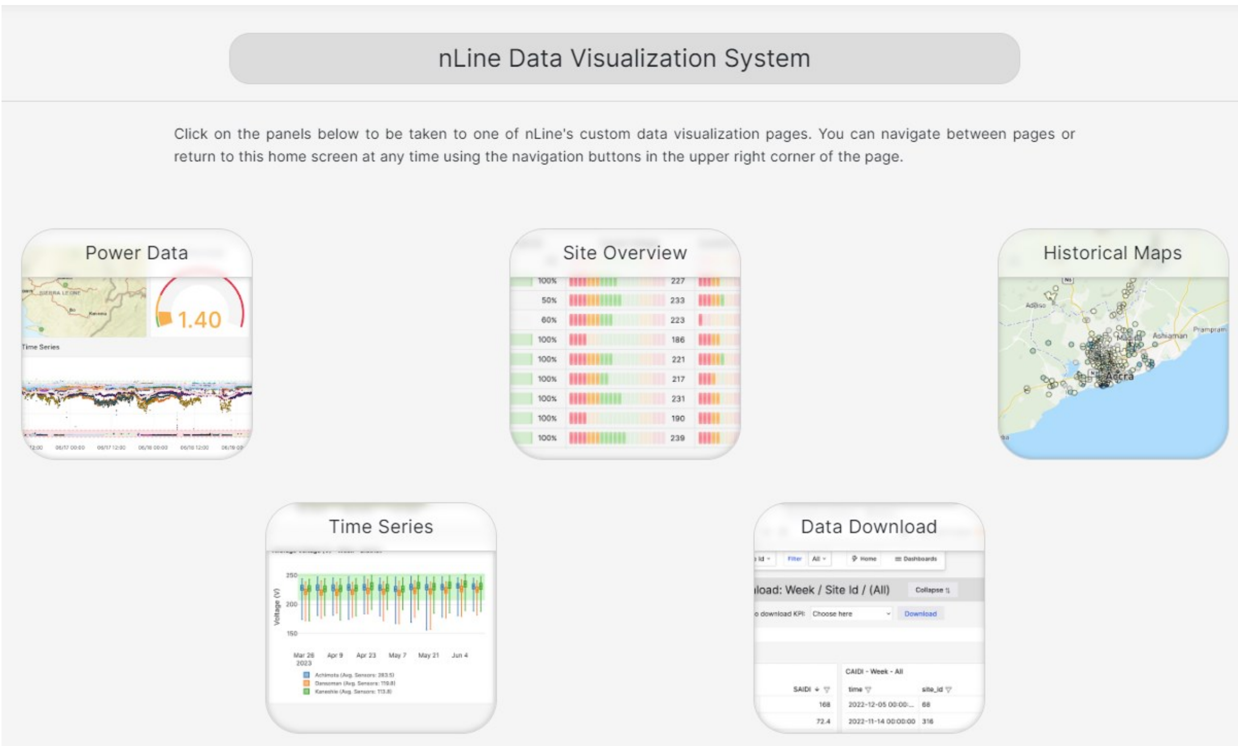


Figure 9: nLine's web-based Data Visualization System. *Users can navigate between a set of dashboards to view different presentations of the data.*

5.2.3 In-Person Surveys

We use surveys to support the installation of the GridWatch sensors. This survey—administered in SurveyCTO—records a unique code for each installed sensor and generates a unique respondent ID for each installation to assist with backend analysis and sensor tracking.

The field team also surveys the head of each health facility prior to sensor installation. Two surveys are completed for each health facility: one "Site Survey" to capture site-level descriptive insights about the health facility's energy profile and one "Installation Survey" to capture descriptive insights that are unique to the ward, building, and/or room where the sensor is installed. Example data collected in these surveys includes:

Survey Category	Detailed Questions	Purpose Of Survey Question
Available energy systems	➢ Energy system type (grid, solar and/or generator ➢ If the system is functioning properly ➢ The system size ➢ Which wards, buildings or rooms are supplied power by the energy system ➢ How primary and secondary power sources are used in relation to each other	To gather information about the energy system(s) currently installed at the health facility and how system(s) are used
PQR challenges	➢ If there are particular wards or rooms where it is critical to ensure 24/7 electricity supply ➢ If there are particular wards or rooms where supplied power is of especially poor quality ➢ If there are services the health facility wishes they could offer but are unable to provide due to lack of access to reliable, high-quality power	To understand the PQR challenges faced by the health facility
Medical equipment and appliances	➢ Types of critical medical equipment at the facility ➢ The room locations of this equipment	To know which critical medical equipment is available at the health facility
Health facility staff point of contact	➢ Name and job title ➢ WhatsApp phone number	To establish a point of contact who can ensure the sensor remains plugged in and collecting data

Figure 10: Health facility site surveys. *For each health facility, an in-person survey is administered to collect key information about energy systems and electricity-dependent medical equipment.*

5.2.4 Ongoing Qualitative Information Gathering

If sensor data revealed irregularities in power reliability and/or quality at any point throughout the data-collection period, the local Project Manager would contact designated sensor point(s) of contact at each health facility about the issue. By reaching out directly to health facility staff via Whatsapp and/or in-person visits, qualitative data was able to complement sensor measurements to better understand socio-economic or techno-economic factors that may be impacting PQR. For example, through discussions with health facility staff we learned that some causes of sensor-detected power outages included: (1) lack of funding to pay for grid power and/or fuel for generators, (2) breakers tripping off and the time required to manually switch breakers back on, and (3) a failed transformer.

> **"Sometimes when you go above the amperage maximum the breakers trip off so they do not cause any harm to any device, like for the emergency ward. So if you (nLine) observe or notice an area (in the hospital) where the lights shut down, it's not that they really shut down. This morning (when I arrived at the hospital) I went and turned the breakers on in the two areas and there was then light again." -** Facility Maintenance Officer at Masanga Government Hospital

This type of qualitative data helps decipher between true PQR issues and issues that impact PQR but are derived from outside of the energy system itself.

Findings

This section describes PQR data and insights generated from eight weeks of data collection at 15 public health facilities. In addition to providing an overview comparison of PQR profiles for each facility, this section groups findings into three sections to show how PQR varies by health-facility type, by location within Freetown's grid network, and by the availability of a secondary, backup power source. This section highlights the multifaceted PQR experience of electrified health facilities. The Appendix includes tables with PQR KPI values for each health facility and data used for each of the three deep-dives outlined below.

This project explores, tests, and analyses PQR data to explore four concepts often referenced across energy-access and health-electrification literature:

1. *Quality and reliability as elements of energy access to ensure usability* - This project generated PQR profiles of electrified health facilities and analysed PQR KPIs to understand what "access" looked like in practice after an initial electricity connection.

2. *Evaluation of health facility type (e.g. hospital) as a determinant of power supply reliability* - The highest tier of health facilities - district, regional or provincial hospitals - are often assumed to fare better in both access to energy and reliability of electricity supply. In our

analysis, we disaggregated PQR data by health facility type to evaluate to what degree hospitals experience better PQR than non-hospitals.

3. *Heterogeneity in PQR based on subregions within the bulk-grid network* - We analysed and disaggregated PQR data for grid-reliant facilities in Freetown to understand whether there are better or worse pockets of grid PQR, and consequently whether grid-related PQR challenges are equally felt by facilities.

4. *Energy stacking as a form of energy resilience for health facilities* - We analyse data from bulk-grid connected health facilities that do and do not have secondary energy solutions to understand if energy stacking results in better PQR.

The project team selected an analysis period beginning July 20, 2023, through August 31, 2023. July 20 was when the final health facility (Hastings CHC) was instrumented with power-monitoring sensors, so this represents a period when all 15 health facilities reported PQR data. This six-week period is used for all subsequent data analysis and results, unless otherwise specified in of the four analysis sections below.

Most of Sierra Leone's installed generation capacity comes from the Bumbuna hydropower plant whose supply is affected by seasonal rainfall. The Bumbuna plant provides 40-50 MW in the wet season and only 10-15 MW in the dry season [19]. As a result, the 6-8 weeks of data presented below is only representative of PQR for the wet season months of July and August. Continued monitoring is required to understand the full seasonal fluctuations in PQR, especially for grid-connected health facilities that receive power from hydro-based generation.

Please note: PQR KPIs were calculated by averaging all reported sensor measurements from a single health facility. The KPI values for the "frequency of outages" and "duration of outages" may appear as fractions because individual sensors may be powered by unique power sources and consequently experience unique power outages. For example, health facilities may have solar panels or generator(s) dedicated to powering wall outlets in specific wards or rooms that provide critical medical care.

6. Power Quality and Reliability Profiles of 15 Health Facilities

To assess PQR in electrified facilities, this project examined the frequency of outages (*i.e. the average number of power outages experienced each day)*; the duration of outages *(i.e. how much time on average health facilities spent without power each day),* and the voltage quality of supplied power.

We observed variations across the 15 health facilities in the quality of electricity available; Figures 11, 12 and 14 illustrate PQR KPIs from July 20 through August 31, 2023 (six weeks). This data allows for a broad comparison and baseline understanding of general PQR values in Sierra Leone's healthcare system.

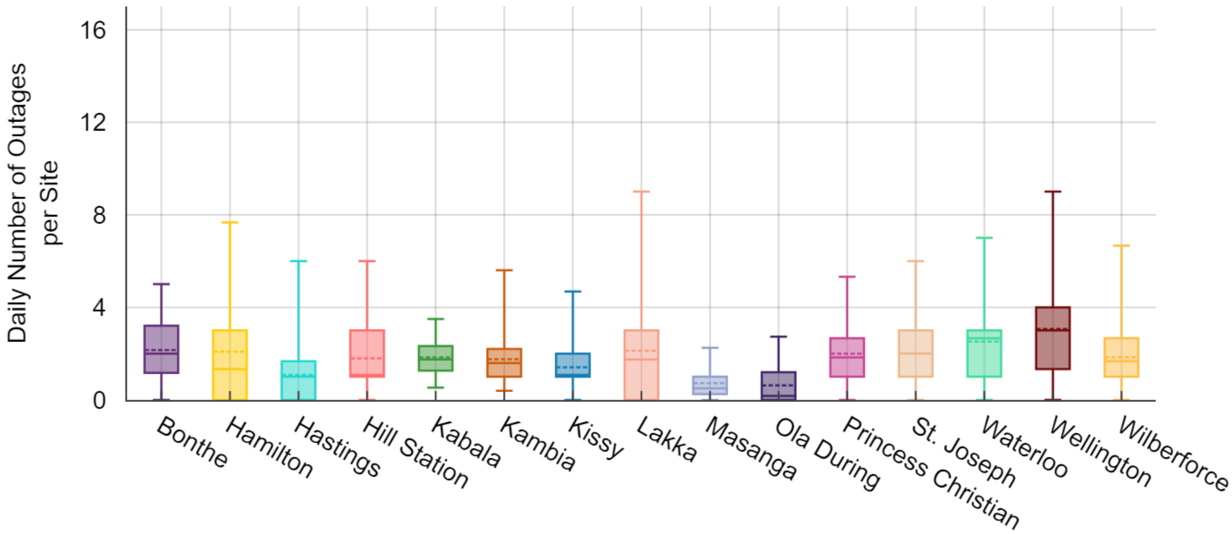


Figure 11: Power Outage Frequency. *Average daily number of power outages measured at 15 health facilities over a six-week period (July 20 - August 31, 2023).*

Frequency of Power Outages: Ola During Children's Hospital and Masanga Government Hospital experienced the fewest average daily number of power outages, with 0.63 and 0.73 outages each day, respectively. In comparison, Bonthe Government Hospital, Hamilton CHP, Lakka Government Hospital, Saint Joseph CHC, and Waterloo CHC all experienced an average of 2.00 - 2.52 power outages each day. Wellington CHC experienced the most power outages, with an average of 3.07 outages per day.

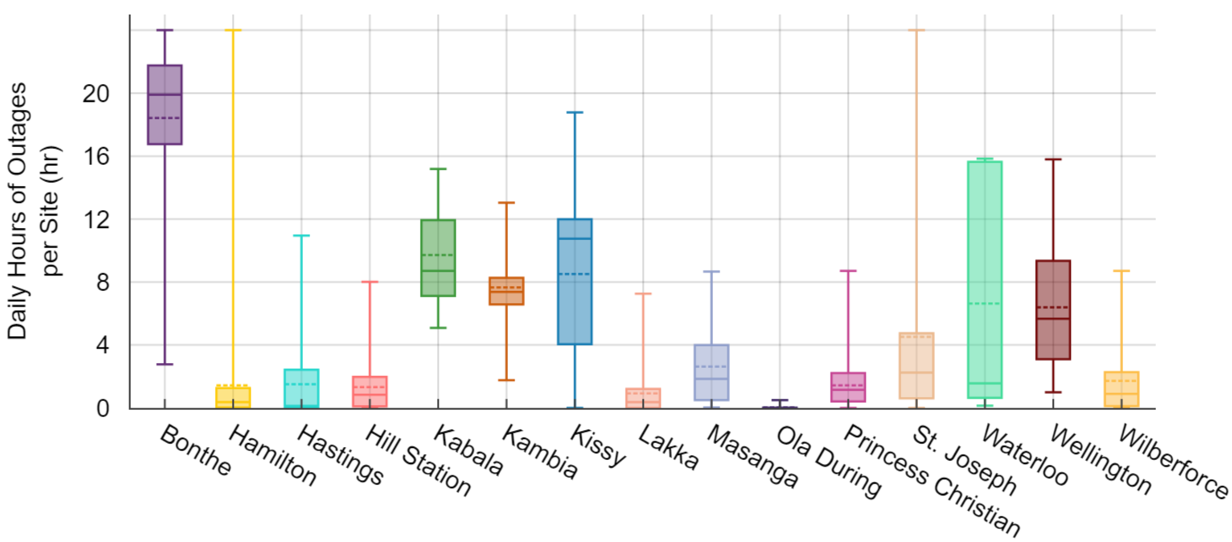


Figure 12: Power Outage Duration. *Average daily hours of power outage measured at 15 health facilities over a six week period (July 20 - August 31, 2023).*

Duration of Power Outages: Ola During Children's Hospital and Lakka Government Hospital experienced the lowest average daily duration of power outage, with 0.03 and 0.92 hours of outage, respectively. In comparison, Kissy CHC, Kabala Government Hospital, Kambia Government Hospital, Waterloo CHC, and Wellington CHC all experienced an average of more than 6.00 hours of power outage each day. Bonthe Government Hospital experienced the most time without power, with 18.43 average hours of power outage daily.

Case Study: Differentiating "Poverty Outages" from True Power Outages

"Poverty outages" or "economic outages" arise when a customer—including a health facility—does not have the means to pay for electricity, even temporarily. This can include grid-connected facilities who fail to pay utility bills as well as off-grid facilities who cannot afford the cost of fuel to power a generator. Beginning July 28, 2023, Waterloo CHC experienced an "economic outage" after failing to pay EDSA utility bills and an inability to finance fuel costs to power the on-site generator. This "economic outage" continued through at least August 31, 2023. The nLine project team removed this poverty outage from the data analysis pipeline in order not to misrepresent power-reliability KPIs, which are measures of the quality and reliability of the energy supply *itself.* But, as a result, Waterloo CHC's calculated average daily hours without power is low (6.63 hours) when compared to the facility's reality during this time: 24 hours without power each day.

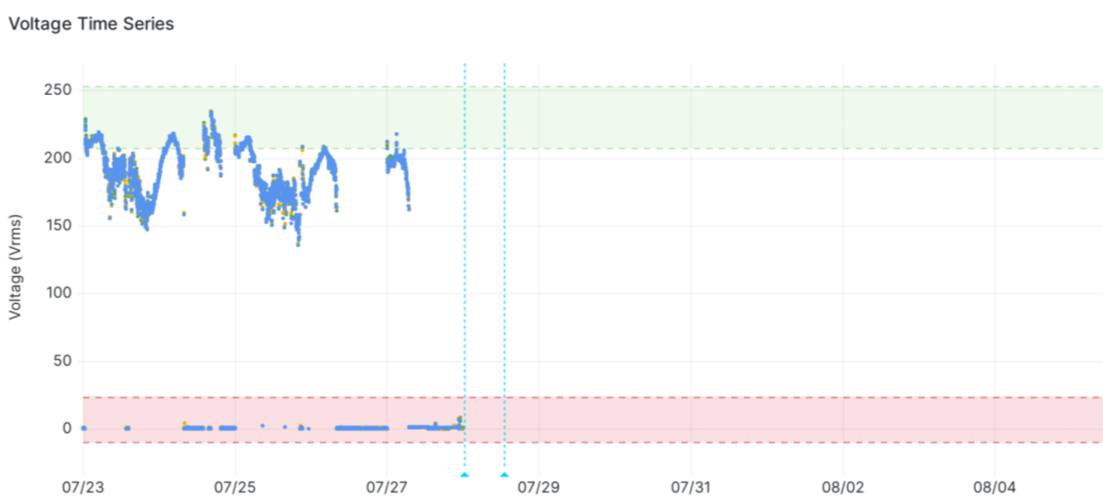


Figure 13: A long duration "poverty outage" at Waterloo CHC. *Beginning on July 28, 2023, the health facility was unable to provide payment for EDSA-provided grid-power, resulting in a power outage that lasted beyond the six-week measurement period.*

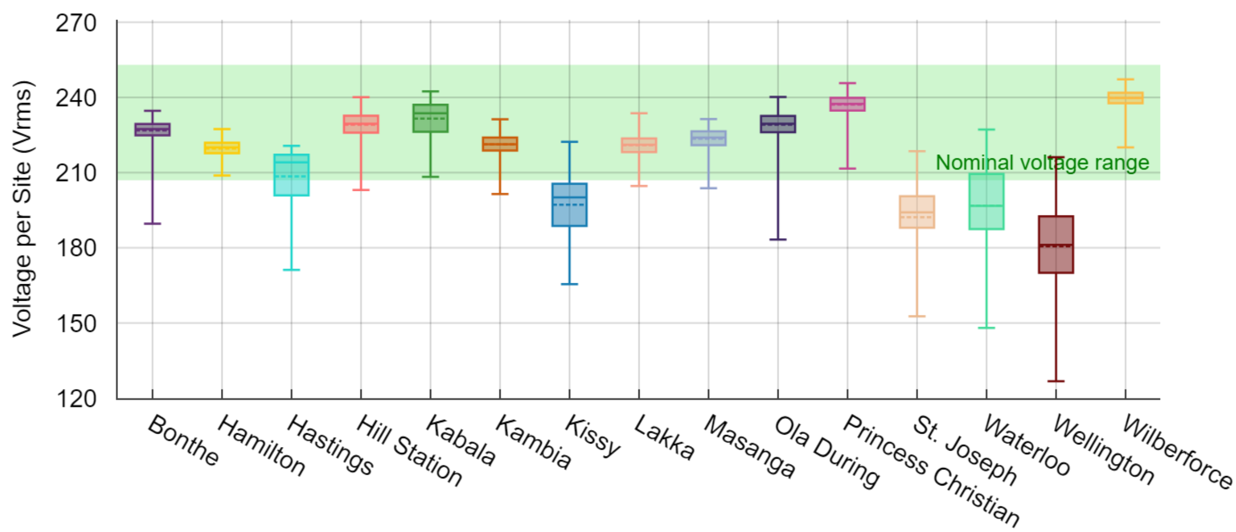


***Figure 14: Power Quality Profiles**. Average voltage magnitude at 15 health facilities over a six-week period (July 20 - August 31, 2023). The widely accepted global IEEE standard is to maintain voltage within ±10 % of nominal (230V in Sierra Leone). This standard nominal voltage range is shaded in green.*

Voltage Levels: Kissy CHC, Saint Joseph CHC, Waterloo CHC, and Wellington CHC all experienced average daily voltage levels below the recommended nominal voltage range in Sierra Leone (i.e. 207 - 253 V). Wellington recorded especially low voltage levels throughout the data-collection period, spending an average 12.78 hours each day outside nominal and dropping as low as 127 V at times. This low voltage level makes the use of electricity-dependent office and medical equipment extremely difficult; Wellington's Community Health Officer shared that EDSA grid-provided power is "very poor and is not able to even turn the fan or turn on [the] computer."

Conclusion

From this overview, it is clear that "electrified" is not a binary state and can range from the dependable, high-quality power experienced at Ola During Children's Hospital (a tertiary hospital with a grid connection, two generators, and dedicated solar) to the sparse power supplied to Bonthe Government Hospital (a geographically remote hospital located on an island and serviced by two generators that are frequently inoperable due to prohibitive fuel costs and an old solar PV system that is not producing at full output). This wide variation in PQR revealed by our data demonstrates the importance of monitoring the *quality* of supplied electricity after an initial connection is made.

Case Study: Seasonal Variations in Power Quality and Reliability at Princess Christian Maternity Hospital (PCMH)

The above data represents a snapshot of PQR KPIs averaged over six weeks for each facility. However, PQR can vary daily, weekly, monthly, and seasonally. Here we present an example of variance in PQR at Princess Christian Maternity Hospital (PCMH) over a four-month period. Power-monitoring sensors were installed April 25, 2023, and continue to collect data through this report's publication. Data shows that April and May exhibited significantly worse power reliability than June, July, and August. For example, for the month of May PCMH experienced a total duration of 130 hours without power and 106 power outages; in August, PCMH experienced a total duration of 49 hours without power and 68 power outages. One plausible reason for this month-to-month difference is the substantial variation in the country's hydropower generation due to seasonal rains, which historically begin in late May or early June. This domestic power-supply fluctuation can significantly impact the reliability of grid-provided power to health facilities such as PCMH. This case study highlights the importance of continuous monitoring to understand the full PQR experience of an electrified facility throughout the year.

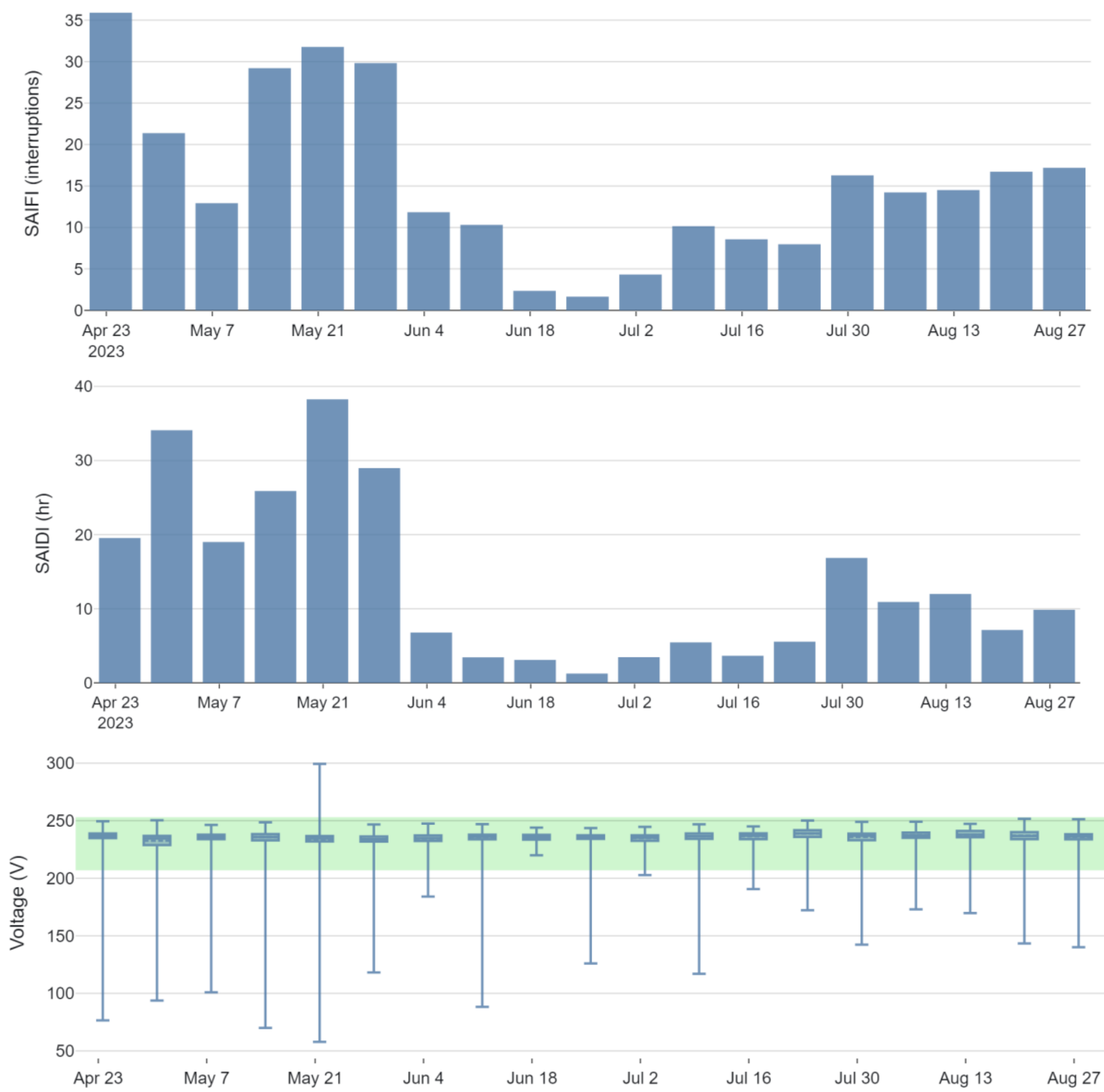


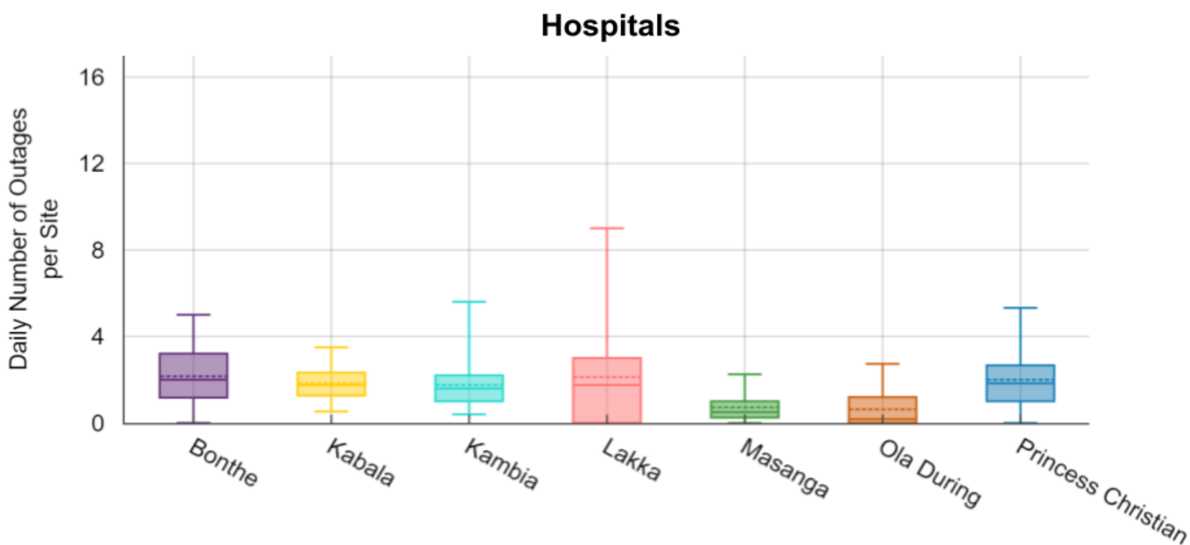
***Figure 15: Visualization of PQR Seasonality at Princess Christian Maternity Hospital**. Weekly time-series data, including the average weekly frequency of outages (top), average weekly duration of*

outages (middle), and voltage levels (bottom). Near the end of the dry season (April and May), power quality and reliability were notably worse than when the rainy season began (the first week of June).

7. Power Quality and Reliability by Health Facility Type

To assess whether hospitals tend to have "better electricity" than non-hospital health facilities in the context of Sierra Leone, this section explores whether there are notable disparities in PQR between facility types. Among the 15 health facilities there are seven hospitals, seven CHCs, and one CHP. This section compares PQR KPIs across the seven hospitals and seven CHCs.

Figures 16, 17, and 18 illustrate PQR KPIs for data collected from July 20 through August 31, 2023 (six weeks).



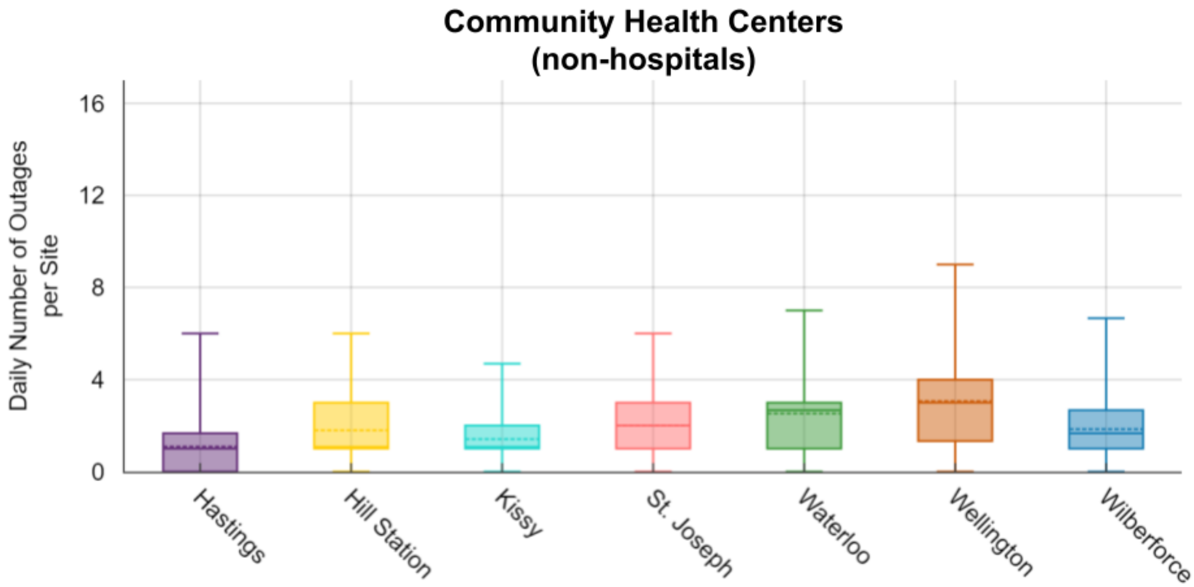


Figure 16: Power Outage Frequency at Hospitals and CHCs. *Average daily number of power outages measured at seven hospitals (top) and seven CHCs (bottom) over a six-week period (July 20 - August 31, 2023).*

Frequency of Power Outages: Hospitals and CHCs experienced nearly the same average daily number of power outages: 1.61 outages and 1.96 outages averaged for each facility type group, respectively. However, CHCs experienced a higher average maximum number of outages than hospitals: 6.48 outages compared to 4.77 outages, respectively. One potential explanation is that all seven CHCs are connected to the national grid, which often experiences frequent - even if momentary - outages throughout the day. In comparison, only three hospitals are grid-connected and all seven hospitals have at least two energy supply sources. In subsequent sections, we explore PQR across the bulk-grid network in Freetown and the effect of energy stacking on PQR.

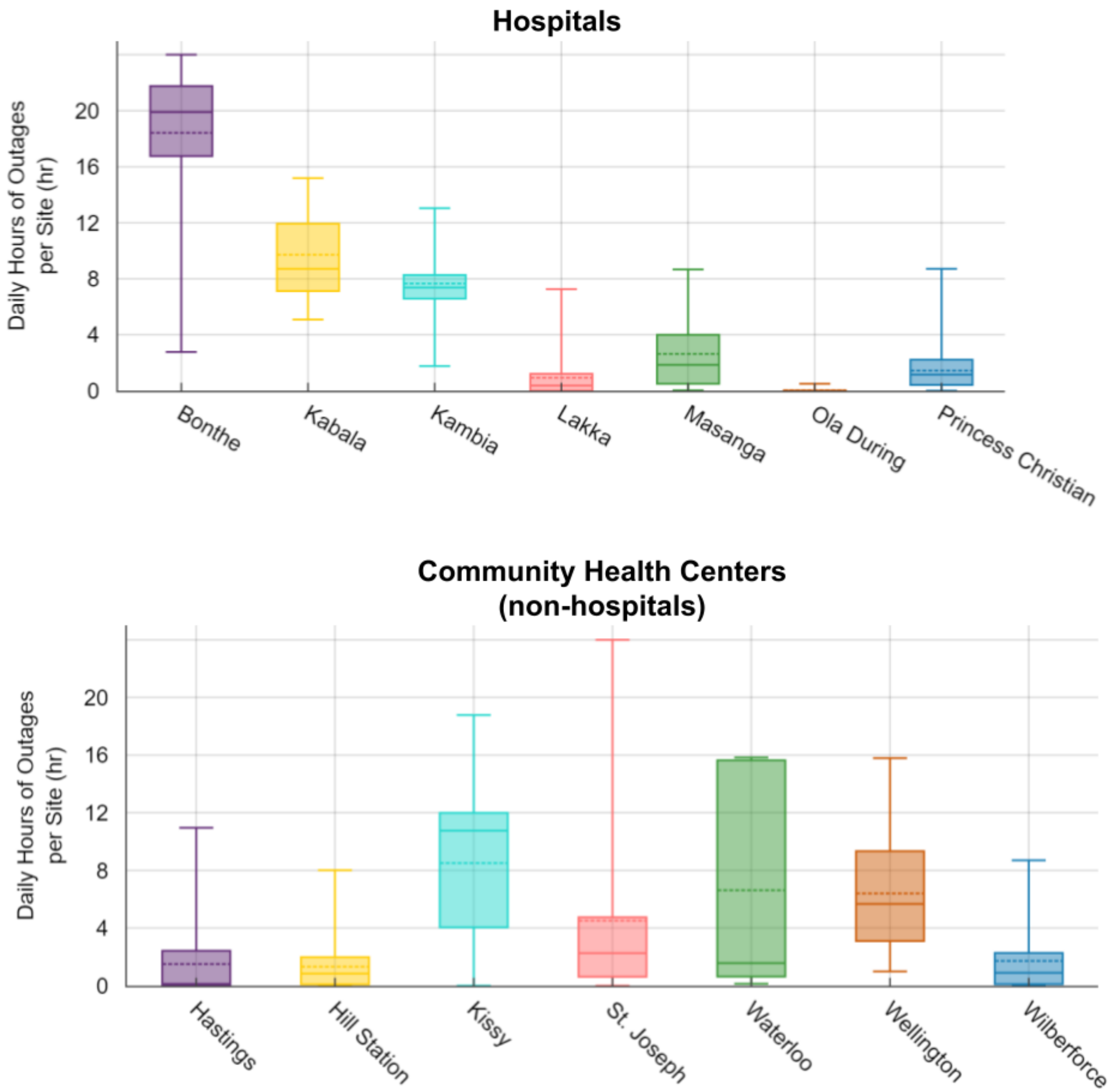
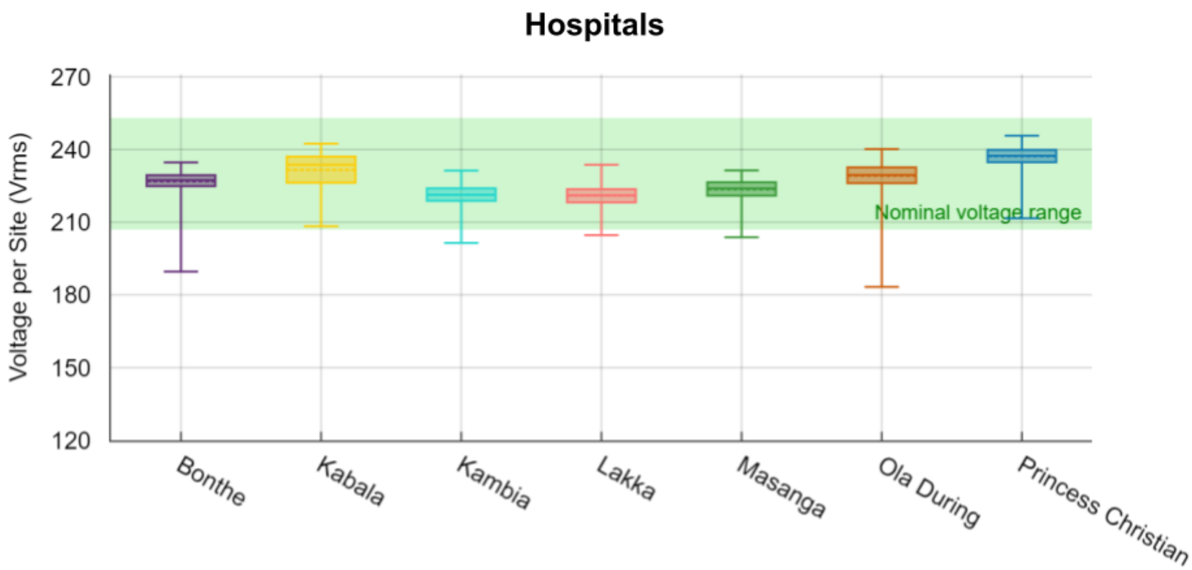


Figure 17: Hours of Power Outage at Hospitals and CHCs. *Average daily number of hours of power outage measured at seven hospitals (top) and seven CHCs (bottom) over a six-week period (July 20 - August 31, 2023).*

Duration of Power Outage: Hospitals experienced slightly higher average daily hours without power than CHCs: 5.83 hours averaged across hospitals compared to 4.37 hours, respectively. This higher average observed for hospitals is skewed by Bonthe Government Hospital (an off-grid hospital with a solar PV system providing limited power to critical loads and two generators used only for emergencies due to fuel costs) and Kabala Government Hospital (an off-grid hospital with a partially functioning solar PV installation and limited generator usage due to fuel costs).



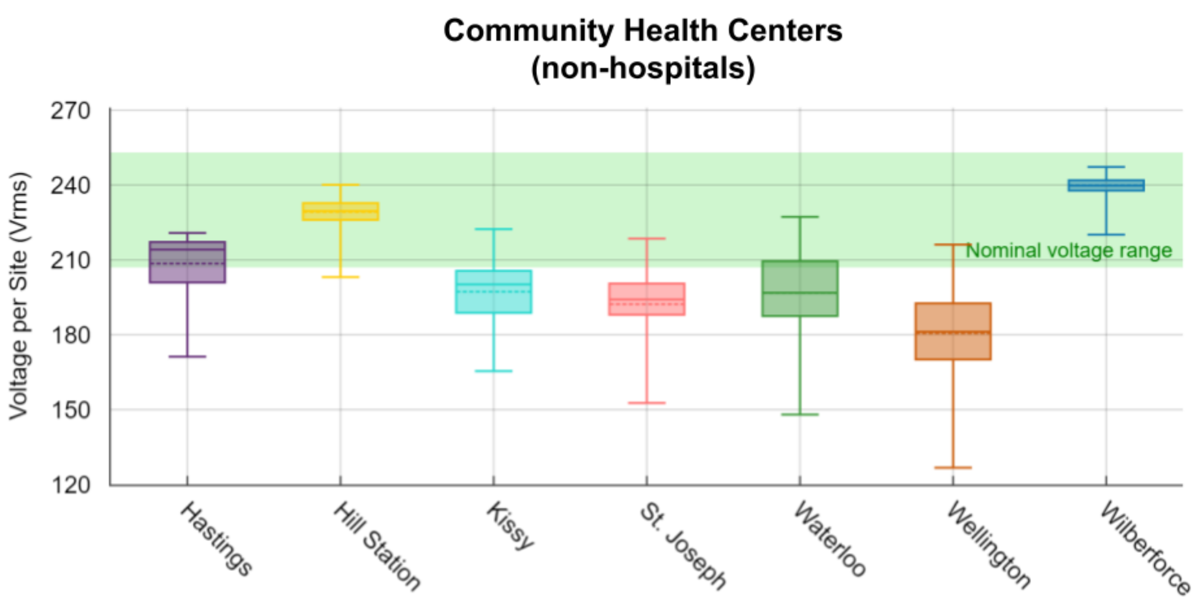


Figure 18: Power Quality at Hospitals and CHCs*. Average voltage magnitude at seven hospitals (top) and seven CHCs (bottom) over a six-week period (July 20 - August 31, 2023). A widely accepted global standard is to maintain voltage within ±10 % of nominal (230V in Sierra Leone). This standard nominal voltage range is shaded in green.*

Voltage Levels: On average, hospitals have better voltage quality than CHCs. Average voltage quality across the seven hospitals is 227V compared to 206V for CHCs. CHCs generally experienced more time with power below the recommended nominal range than hospitals, and also experienced a lower minimum voltage—170V—averaged across all seven CHCs, compared to 200V as the average minimum for hospitals. The lower quality in power supplied to CHCs is likely due to the fact that, on average, the grid-supplied power in Freetown has lower voltage levels than solar and generator-provided power. While four of the seven hospitals are strictly off-grid, all seven CHCs receive power from the bulk-grid in Freetown.

Conclusion

Data shows that the hospitals sampled have better quality power than non-hospital health facilities. Power-reliability differences between hospitals and non-hospital health facilities are not as clear, with hospitals experiencing slightly fewer average daily outages but slightly more average daily hours without power than CHCs. Data also reveal that the PQR narrative is not homogenous across facility types: there are notable differences in experienced PQR between hospitals and between CHCs. This is primarily due to differences in grid-supplied power (whether the facility is on- or off-grid) and whether the facility has more than one available power source.

PQR data reveals that off-grid regional government hospitals in Sierra Leone are still experiencing meaningful time each day without power—a serious problem for these facilities, which require continuous power supply to provide comprehensive non-emergency services and critical emergency care. Results from this project show that energy security for electrified health facilities is a pervasive issue even for facilities providing the highest tiers of health care.

8. Power Quality and Reliability Inequities for Grid-Connected Facilities in Freetown

This section analyses whether there are variations in PQR between grid-connected health facilities in different areas of Freetown. To uncover any non-homogeneity of electricity reliability across subregions in the bulk grid, we selected a sub-sample of health facilities that met the following criteria:

1. **The health facilities are grid-connected.**
2. **The health facilities do not receive power from a secondary power source.** A few facilities had alternative energy sources on the premises, but the energy system did not actively provide power to the facility. For example, Wellington CHC has an on-site generator. However, when the CHO arrived at the facility in 2017, “No one took care of it (the generator) for a very long time so I tried to repair it. But the only problem… is that there is no battery and it costs 890,000 leones”, a prohibitive cost for purchasing a new battery. Consequently, Wellington CHC relies strictly on EDSA-provided grid power. Similarly, Waterloo CHC has an on-site generator that is not used because of prohibitive fuel costs and relies strictly on power from the grid.

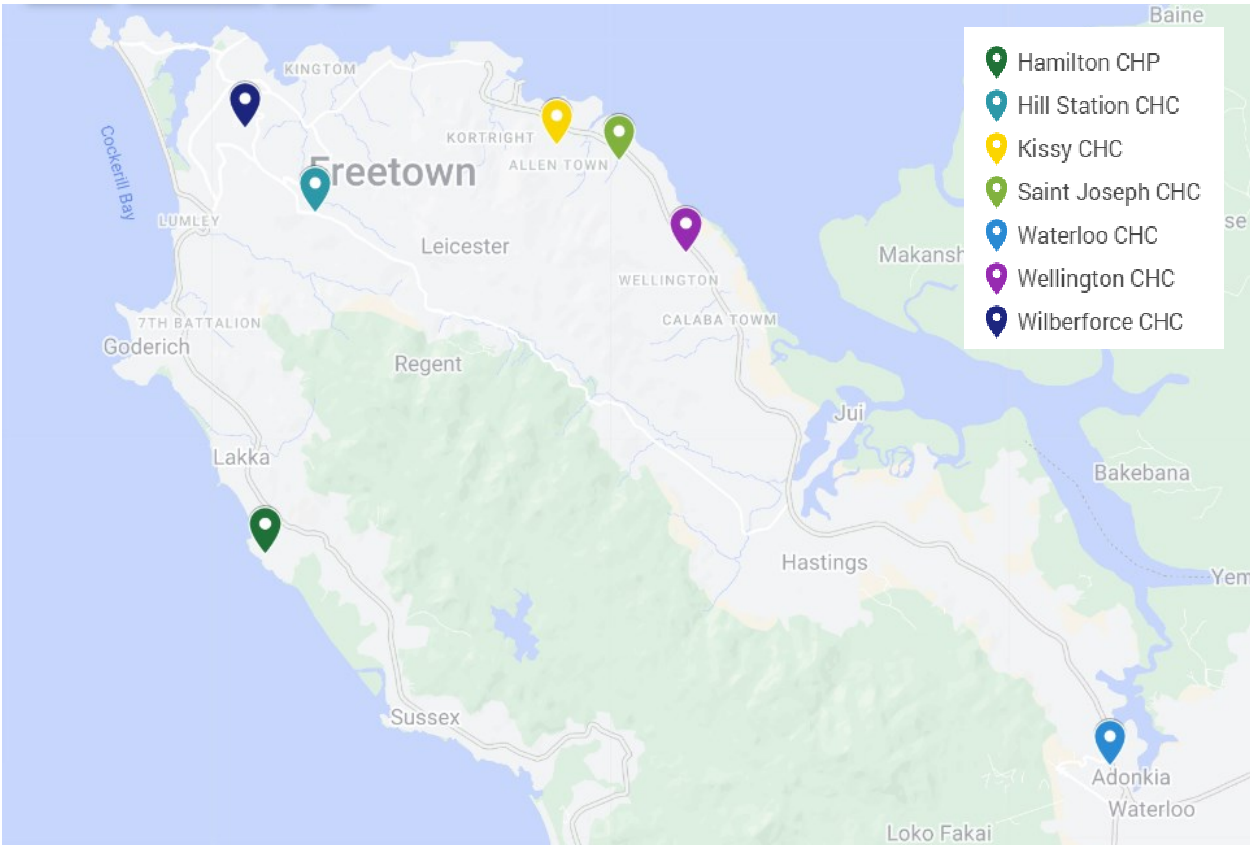
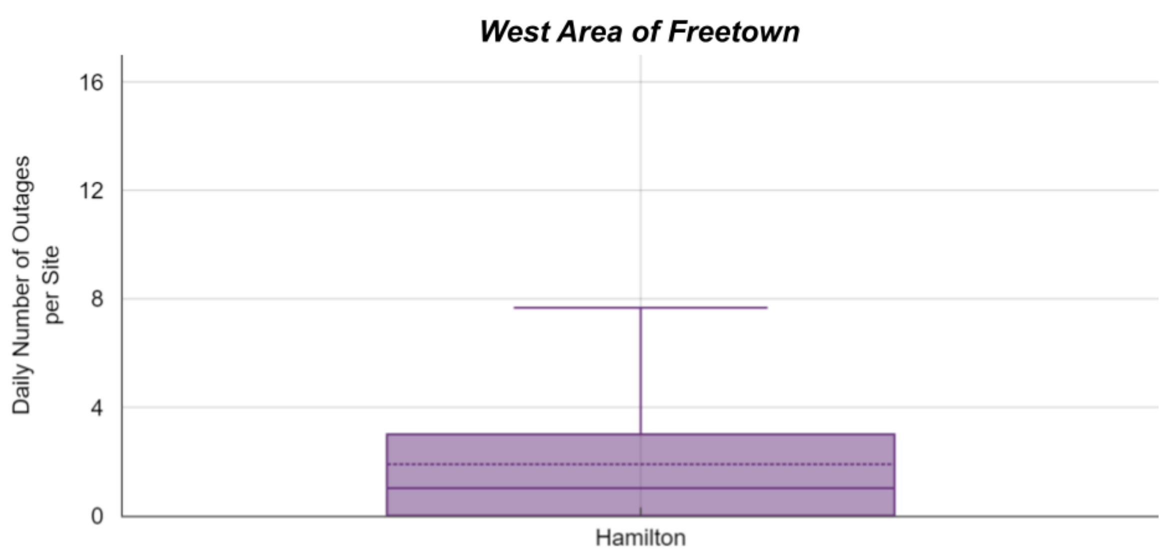
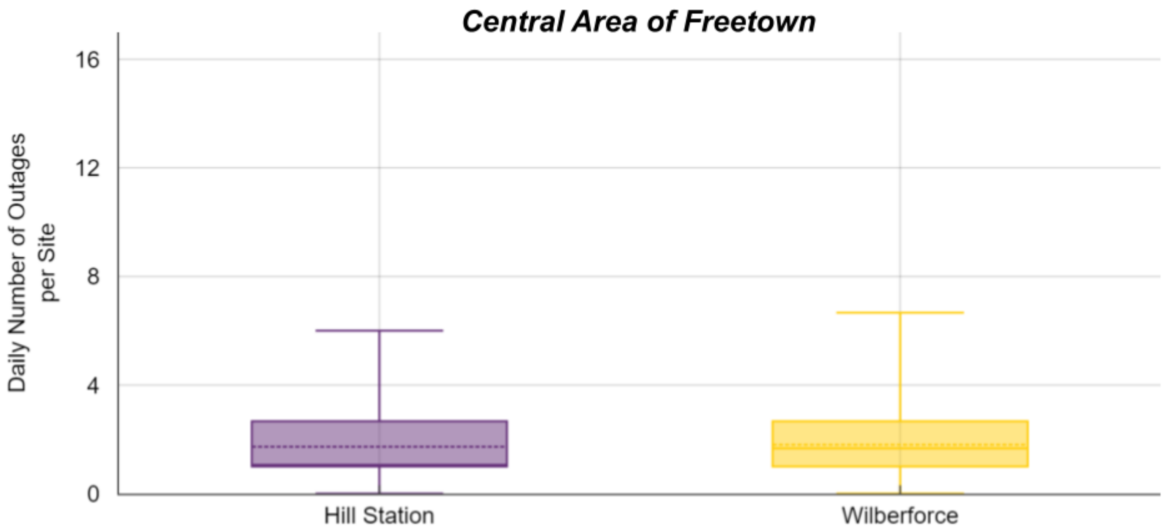


Figure 19: Primarily grid-powered facilities in Freetown. *The locations of seven health facilities in Freetown that rely strictly on EDSA-provided grid power.*

Figures 20, 21, and 22 illustrate PQR KPIs from July 10 through August 31, 2023 (eight weeks).





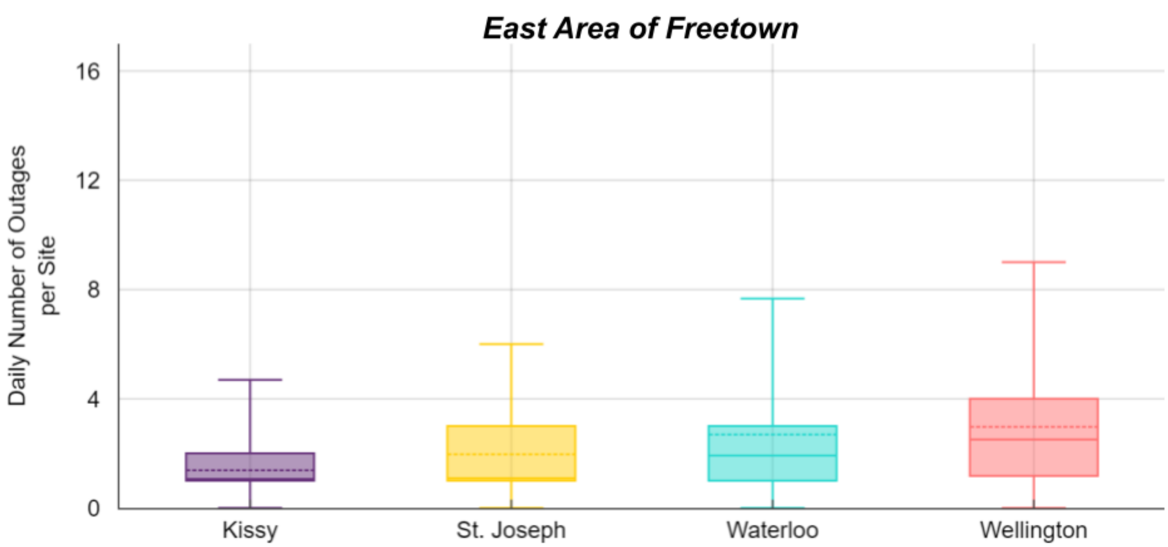
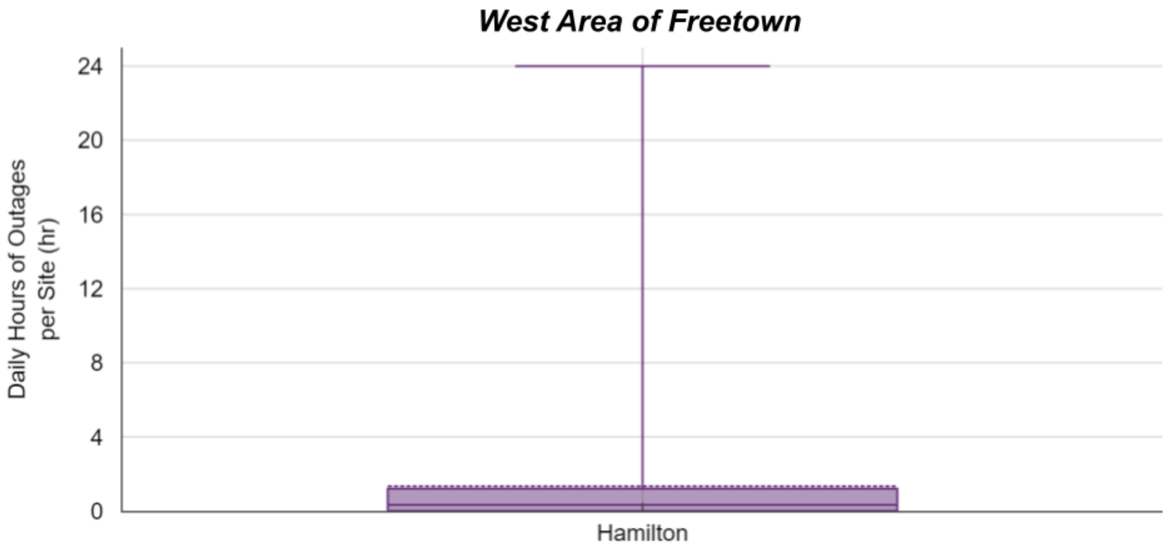
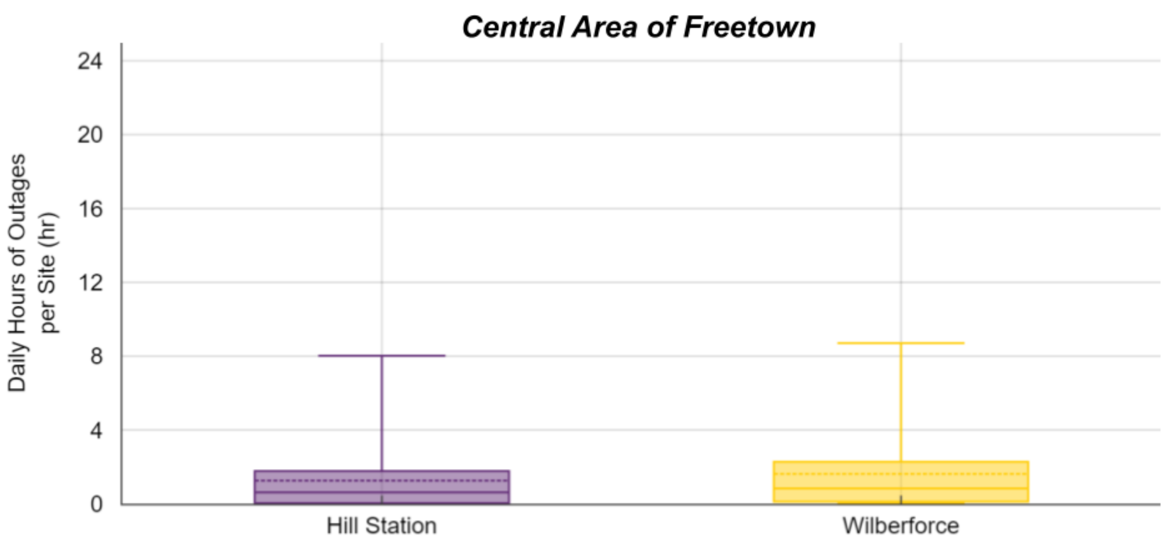


Figure 20: Frequency of grid outages in west, central and east areas of Freetown*. Average daily number of power outages at one grid-connected CHP on the west side of Freetown (top), two grid-connected CHCs in central Freetown (middle), and four grid-connected CHCs on the east side of Freetown. Data was collected over an eight-week period (July 10 - August 31, 2023).*

Frequency of Power Outages: Grid-powered health facilities located in the eastern side of Freetown experienced, on average, more power outages each day than facilities located in the central or western areas of Freetown. The four facilities in the east experienced a combined average of 2.24 power outages each day, compared to 1.73 outages for CHCs in central Freetown, and 1.92 average daily outages for the CHP in the west.



West Area of Freetown
Daily Hours of Outages per Site (hr)
24
20
16
12
8
4
0
Hamilton



Central Area of Freetown
Daily Hours of Outages per Site (hr)
24
20
16
12
8
4
0
Hill Station
Wilberforce

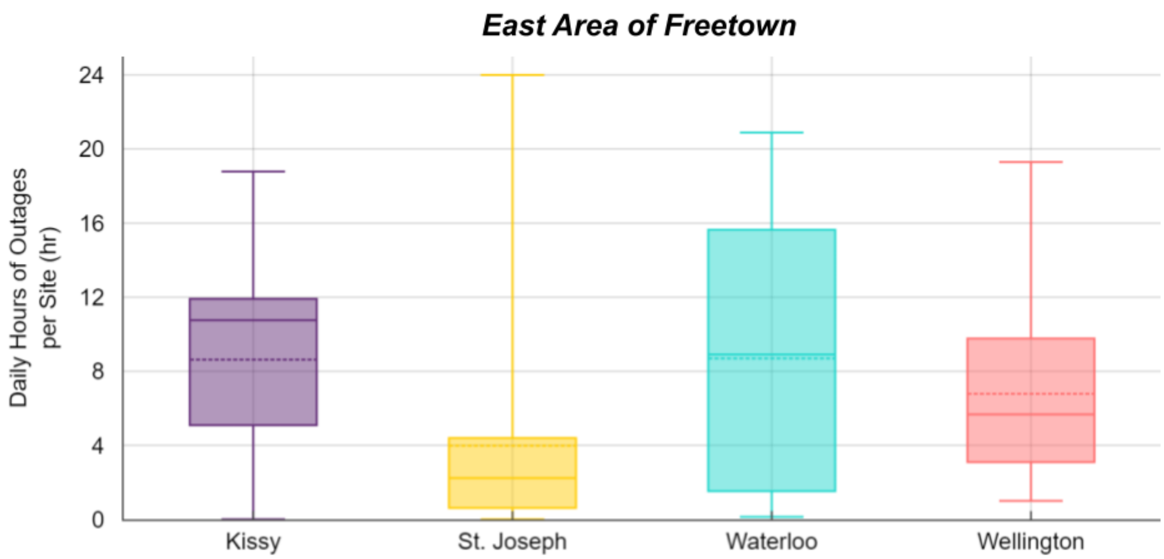
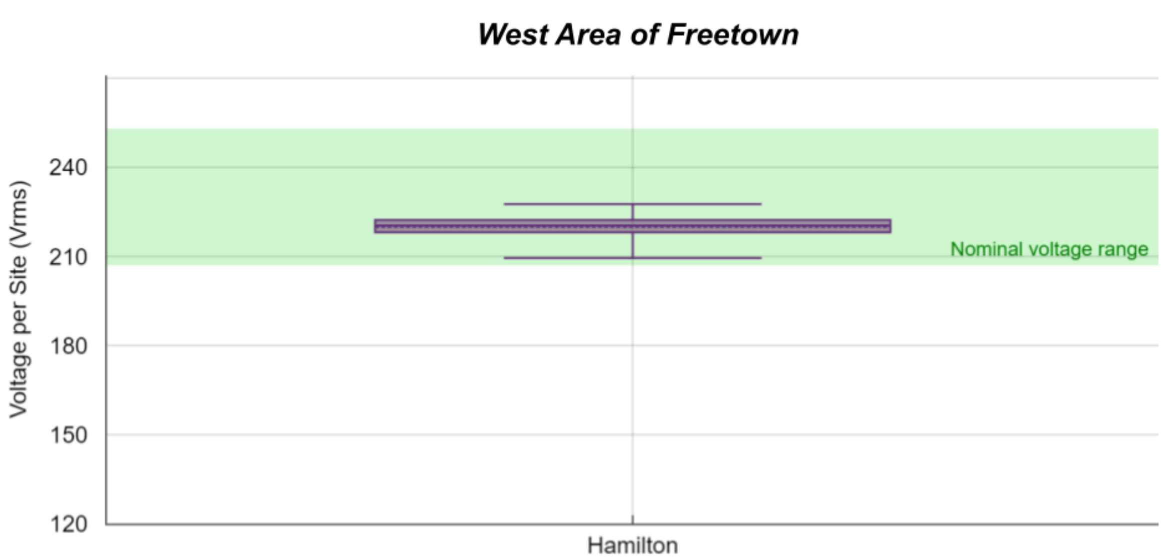
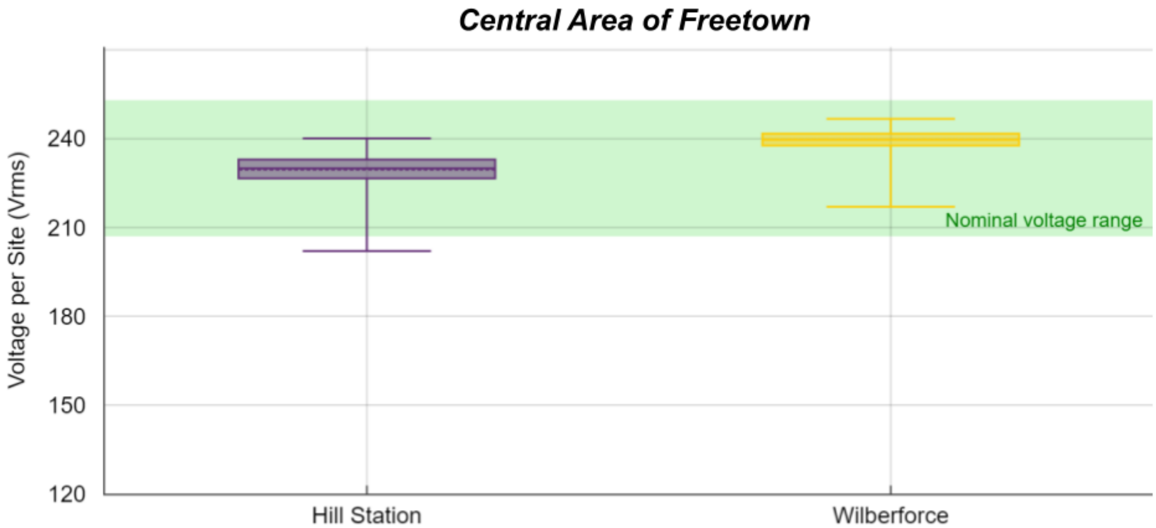


Figure 21: Hours of grid outages in west, central, and east areas of Freetown*. Average daily hours without power at one grid-connected CHP on the west side of Freetown (top), two grid-connected CHCs in central Freetown (middle), and four grid-connected CHCs on the east side of Freetown. Data was collected over an eight-week period (July 10 - August 31, 2023).*

Duration of Power Outages: Grid-powered health facilities on the eastern side of Freetown experienced significantly more time without power than facilities located in either the central and west areas. Kissy CHC, Saint Joseph CHC, Waterloo CHC, and Wellington CHC experienced a combined daily average of 7.12 hours without power, compared to a combined daily average of 1.46 hours without power for Hill Station and Wilberforce CHCs, and 1.36 daily hours of outages for Hamilton CHP.





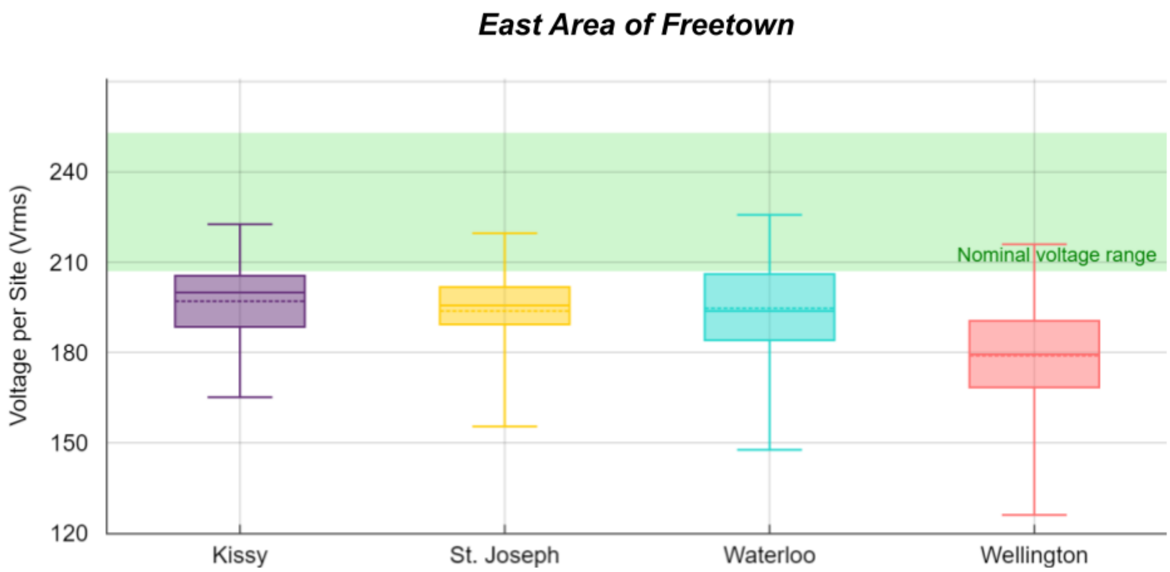


Figure 22: Grid power quality in west, central and east areas of Freetown*. Average voltage magnitude at one grid-connected CHP in the west (top), two grid-connected CHCs in central Freetown (middle), and four grid-connected CHCs on the east side of Freetown. Data was collected over an eight-week period (July 10 - August 31, 2023). A widely accepted global standard is to maintain voltage within ±10 % of nominal (230V in Sierra Leone). This standard nominal voltage range is shaded in green.*

Voltage Levels: The two grid-powered health facilities in central Freetown experienced the best average power quality, with a combined average voltage level of 235V over the eight-week period. Hamilton CHP, in the west, also experienced good voltage levels, with an average of 220V over the eight-week period, and notably had the least fluctuation in voltage levels and time spent outside the nominal voltage range. In contrast, facilities in the east experienced relatively poor power quality, with a combined average voltage level of 192V, below the recommended threshold of 207V.

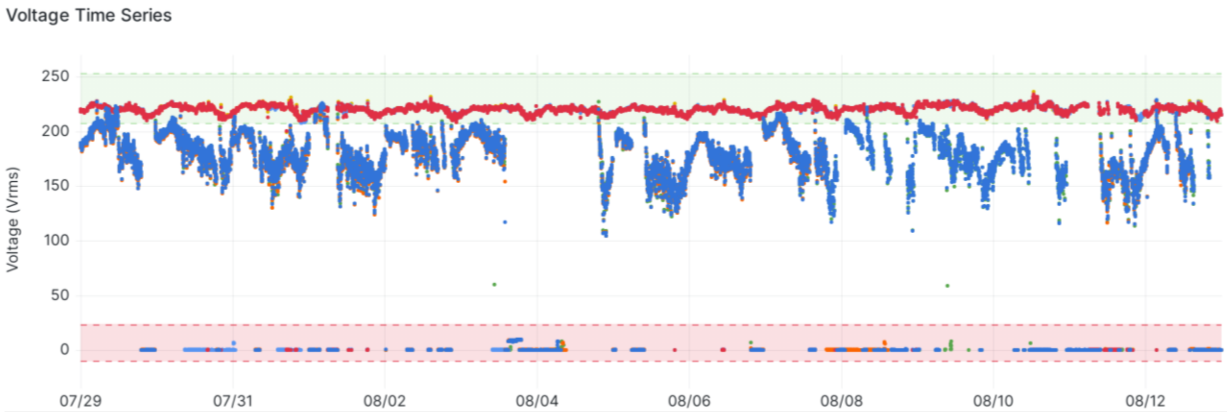


Figure 23: Comparing differences in PQR between two grid-reliant health facilities. *This time series view of raw sensor voltage levels (reported every two minutes) illustrates the difference in PQR experienced by Hamilton CHP (red) and Wellington CHC (blue). Hamilton CHP experiences relatively few, momentary outages and receives power that is consistently within recommended nominal voltage ranges (green shaded area). In contrast, Wellington CHC experiences daily outages of extended duration (4-6 hours on average) and consistently receives power below nominal voltage levels.*

Conclusion

Our data illustrate a clear difference in the quality and reliability of EDSA-supplied power based on sub-regions in the bulk grid: both power reliability and quality are best for grid-connected facilities in Freetown's west region, slightly worse in Freetown's central region, and meaningfully worse in Freetown's east region.

One potential explanation for this sub-regional variation is that Freetown's east side is heavily populated and serves as the main region for commercial industries and manufacturing. As a result, the grid infrastructure may be insufficient to satisfy the area's large electricity demand. In contrast, Freetown's west side is less populated and more recently developed, with fewer homes and businesses competing for energy from the grid.

Because PQR for grid-connected health facilities in Freetown varies by geographic region within the bulk-grid network, it cannot be assumed that all grid-connected health facilities are "fine" electricity-wise, and no further energy resiliency investments are needed. It is clear that a base level of service—in terms of supplying power within nominal voltage range and of reasonable reliability—is not provided equally for all utility-paying health facilities. For facilities that rely strictly on the grid as their sole power source, this can have meaningful impacts on the delivery of healthcare services.

9. The Impacts of EnergyStacking o n Power Quality and Reliability

This section analyses to what extent energy stacking may affect PQR for health facilities. For example, we explore whether grid-connected health facilities with a secondary energy solution experience better PQR than facilities that rely strictly on grid-supplied power. For this analysis, we selected a subsample of four health facilities using the following criteria:

1. **The health facilities are grid-connected**
2. **The health facilities are located in the eastern region of Freetown.** We focus on the eastern region to control for variations in PQR between subregions in the bulk-grid network (see the previous section on PQR by subregion).

We found that three out of the four facilities do not perform energy stacking and rely 100% on EDSA-provided grid power. Only one facility performs energy stacking by relying on solar-provided power primarily and grid-provided power as a backup energy source.

Health Facility	Electricity Source		
	Solar	Generator	Grid
Hastings CHC	✓	✗	✓
Saint Joseph CHC	✗	✗	✓
Wellington CHC	✗	✗	✓
Kissy CHC	✗	✗	✓

Figure 24: Energy solutions at health facilities in eastern Freetown. *An electricity source is marked as "✓" only if it is functional and actively supplied power (even if used only sporadically).*

Figures 25, 26, and 27 illustrate PQR KPIs from July 20 through August 31, 2023 (six weeks).

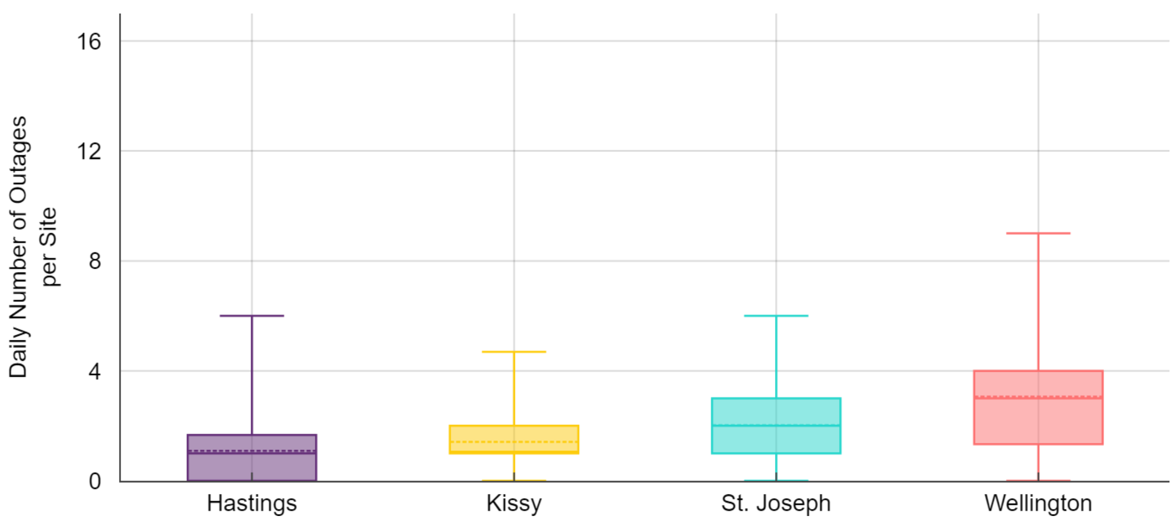


__Figure 25: Power Outage Frequency.__ Average daily number of power outages measured at four health facilities over a six-week period (July 20 - August 31, 2023). Hastings CHC relies primarily on solar and reverts to grid power as backup. Kissy, Saint Joseph, and Wellington CHCs rely strictly on grid power.

Frequency of Power Outages: Hastings CHC—which relies primarily on solar with grid as a backup energy source—experienced less-frequent power outages than the three CHCs that rely solely on EDSA-provided grid power. Hastings CHC experienced a daily average of 1.09 outages, while Kissy, Saint Joseph, and Wellington CHCs experienced a combined average of 2.17 power outages per day.

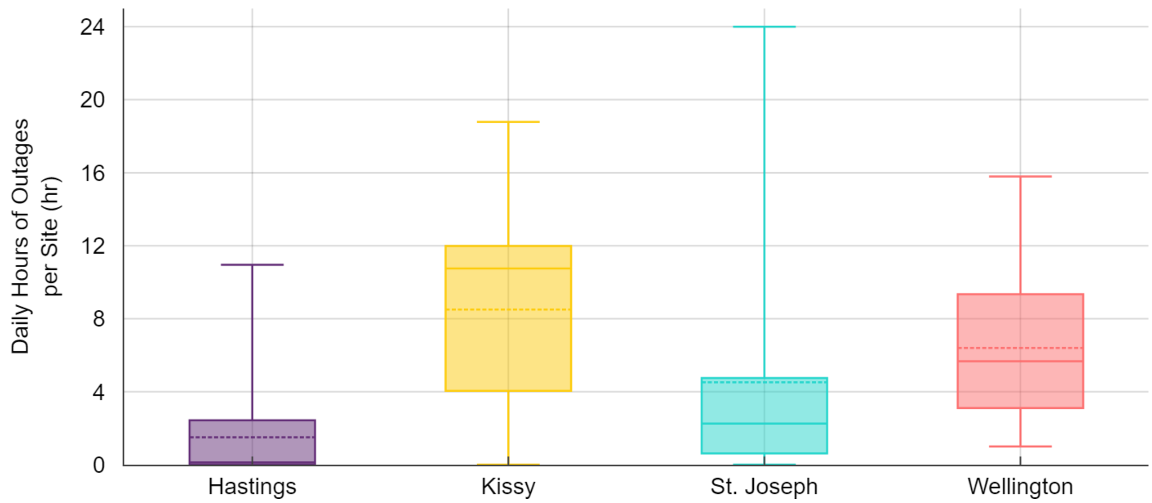


__Figure 26: Power Outage Duration.__ Average daily hours without power measured at four health facilities over a six-week period (July 20 - August 31, 2023). Hastings CHC relies primarily on solar and reverts to grid power as backup. Kissy, Saint Joseph, and Wellington CHCs rely strictly on grid power.

Duration of Power Outages: Hastings CHC experienced fewer average hours without power than Kissy, Saint Joseph, and Wellington CHCs. Hastings CHC had an average of 1.50 hours without power each day, while the three other, strictly-grid-powered health facilities had a combined average of 6.47 hours without power each day.

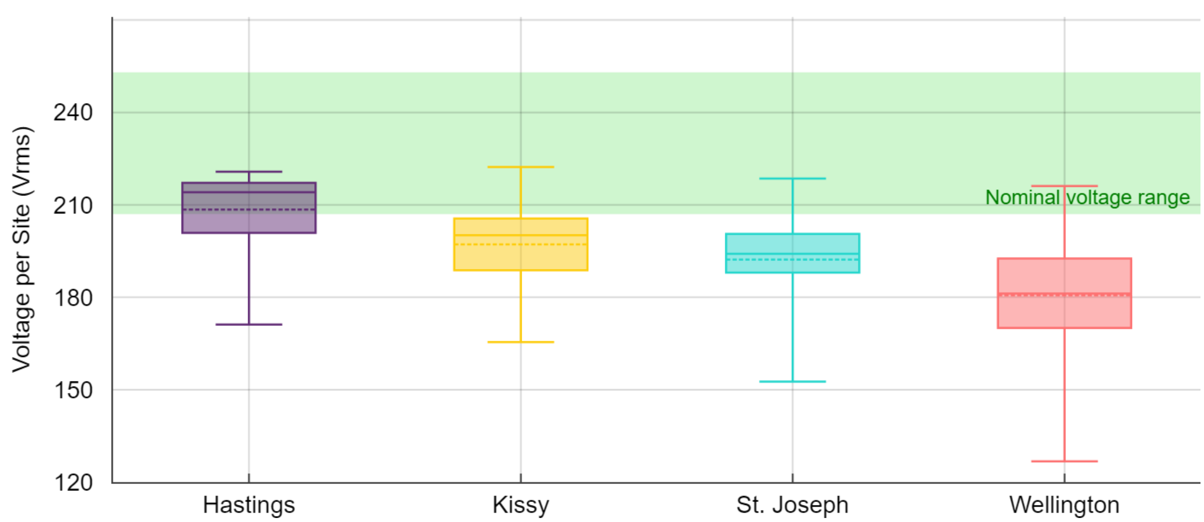


Figure 27: Power Quality Profiles*. Average voltage magnitude at four health facilities over a six-week period (July 20 - August 31, 2023). Hastings CHC relies primarily on solar and reverts to grid power as backup. Kissy, Saint Joseph, and Wellington CHCs rely strictly on grid power. A widely accepted global standard is to maintain voltage within ±10 % of nominal (230V in Sierra Leone). This standard nominal voltage range is shaded in green.*

Voltage levels: Voltage levels at Hastings CHC largely remain within nominal voltage range, with an average voltage of 209V, while the facilities depending on EDSA-provided grid power had a combined average voltage of 190V.

Conclusion

Hastings CHC—the energy-stacking facility in this sample—experiences better power quality and reliability than the grid-dependent facilities in the same region. Energy stacking solar with grid power clearly provides Hastings CHC with greater energy security; by relying primarily on solar and switching to grid power as a backup energy source, the facility is able to reduce both the number of outages and time spent without power. These results show that when the grid is not supplying reliable power, energy stacking (with solar) can make a notable difference in improving power reliability for a health facility. Further, the solar PV system supplies quality power that is consistently within nominal voltage range, which ensures voltage levels are sufficient to power medical and office equipment.

Case Study: Energy Stacking at Hastings CHC

Hastings CHC is a relatively large facility; it employs around 50 medical staff and contains, among other things, a maternity unit with labor and delivery, antenatal, and postnatal rooms, an HIV/TB unit, an "under five" unit, a well-equipped laboratory, a drug store, and administrative offices.

Two main power sources provide electricity for the facility: a 15kW solar PV system (provided by the Western Area Rural District Council) and EDSA grid power. All functional wall sockets are dual connected to both the solar PV system and grid power. To save on utility costs, Hastings CHC primarily relies on solar power. As explained by the CHO: "We only use the EDSA power if the solar power is off . . . most of the time we prefer to use solar than the [grid power] because [grid power] is less cost-effective."

Voltage data clearly shows the facility switching between the two power sources: shortly before midnight each day, power from solar runs out and the facility automatically switches to grid power until around 8:00 or 9:00 AM when solar power is restored (see Figure 28 below). The voltage time series displays the variation in power quality provided by the two energy sources: voltage levels from the solar PV system are consistently within nominal range at an average of 215V (the horizontal lines). In contrast, grid power is consistently low quality and ranges from an average of 139V to 195V (the arched lines).

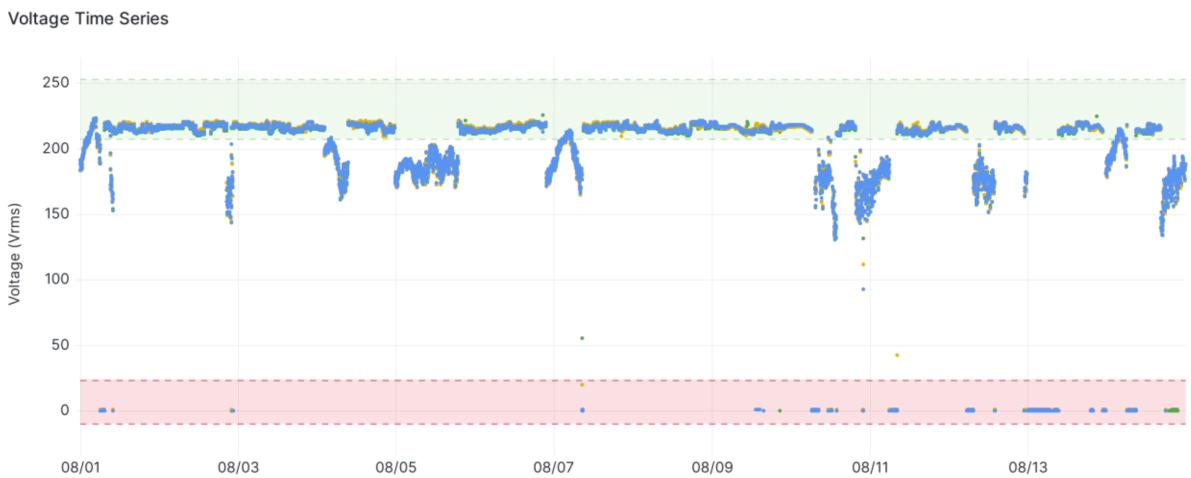


Figure 28: Voltage time series at Hastings CHC. *Snapshot of nLine's data dashboard showing the facility's daily switch between solar and grid power and the variation in voltage stability and quality between solar (horizontal lines within nominal voltage range) and grid power (arches below nominal voltage range).*

Policy Implications

The data and analysis from this project provide crucial insights into the reliability and quality of electricity access for 15 public health facilities in Sierra Leone. Our findings suggest several policy implications and underscore the need for further work to understand PQR for healthcare across a wider scale of energy solutions and investments.

10.1 Advance more high-resolution, standardised frameworks for measuring dimensions of electricity access in health facilities

As decision makers involved in healthcare electrification move beyond binary definitions of "energy access" to measure electrification progress, efforts should also be made to move beyond recall-based surveys as the standard PQR measurement approach, when appropriate. For example, ESMAP's recommended metrics for measuring multidimensional measures of electricity access (below) can be collected at-scale and free of recall bias by using innovative technologies, such as remote monitoring.

Availability	HE7. In the last 7 days, how many hours of electricity were available each day on average from [NAME MAIN electricity system]? (Maximum 24 hours) HE8. In the last 7 days, how many hours of electricity were available each evening on average, from 6:00 pm to 10:00 pm from [NAME MAIN electricity system]? (Maximum 4 hours)
Reliability	HE9. In the last 7 days, how many times were there unscheduled outages or blackouts from [NAME MAIN electricity system]? HE10. What is the total duration of all the unscheduled outages or blackouts in the last 7 days?
Quality	HE12. In the last 12 months, did any of this household's appliances get damaged because the voltage was going up and down in the [NAME MAIN electricity system from HE3]?

Figure 29: *PQR-related survey questions developed by the WB and the WHO to measure household electricity access [22]. Surveyed individuals are expected to recall the cumulative hours and number of power outages experienced in the last week, which poses numerous challenges for data accuracy.*

Electrification policies and investments should be informed by PQR data from affordable, high-resolution, longitudinal data collection approaches that are becoming available. This data has the ability to capture and expose—at scale—the PQR challenges that already electrified health facilities often experience, which can in turn be used to inform the allocation of resources to target electricity interventions where it is needed most. Remote monitoring PQR of energy supply should be the norm for expanding healthcare electrification and can establish and advance a standardised framework for "uniformly and fully measure(ing) the diverse dimensions of sustainable energy access" [4].

This push beyond the norm cannot happen on its own. SDG 3 and 7 actors—including development agencies (e.g. USAID and FCDO), multilateral development banks (e.g. WB), and intergovernmental organizations (e.g. WHO)—should promote and support the development and scaled testing of innovative data collection methods that provide low-cost, accurate, continuous measurements of power quality and reliability. Aggregated insights from these methods and tools can be leveraged to formalize a set of recommended PQR KPIs and standards for healthcare electrification.

10.2 Conduct rigorous research to understand how power quality and reliability impact health facility operational effectiveness and healthcare service delivery

To develop electricity indicators and thresholds of "acceptable PQR", there must be a more rigorous understanding of how PQR affects the provision of medical services and a subsequent quantification of the human cost of such impacts. Anecdotally, it is widely known that the efficient operation of medical equipment and appliances hinges on the reliability and quality of supplied electricity. For example, the World Bank's ESAMP states that "voltage should be adequate and stable, as it can otherwise affect the delivery of health services and may damage vital medical equipment" [1]. But it is necessary to define what actually constitutes a "reliable" power supply for a health facility—which may vary based on facility type, size, and healthcare services provided—and what constitutes "adequate" voltage levels for equipment to operate properly. Pairing direct, continuous PQR measurements at health facilities with data on medical equipment usage and patient outcomes can help standardise acceptable electricity parameters for healthcare electrification [3].

10.3 Move away from "install and forget" towards "install, monitor, and maintain"

Electrifying health facilities through decentralized renewable energy solutions can help build climate resilience and provide relatively rapid access to energy in rural contexts without waiting for grid connectivity [2]. However, renewable energy projects need to be measured, monitored, and evaluated to ensure these solutions provide adequate power to meet health facilities' operating needs. Similarly, power supply at grid-connected facilities should be monitored to inform if additional energy resiliency solutions are needed. As shown in the case study with Princess Christian Maternity Hospital, it is important to collect longitudinal data: PQR often changes month to month and seasonally. Real-time, high-resolution data is equally important as even outages of just a few minutes can mean the difference between life and death, for example, for a patient on an oxygen concentrator. It is thus imperative to verify system performance after an initial electricity connection is made and to establish "accountability mechanisms and long-term operations and maintenance" plans [2].

10.4 Harmonise electricity data into existing public health facility national datasets to inform holistic health sector electricity interventions

PQR data should be "shared between energy, health, finance and planning ministries, as well as with public and private finance providers and development partners", to help design, monitor, evaluate, and prioritise healthcare electrification interventions [3]. In 2023, Sierra Leone's MoHS launched the nation's first openly accessible health facility dataset with data on over 1,500 facilities [20]. While this dataset is commendable for standardising national data collection and collecting attributes such as facility name, geolocation, facility type, and ownership, the dataset lacks any data on energy access and electrification status. We recommend harmonising existing public health facility national datasets — such as this GRID3 dataset — with PQR datasets to track the state of electrification at facilities. This merged dataset can serve as a national repository used by ministries of health and energy, in partnership with donors and investors, to prioritise healthcare electrification investments where they are needed most in Sierra Leone.

Conclusion

The existence of independent, direct measurements of PQR at health facilities allows public health agencies, ministries of energy, project implementers, and global investors to gain insight into the PQR challenges faced by already-electrified health facilities and how to remedy these challenges in future electrification initiatives. This study leveraged a novel, real-time, remote monitoring approach to assess PQR in 15 public health facilities in both urban and rural settings in Sierra Leone. Continuous data was collected from outlet-level power monitoring sensors at the facilities, each powered by a distinct combination of on- and off-grid energy systems. Based on our findings, we demonstrate that high-resolution, quantitative PQR data can provide data-driven answers to the question of how energy access solutions should be designed to support critical healthcare infrastructure.

Finally, this project uniquely reveals the near-universal presence of PQR issues at electrified health facilities and the dire need to collect objective, localized PQR data if healthcare electrification investments truly aim to achieve sustainability.

References

1. Bhatia, Mikul; Angelou, Niki. 2015. “Beyond Connections: Energy Access Redefined”. ESMAP Technical Report;008/15. © World Bank, Washington, DC. License: CC BY 3.0 IGO.
2. IEA (2023), “Tracking SDG7: The Energy Progress Report”, 2023, IEA, Paris, License: CC BY 4.0.
3. “Energizing health: accelerating electricity access in health-care facilities”. Geneva: World Health Organization, the World Bank, Sustainable Energy for All and the International Renewable Energy Agency; 2023. License: CC BY-NC-SA 3.0 IGO.
4. Adair-Rohani H, Zukor K, Bonjour S, Wilburn S, Kuesel AC, Hebert R, Fletcher ER. “Limited electricity access in health facilities of sub-Saharan Africa: a systematic review of data on electricity access, sources, and reliability”. Glob Health Sci Pract. 2013 Aug 14;1(2):249-61. doi: 10.9745/GHSP-D-13-00037. PMID: 25276537; PMCID: PMC4168575.
5. Apenteng BA, Opoku ST, Ansong D, Akowuah EA, Afriyie-Gyawu E. “The effect of power outages on in-facility mortality in healthcare facilities: Evidence from Ghana”. Glob Public Health. 2018 May; 13(5):545-555. doi: 10.1080/17441692.2016.1217031. Epub 2016 Aug 17. PMID: 27533753.
6. Alhadi Khogali, Almegdad Ahmed, Mona Ibrahim, Karrar Karrar, Mohamed Elsheikh, Elfatih Abdelraheem, Lucie Cluver & Elsiddig Elmukashfi (2022). “Building power-ful health systems: the impacts of electrification on health outcomes in LMICs”, Psychology, Health & Medicine, 27:sup1, 124-137, DOI: 10.1080/13548506.2022.2109049.
7. “Powering Social Infrastructure in Sierra Leone: Market Assessment and Roadmap for Health Facilities”, SEforALL, 2023.
8. “Location Report - Sierra Leone”, Human Resources Health Directorate, Ministry of Health and Sanitation, https://hrhsl.org/reports/location.
9. “Electricity in Health-Care Facilities”, Sun-Connect, 2023 Aug 23, https://sun-connect.org/electricity-in-health-care-facilities/.
10. “Database on Electrification of Health-Care Facilities”, The Global Health Observatory, WHO. https://www.who.int/data/gho/data/themes/database-on-electrification-of-health-care-facilities
11. “Maternal and Newborn Health Disparities: Sierra Leone,” UNICEF, 2023.
12. Sierra Leone, The World Factbook, CIA.
13. Levine, Madison; Meriggi, Niccolo; Mobarak, Mishfiq; Ramakrishna, Vasudha; Sattlegger, Lennart; Voors, Maarten; Islam, Artiful; Kallon, Sellu. “Rural Renewable Energy Project in Sierra Leone: Impact Evaluation Report”, May 2022, International Growth Centre.
14. “Opinion: Power in a Pandemic - Why Energy Access Matters During Coronavirus”, Damilola Ogunbiyi, Thomas Reuters Foundation News, 2020 March 31. https://news.trust.org/item/20200331134807-w6a0h/
15. “From Procurement to Performance: Towards a private sector-led, service-based model to scale up sustainable electrification of public institutions“, SEforALL, 2021 Dec 02.
16. Ferrall, Isa; Callaway, Duncan; Kammen, Daniel M. “Measuring the reliability of SDG 7: the reasons, timing, and fairness of outage distribution for household electricity access solutions”. Environmental Research Communications, 2022 May 6.
17. Aidoo K and Briggs R C. “Underpowered: Rolling blackouts in Africa disproportionately hurt the poor”, African Studies Review, 2019.

18. Odero, Margaret and Bariya, Mohini. “A Clustering Algorithm for Power Outage Detection”, January 5 2023. https://blog.nline.io/clustering-1
19. “International Development Association Project Paper on a Proposed Additional Credit in the Amount of SDR 36.1 Million to the Republic of Sierra Leone for the Energy Sector Utility Reform Project”, the World Bank, April 25 2019.
20. “Sierra Leone’s first openly accessible health facilities dataset now available”, Grid3, August 29 2023. https://grid3.org/news/sierra-leone-health-facilities-dataset?utm_source=marketo&utm_medium=email&utm_campaign=idev-weekly&utm_content=grid3article&mkt_tok=ODcwLUNSVy05NzMAAAGOMQhtLzQCe-A-wLcneho1JvQw5WFJoZCuvuEK7Gq5gxrb1Ey3htDk0WfUN6KxJ9Hp9z8NnyQq54GPC1dld4XBeDbvt2lOJhAXYAz70JPR
21. “International Bank for Reconstruction and Development Program Appraisal Document on a Proposed Loan in the Amount of US$500 million to the Federal Republic of Nigeria for the Nigeria Distribution Sector Recovery Program”, the World Bank, January 13 2021.
22. World Bank and the World Health Organization. 2021. Measuring Energy Access: A guide to collecting data using ‘the core questions on household energy use’. Washington, DC: World Bank. (WHO/HEP/ECH/AQH/2021.9). License: Creative Commons Attribution CC BY 3.0 IGO

Appendix

PQR Profiles of 15 Health Facilities

Data collection time period: July 20 2023 - August 31 2023

Daily Hours of Outage Per Site (hours)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Ola During	0.03	0.00	0.00	0.50
Hastings	1.50	0.12	0.00	10.95
Wilberforce	1.72	0.90	0.00	8.71
Princess Christian	1.43	1.15	0.00	8.71
Hamilton	1.44	0.37	0.00	24.00
Masanga	2.63	1.84	0.03	8.66
Lakka	0.92	0.37	0.00	7.26
Hill Station	1.32	0.84	0.00	8.01
St. Joseph	4.51	2.25	0.00	24.00
Kissy	8.51	10.76	0.00	18.78
Kambia	7.66	7.37	1.77	13.03
Kabala	9.71	8.70	5.08	15.19
Wellington	6.40	5.67	1.00	15.80
Waterloo	6.63	1.57	0.14	15.83
Bonthe	18.43	19.91	2.77	24.00

Daily Number of Outages per Site (number)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Ola During	0.63	0.17	0.00	2.73
Masanga	0.73	0.50	0.00	2.25
Waterloo	2.52	2.67	0.00	7.00
Hastings	1.09	1.00	0.00	6.00
Kissy	1.41	1.01	0.00	4.69
Kambia	1.76	1.60	0.40	5.60
Kabala	1.84	1.75	0.53	3.50
Hill Station	1.80	1.00	0.00	6.00
Wilberforce	1.84	1.67	0.00	6.67
Princess Christian	1.99	1.84	0.00	5.32
Lakka	2.13	1.75	0.00	9.00
Hamilton	2.09	1.33	0.00	7.67
Bonthe	2.16	2.00	0.00	5.00
St. Joseph	2.02	2.00	0.00	6.00
Wellington	3.07	3.00	0.00	9.00

Voltage per Site (Vrms)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Wilberforce	240	240	220	247
Princess Christian	237	237	212	246
Kabala	232	234	208	242
Ola During	229	230	183	240
Bonthe	227	227	190	235
Hill Station	229	230	205	240
Masanga	224	224	204	231
Kambia	221	221	201	231
Lakka	221	221	205	234
Hamilton	220	220	209	227
Hastings	209	214	172	221
Kissy	197	200	165	222
St. Joseph	192	194	153	219
Waterloo	197	197	148	227
Wellington	181	182	127	216

PQR by Health Facility Type (Hospitals vs. Non-Hospitals)

Data collection time period: July 20 2023 - August 31 2023

Daily Hours of Outage Per Site - Hospitals (hours)				
Health Facility	**Mean**	**Median**	**Min**	**Max**
Bonthe	18.43	19.91	2.77	24.00
Kabala	9.71	8.70	5.08	15.19
Kambia	7.66	7.37	1.77	13.03
Lakka	0.92	0.37	0.00	7.26
Masanga	2.63	1.84	0.03	8.66
Ola During	0.03	0.00	0.00	0.50
Princess Christian	1.43	1.15	0.00	8.71
TOTAL AVERAGE	**5.83**	**5.62**	**1.38**	**11.05**

Daily Number of Outages - Hospitals (number)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Bonthe	2.16	2.00	0.00	5.00
Kabala	1.84	1.75	0.53	3.5
Kambia	1.76	1.60	0.40	5.60
Lakka	2.13	1.75	0.00	9.00
Masanga	0.73	0.50	0.00	2.25
Ola During	0.63	0.17	0.00	2.73
Princess Christian	1.99	1.84	0.00	5.32
TOTAL AVERAGE	**1.61**	**1.37**	**0.13**	**4.77**

Voltage Statistics - Hospitals				
Site ID	**Mean**	**Median**	**Min**	**Max**
Bonthe	227	227	190	235
Kabala	232	234	208	242
Kambia	221	221	201	231
Lakka	221	221	205	234
Masanga	224	224	204	231
Ola During	229	230	183	240
Princess Christian	237	237	212	246
TOTAL AVERAGE	**227**	**228**	**200**	**237**

Daily Hours of Outage Per Site - Community Health Centers (CHCs) (hours)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hastings	1.50	0.12	0.00	10.95
Hill Station	1.32	0.84	0.00	8.01
Kissy	8.51	10.76	0.00	18.78
St. Joseph	4.51	2.25	0.00	24.00
Waterloo	6.63	1.57	0.14	15.83
Wellington	6.40	5.67	1.00	15.80
Wilberforce	1.72	0.90	0.00	8.71
TOTAL AVERAGE	**4.37**	**3.16**	**0.16**	**14.58**

Daily Number of Outages - Community Health Centers (CHCs) (number)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hastings	1.09	1.00	0.00	6.00
Hill Station	1.8	1.00	0.00	6.00
Kissy	1.41	1.01	0.00	4.69
St. Joseph	2.02	2.00	0.00	6.00
Waterloo	2.52	2.67	0.00	7.00
Wellington	3.07	3.00	0.00	9.00
Wilberforce	1.84	1.67	0.00	6.67
TOTAL AVERAGE	**1.96**	**1.76**	**0.00**	**6.48**

Voltage Statistics - Community Health Centers (CHCs)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hastings	209	214	172	221
Hill Station	229	230	205	240
Kissy	197	200	165	222
St. Joseph	192	194	153	219
Waterloo	197	197	148	227
Wellington	181	182	127	216
Wilberforce	240	240	220	247
TOTAL AVERAGE	**206**	**208**	**170**	**227**

PQR by Subregion in Freetown's Grid Network

Data collection time period: July 10 2023 - August 31 2023

Daily Hours of Outage Per Site - WEST (hours)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hamilton	1.36	0.37	0.00	24.00

Daily Number of Outages Per Site - WEST (number)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hamilton	1.92	1.33	0.00	7.67

Voltage Statistics Per Site - WEST				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hamilton	220	220	209	228

Daily Hours of Outage Per Site - CENTRAL (hours)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hill Station	1.28	0.62	0.00	8.01
Wilberforce	1.63	0.83	0.00	8.71
TOTAL AVERAGE	**1.46**	**0.73**	**0.00**	**8.36**

Daily Number of Outages Per Site - CENTRAL (number)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hill Station	1.72	1.00	0.00	6.00
Wilberforce	1.73	1.67	0.00	6.00
TOTAL AVERAGE	**1.73**	**1.34**	**0.00**	**6.00**

Voltage Statistics Per Site - CENTRAL				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hill Station	230	230	202	240
Wilberforce	240	240	217	247
TOTAL AVERAGE	**235.00**	**235.00**	**209.50**	**243.50**

Daily Hours of Outage Per Site - EAST				
Site ID	**Mean**	**Median**	**Min**	**Max**
Kissy	8.60	10.76	0.00	18.78
St. Joseph	4.00	2.23	0.00	24.00
Waterloo	9.21	8.90	0.14	20.89
Wellington	6.67	5.21	1.00	19.30
TOTAL AVERAGE	**7.12**	**6.78**	**0.29**	**20.74**

Daily Number of Outages Per Site - EAST				
Site ID	**Mean**	**Median**	**Min**	**Max**
Kissy	1.39	1.01	0.00	4.69
St. Joseph	1.95	1.09	0.00	6.00
Waterloo	2.74	1.70	0.00	7.67
Wellington	2.89	2.33	0.00	9.00
TOTAL AVERAGE	**2.24**	**1.53**	**0.00**	**6.84**

Voltage Statistics Per Site - EAST				
Site ID	**Mean**	**Median**	**Min**	**Max**
Kissy	197	200	165	222
St. Joseph	194	195	156	220
Waterloo	196	195	149	226
Wellington	179	179	126	216
TOTAL AVERAGE	**191.50**	**192.25**	**149.00**	**221.00**

Stacking Energy Solutions

Data collection time period: July 20 2023 - August 31 2023

Daily Hours of Outage Per Site - Energy Stacking (hours)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hastings (stacker)	1.50	0.12	0.00	10.95
Kissy	8.51	10.76	0.00	18.78
St. Joseph	4.51	2.25	0.00	24.00
Wellington	6.40	5.67	1.00	15.80
Average for non-stackers	**6.47**	**6.23**	**0.33**	**19.53**

Daily Number of Outages Per Site - Energy Stacking (number)				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hastings (stacker)	1.09	1.00	0.00	6.00
Kissy	1.41	1.01	0.00	4.69
St. Joseph	2.02	2.00	0.00	6.00
Wellington	3.07	3.00	0.00	9.00
Average for non-stackers	**2.17**	**2.00**	**0.00**	**6.56**

Voltage Statistics Per Site - Energy Stacking				
Site ID	**Mean**	**Median**	**Min**	**Max**
Hastings (stacker)	209	214	172	221
Kissy	197	200	165	222
St. Joseph	192	194	153	219
Wellington	181	182	127	216
Average for non-stackers	**190.00**	**192.00**	**148.33**	**219.00**

IGC

www.theigc.org