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Are we on the path to sustainable health electrification? Lessons from remote power quality and reliability monitoring at health facilities in Sierra Leone

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- Access to quality electricity plays an essential role in the delivery of quality healthcare services. In the effort to improve electricity access globally, there has been little focus on quality of the resulting electricity. Across the thousands of already-electrified clinics in sub-Saharan Africa (SSA), widespread anecdotes speak to chronically poor power quality and reliability (PQR).
- There is little quantitative evidence on the nature and scale of PQR challenges and their impact on healthcare provision. Understanding PQR in electrified health facilities across SSA is critical to improving programme designs, targeting energy planning investments, and ensuring sustainable health electrification.
- PQR data has been challenging to collect in SSA due to a lack of remote monitoring technologies that can collect high-resolution, longitudinal PQR measurements at scale.
- This project leverages an innovative remote monitoring approach to collect minute-by-minute PQR for over eight weeks at 15 public health facilities (on- and off-grid) in both rural and urban settings in Sierra Leone.
- This brief highlights policies that can bridge PQR data gaps and standards, contributing to more sustainable healthcare electrification investments. The findings show meaningful variations in PQR at electrified health facilities that differ based on facility type, available energy systems, access to backup energy sources, and geographic location within Freetown's bulk-grid network.

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Introduction

High quality energy access for healthcare delivery

While 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") have helped drive policy and investment actions at the health-energy intersection in sub-Saharan Africa (SSA), the COVID-19 pandemic became a tipping point, demonstrating the need for energy resilience to respond to public health emergencies. Recent evaluations of health electrification projects are beginning to emphasise power quality and reliability (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 untenable (Adair-Rohani et al, 2013). 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 sterilisation and refrigerated vaccine and medicine storage (Bhatia and Angelou, 2015).

> **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.**
>
> - Damilola Ogunbiyi, CEO of SEforALL

Healthcare electrification in Sierra Leone

This project studied healthcare electrification in the context of Sierra Leone, a West African country with a population of approximately 8.9 million people (The World Factbook, 2023). Only 26% of Sierra Leone's population has access to electricity, with rural access estimated as 6% (SEforALL, 2023). 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. For example, the nation holds one of the highest maternal mortality rates in the world, in no small part due to the absence of resources—such as electricity—that contributes to the lack of access to high-quality maternal healthcare, including the ability to treat postpartum hemorrhage by blood transfusion (Qiao, 2023). Roughly 38% of health facilities in Sierra Leone lack any access to electricity and for those facilities with some form of access, most experience unreliable and inadequate electricity regardless of their combination of energy sources (SEforALL, 2023).

Challenges collecting high-resolution, independent, longitudinal power quality and reliability data

Despite the glaring impacts of PQR on healthcare delivery and the devastating human costs, electrification programmes continue to measure electricity access primarily using metrics such as the number of electricity connections added and to measure power reliability primarily using survey-based recall questions. This is problematic because neither method accurately measures PQR.

> **Even when health facilities [have] an electricity connection, there may [be] significant quality-of-supply issues for which data are not collected (Bhatia and Angelou, 2015).**

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 as well as monetary costs associated with collecting standardised PQR data in low-resource settings at-scale. Additionally, few utilities—including solar mini-grid providers—are required to report quality and reliability data to investors, donors, or regulators. These challenges have allowed binary measurements of electricity access and PQR data collection through surveys to remain as the status quo.

Project overview

This project sought to provide a solution to this PQR data gap by leveraging Gridwatch, a novel remote measurement approach that combines quickly deployable wall outlet sensors with cloud algorithms to aggregate sensor data into key performance indicators (KPIs) of energy system quality and reliability. Over a period of eight weeks, real-time sensor data was collected on power outages (frequency and duration) and voltage and frequency levels at 15 public health facilities. These facilities were powered by a combination of on- and off-grid, renewable- and non-renewable energy sources.

By using a combination of sensor data, site energy assessments, and in-person surveys, the project generated detailed PQR profiles for each facility and a suite of comparable PQR KPIs. Further, the project explored whether PQR varies by health facility type (eg hospital vs. non-hospital), geographic location in Freetown's bulk-grid network, and availability of backup energy sources. The findings are based on data collected from 10 July through 31 August, 2023 (eight weeks).

TABLE 1: Available electricity sources at 15 public health facilities*.

Health Facility Type	Health Facility	Electricity Source		
		Solar	Generator	Grid
Teaching / Tertiary Hospital	Ola During Children's Hospital	✓	✓	✓
	Princess Christian Maternity Hospital	✗	✓	✓
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	✗	✗	✓

*Note: Energy sources are marked as present (✔) if the 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.

Key findings

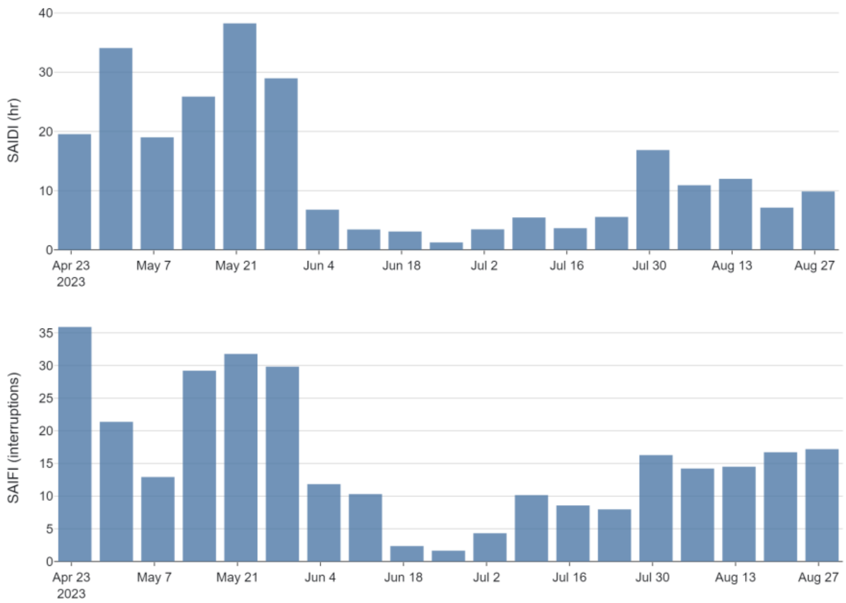
Meaningful differences in power quality and reliability exist among electrified health facilities

Having access to electricity—whether through grid, solar and/or generator provided power—does not necessarily mean a health facility has a reliable power supply that is of sufficient quality for providing medical services. Among the 15 health facilities, some facilities experienced few power outages with short durations each day and received power that is consistently within recommended nominal voltage range. For example, Ola During Children's Hospital—a grid-connected hospital with both solar and diesel generator backups—experienced an average of less than one power outage per day and less than one hour without power, leveraging a combination of grid power and diesel generator and solar backups.

In contrast, other facilities, such as Wellington Community Health Centre, experienced meaningfully worse power, with an average of three daily power outages and over five hours without power each day on average. This wide variation in PQR demonstrates the importance of longitudinal monitoring to ensure reliable, high-quality electricity is provided after an initial connection is made.

Case study: Seasonal variations in power quality and reliability at Princess Christian Maternity Hospital (PCMH)

PQR can vary daily, weekly, monthly, and seasonally. Here we present an example of variance in PQR at PCMH over time. Data shows that April and May exhibited significantly worse power reliability than June, July, and August. This trend coincides with Sierra Leone's rainy season that historically begins in late May or early June, which results in substantial variation in the country's hydropower generation capacity. 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.



Power reliability is more influenced by available energy sources than by the facility type itself

The highest tier of health facilities are often assumed to fare better than primary health centres in both electricity access and reliability of electricity supply.

However, findings show that while hospitals have better-quality power on average than community health centres (CHCs), power reliability differences between hospitals and CHCs are not as clear; hospitals experience slightly fewer average daily outages but slightly more average daily hours spent without power than CHCs. Seven hospitals and seven CHCs experienced nearly the same average daily number of power outages: 1.61 and 1.96 outages daily respectively. Hospitals experienced slightly higher average daily hours without power than CHCs: 5.83 hours averaged across hospitals compared to 4.37 hours respectively. However, higher averages for hospitals are skewed by Bonthe Government Hospital, an off-grid hospital that experiences an average of more than 12 hours of outages each day.

The CHCs, all of which were grid-connected, experienced worse power quality due to the below-nominal voltage on large parts of the Sierra Leonean grid; off-grid hospitals were powered by solar and generator-provided power that provided more stable voltage. Importantly, the data reveals notable differences in PQR *among* hospitals and *among* CHCs that were substantially impacted by their power supply (grid, solar, generator). Overall, results show that there are still pervasive power quality and reliability issues even for already electrified facilities providing the highest tiers of health care.

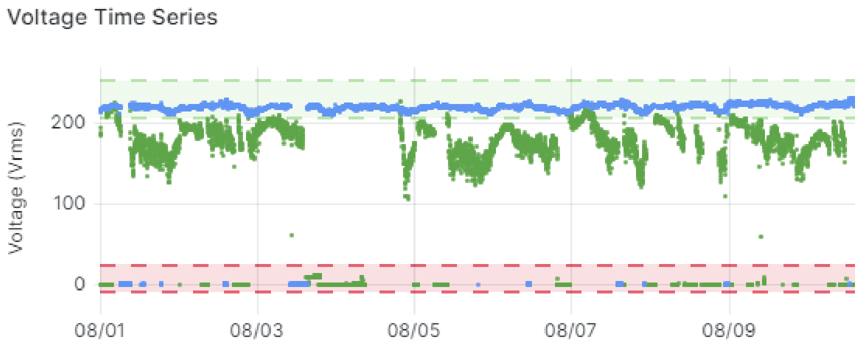
Health facilities do not experience the same level of quality and reliability from grid-supplied power in Freetown

Sensor data illustrate a clear difference in the quality and reliability of grid power provided by the Electricity Distribution and Supply Authority (EDSA) based on sub-regions in the bulk grid. PQR is best for grid-connected facilities in Freetown's west region, slightly worse in Freetown's central region, and drastically worse in Freetown's east region. Hamilton CHP, in the west, experienced an average of 220V over the eight-week period and CHCs in the central area experienced a combined average of 235V. In contrast, CHCs in the east experienced a combined average of 192V, below the IEEE recommended threshold of 207V (i.e. 10% below 230V). The average daily duration of power outage in the west, central, and east areas of Freetown were 1.36 hours, 1.46 hours, and 7.12 hours, respectively. While further grid infrastructure research is required to understand the exact reasons for PQR variability, 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. For health facilities in the eastern region of Freetown that rely strictly on the grid for electricity, this can have meaningful impacts on the delivery of healthcare services.

> **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.**

Case study: Two grid-reliant health facilities

Visualisations of real-time voltage readings from Gridwatch sensors show a clear difference in the reliability and quality of bulk-grid supplied power to health facilities in the western region of Freetown compared to the eastern region. Here, Hamilton CHP (located on the western side of Freetown and shown in blue below) experiences consistently good grid voltage within nominal range and generally good grid reliability (2.09 average daily outages and an average of 1.44 hours without power each day). In contrast, Wellington CHC (located on the east side of Freetown and shown in green below) experiences grid voltage levels that are consistently below recommended levels (green shaded area) and poor grid reliability (3.07 average daily outages and an average of 6.40 hours without power each day). *Note: power outages can be seen in the visualisation below via the gaps in voltage data and corresponding 0V levels*.



Energy stacking helps mitigate challenges from inadequate and unreliable grid power

Given the observed inequities in PQR within Freetown's bulk-grid network, we explored to what extent energy stacking may affect PQR for grid-connected health facilities. In the eastern region of Freetown, three out of four CHCs from our sample rely 100% on EDSA-provided grid power, while one CHC relies on solar-provided power primarily and grid-provided power as a backup energy source. Findings show that a secondary, non-grid power source meaningfully improves energy resilience. Hastings CHC—the facility that performs energy stacking—experienced a daily average of 1.09 outages and 1.50 average hours without power each day. By comparison, Kissy CHC, Saint Joseph CHC, and Wellington CHC—the three CHCs with grid power only—-experience a combined daily average of 2.17 outages and 6.47 average hours without power each day. Voltage levels at Hastings CHC were largely within nominal range while the three CHCs depending on EDSA-provided grid power had a combined average voltage below nominal (190V).These results show that when the grid is not supplying high-quality, reliable power, energy stacking (with solar) can make a notable difference in improving PQR for a health facility.

Policy recommendations

Below are five recommendations for ministries of health and energy, healthcare electrification donors and investors, project implementers, regulators, and researchers to improve the sustainability of healthcare electrification investments.

Support 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. Instead, electrification policies and investments should be grounded in independent, high-resolution, longitudinal data collection approaches to unmask disparities in reliability and mitigate disruptions to the delivery of quality health care. The utilisation of available real-time and direct monitoring methodologies and tools should be the norm for expanding healthcare electrification, as this is a first step towards building a standardised framework for “uniformly and fully measure(ing) the diverse dimensions of sustainable energy access” (Adair-Rohani et al, 2013).

> **Innovative technologies such as remote monitoring can generate valuable data that can help validate [energy system] performance and [energy] services…[Use] digital remote monitoring to calculate and monitor KPIs, and to offer public and private actors real-time information about the state of health centre electrification SEforALL, 2021.**

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. Furthermore, 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 medical equipment and appliances 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 (World Health Organization et al., 2023).

Move away from “install and forget” towards “install, monitor, and maintain”.

It is imperative to verify system performance after an initial electricity connection is made and to establish “accountability mechanisms and long-term operations and maintenance” (SEforALL, 2021). 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.

Harmonise electricity data with existing public health facility national datasets to inform holistic health sector electricity interventions.

The harmonisation of existing public health facility national datasets — such as Sierra Leone’s openly accessible health facility dataset which contains attributes for over 1,500 facilities — with PQR datasets that track the state of electrification at facilities can provide a holistic and proactive approach to targeting energy interventions aimed at tackling unreliable, low-quality power supply (Grid3, 2023). This merged dataset can serve as a national repository shared between ministries, public and private finance providers, and development implementing partners to prioritise healthcare electrification investments and better design, monitor, and evaluate these interventions.

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