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Medical appliances for resource-constrained settings

Strategies for context-aware, energy-efficient and scalable healthcare solutions

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Abbreviations

AfCFTA	African Continental Free Trade Area
AMA	African Medicines Agency
AI	Artificial intelligence
AR	Augmented reality
CAPEX	Capital expenditure
CDC	Centers for Disease Control and Prevention
CE	Conformité Européenne
CMCTH	Chitwan Medical College Teaching Hospital
CO2	Carbon dioxide
CoBA	Coalition of Blood for Africa
COP	Conference of Parties
DRE	Distributed renewable energy
EaaS	Energy-as-a-service
EE	Energy efficiency
EPC	Engineering, procurement and construction
ESCO	Energy service company
GHG	Greenhouse gas
GoK	Government of Kenya
HIC	High Income Countries
HIV	Human immunodeficiency virus
ICT	Information and Communication Technology
ICU	Intensive Care Unit
IEA	International Energy Agency
IoMT	Internet of medical things
IoT	Internet of things
IRENA	International Renewable Energy Agency
KEBS	Kenya Bureau of Standards
KIRDI	Kenya Industrial Research and Development Institute
KWh	Kilowatt hour
KWp	Kilowatt power
LMIC	Low- and middle-income countries
MEPS	Minimum Energy Performance Standards
MoEP	Ministry of Energy and Petroleum
MoH	Ministry of Health
MRI	Magnetic resonance imaging
NRAs	National Regulatory Authorities
OPEX	Operation expenditure
O&M	Operations and maintenance
PAYG	Pay-as-you-go
PHC	Primary healthcare
PoC	Point-of-care
PoCT	Point-of-care testing
PPA	Power purchase agreement
PPB	Pharmacy and Poisons Board
PV	Photovoltaic
RBF	Result-based finance
RE	Renewable Energy
SDG	Sustainable Development Goal
SEforALL	Sustainable Energy for All
SSA	Sub-Saharan Africa
TB	Tuberculosis
UN	United Nations
UNDP	United Nations Development Programme
UNSD	United Nations Statistics Division
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
W	Watt
WB	World Bank
WHO	World Health Organization
WWF	World Wildlife Fund

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Executive Summary

Medical appliances are essential for healthcare delivery, yet their performance is often compromised in resource-constrained settings. In Sub-Saharan Africa (SSA), healthcare facilities face high rates of equipment underutilization, driven not only by limited electricity access but also by the unsuitability of medical devices for low-resource environments.

This report, developed by Sustainable Energy for All (SEforALL) and CLASP, explores how energy-intensive, wrong sized, and poorly maintained medical equipment undermines healthcare services, with a focus on findings based on direct measurements as well as interview-based anecdotal evidence from 29 facilities in Kisumu County, Kenya.

The availability of medical equipment does not ensure functionality. Devices such as autoclaves, oxygen concentrators, and infant warmers (also commonly known as resuscitaires)—although present in many facilities—are frequently idle due to high power consumption, sensitivity to voltage fluctuations, poor equipment quality or inadequate technical support. Monitoring data from the facilities studied revealed inconsistencies between manufacturer-rated power and actual energy use, indicating inefficiencies and operational challenges. In many facilities, alternative devices like oxygen cylinders are favored due to their simplicity and independence from power supply.

Many medical appliances are unsuitable for weak-grid and off-grid conditions. Over 45% of devices assessed were incompatible with local power infrastructure, either due to voltage requirements or durability issues. Power instability leads to frequent equipment breakdowns, while the lack of appropriate maintenance access to spare parts further reduces uptime. As a result, essential appliances are often stored rather than used, creating medical equipment graveyards and contributing to the growing burden of e-waste.

Donation practices and procurement systems exacerbate the problem. Up to 70% of do-

nated medical equipment in low- and middle-income countries (LMICs) is unused. Donated devices often arrive without prior consultation, are mismatched with facility needs, or are delivered without training or ongoing maintenance and support infrastructure. Procurement decisions prioritize cost savings over efficiency and usability, often overlooking the long-term performance, maintenance requirements, and energy implications of medical equipment.

Inefficient devices increase costs and limit service delivery. Energy-inefficient appliances raise operational costs and strain fragile power systems. In response, some facilities limit the frequency of equipment use—such as sterilizing instruments biweekly—to reduce energy bills. Meanwhile, nearly all of the 29 health professionals interviewed stressed the importance of acquiring energy-efficient appliances to ensure consistent service delivery during power outages and minimize operating expenses.

Local innovation and testing capacity are underutilized. The African region has emerging potential for local manufacturing and adaptation of medical equipment tailored to low-resource settings. However, these efforts are hindered by bureaucratic hurdles, lack of financial support, and weak regulatory frameworks. Even promising locally produced devices, such as ventilators or patient monitoring systems, often struggle to commercially scale due to fragmented policy and procurement landscapes.

Targeted policy interventions and procurement reforms are urgently needed. The report recommends the development of minimum energy performance standards (MEPS), and quality assurance frameworks tailored to energy-constrained environments. Establishing testing labs and supporting capacity building for biomedical engineers are key strategies. Priority should be given to procuring energy-efficient, context-appropriate medical appliances designed for durability, low maintenance, and compatibility with decentralized energy systems.

Ultimately, effective healthcare in SSA requires more than electricity—it requires the right equipment. Ensuring the suitability, efficiency, and maintainability of medical appliances is critical to improving health outcomes, reducing waste, and enabling sustainable, scalable healthcare delivery in low-resource settings. Addressing these challenges at the intersection of design, policy, and practice is essential to realizing the full potential of medical technology in advancing public health across the region.

Reliance on diesel generators is prevalent. All the healthcare facilities assessed during the study are grid-connected; however, the majority rely on diesel generators as a secondary power source due to frequent grid instability and outages. Given the critical nature of continuous power supply in clinical environments—where medical devices such as oxygen concentrators, incubators, and diagnostic equipment must operate without interruption to ensure patient safety—diesel generators remain the dominant form of backup. Despite their operational reliability, diesel generators pose significant environmental and operational challenges, including high fuel consumption, greenhouse gas emissions, and increased maintenance requirements. Their continued use underscores the urgent need for resilient, cleaner energy alternatives capable of delivering stable and uninterrupted power in resource-constrained healthcare settings.

CHAPTER ONE

Background and Methodology

1.1 Background

Access to quality healthcare is a fundamental human right, yet billions of people, primarily residing in remote and rural areas of the world, still struggle to obtain adequate medical services (Izuka, et al., 2023). In many of these settings, unreliable or non-existent energy access directly undermines the functioning of health systems and critical equipment.

Ensuring universal access to reliable energy in healthcare facilities is essential for achieving Sustainable Development Goal 3 (SDG 3), which aims to ensure good health and well-being for all. As such, SDG 7 – access to reliable energy – is deeply intertwined with SDG 3. The nexus between health and energy highlights that modern energy services are not just supportive – but foundational – to effective healthcare delivery, particularly in regions where energy access remains a significant challenge.

In Sub-Saharan Africa (SSA), out of the 167,000 health facilities, approximately 25,000 lack electricity entirely, while another 70,000 operate with unreliable power supplies (WHO, SEforALL, IRENA, World Bank, 2023). **These gaps in energy access directly compromise healthcare delivery, from vaccine preservation to life-saving procedures.** The region's deteriorating infrastructure contributes to alarmingly high mortality rates: nearly half of global deaths among children under five and two-thirds of maternal deaths (WHO, 2019). The situation was exacerbated during COVID-19 due to unreliable electricity, an important but less often discussed factor. While shortage of healthcare workers, underfunded health infrastructure, and inadequate access to essential services have been highlighted as the main issues contributing to the weak health systems, the pandemic exposed vulnerabilities in the African health system attributed to unreliable electricity (Gebreslassie, 2020). The issue was no longer a matter of increased infections,

but how to deal with an already vulnerable health delivery system that was on the verge of collapsing.

Extensive dialogue has taken place since the COVID-19 pandemic on the vulnerability of health systems, particularly in the context of unreliable electricity and inadequate infrastructure. Discussions at the 2024 Conference of Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) emphasized the importance of prioritizing health in national climate plans. It framed human well-being and universal health coverage as a catalyst for climate action and essential to ensuring that efforts to combat climate change also reinforce healthcare systems (WHO, 2024). **Yet, access to reliable power in rural healthcare facilities remains a persistent challenge – largely due to economic constraints.** Extending the electricity grid to low-demand, remote areas is often considered financially unviable by governments and utilities, given high infrastructure costs and limited returns (SEforALL, 2022). As a result, many healthcare facilities in off-grid areas rely heavily on diesel generators as a primary source of power, despite the high cost, unreliability of fuel availability, and harmful emissions that pose health risks to both patients and staff.

Beyond electrification, healthcare facilities in weak- and off-grid settings are plagued with issues of non-functional and obsolete medical devices, which ultimately end up being prematurely disposed of. The donation or dumping of unwanted equipment, fuelled by a donor-recipient power imbalance coupled with the mindset that 'anything is better than nothing', has been perceived to be morally wrong and has garnered bad media publicity (Marks, et al., 2019). This mindset in low- and middle-income countries (LMIC) prevents recipients from rejecting unsuitable donations, resulting in widespread medical equipment graveyards healthcare facilities. This contributes to the 282,447 tonnes of waste generated by the healthcare sector in Africa each year (Samenjo, et al., 2023). **Up to 70% of medical equipment in LMICs remain unused as they are either broken or not fit for purpose, with power-related issues being cited as a major reason** (Ucin, et al., 2024). The problem is compounded by the mismatch between imported or donated equipment and the infrastructural realities of off-grid and weak-grid settings, where voltage fluctuations and power outages are common. This reliance on external supply chains further complicates efforts to build resilient and sustainable healthcare systems (Insight, 2024). At the core of the issue lie undiscerning procurement decisions as well as the inadequate capacity of biomedical engineers in LMIC to maintain and repair the appliances (Ayah, et al., 2020). As a result, proper training during procurement is needed to effectively offer installation and maintenance services, both preventive and corrective (Diaconu, et al., 2017).

To improve efficient use of health technologies, regulatory and governance frameworks are necessary as they ensure optimization of resources. Governance systems are important due to their ability to influence not only the selection of suitable health technologies but also their introduction, adoption, and proper use (Schulmann, et al., 2024). A streamlined regulatory system encourages domestic product development and ensures quality, safety and efficacy. Strengthening the capacity of the National Medicines Regulatory Authorities and enabling its collaborations at a regional level can ensure effective medicines regulation (Ncube, et al., 2021). The newly established African Medicines Agency (AMA) is a continent-wide platform for strengthening and harmonizing continental and regional regulatory authorities. It is mandated to regulate and harmonize standards for medicines, vaccines, and medical devices, including some categories of medical equipment. By October 2023, 37 African countries had ratified the treaty with the remaining (18 out of 55) member countries being encouraged to fully ratify the AMA.

By pooling expertise and capacities and coordinating across countries and regions, the AMA will ensure more high-quality local products reach the people who need them. For example, the AMA is expected to capitalize on opportunities arising from the African Continental Free Trade Area (AfCFTA) to merge on a regional level the national pharmaceutical markets that are currently fragmented (Abdulwahab, et al., 2024). The joint status will enable Africa to effectively partner with health agencies, such as the WHO, and develop joint regulations that protect African consumers from counterfeit products and services. It is estimated that the pharmaceutical market will have a value of more than $40 billion by 2030, attributed to Africa being the second most populated continent (Abdulwahab, et al., 2024).

As the continent accelerates efforts to expand and modernize healthcare infrastructure through increased electrification, it is equally important to integrate energy efficiency considerations into the design and selection of medical equipment. Integrating medical equipment testing into clinic electrification investments is crucial, allowing healthcare facilities to reduce power consumption, ensure reliable medical equipment operation, and enhance the sustainability of electrification initiatives (CLASP, 2021). The recent emergence of energy efficient medical equipment capable of operating on low-power batteries and solar PV systems presents a promising opportunity to improve energy access through demand-side measures (SEforALL, 2024). By adopting such innovations, healthcare facilities can strengthen their operations, reduce their reliance on costly and polluting diesel generators, and deliver better health outcomes for their communities.

1.2 Objectives

The findings presented in this report aims to support sustainable healthcare electrification and improved medical equipment availability by providing a high-level assessment of the market's supply chain, as well as an exploration of the energy consumption and efficiency of selected medical devices commonly used in off-grid and weak-grid healthcare facilities. Central to this objective is equipping policymakers, health planners, and electrification partners with actionable, evidence-based recommendations to inform energy management, equipment selection, and electrification strategies tailored for energy-constrained environments.

Progress towards adopting energy efficient medical equipment remains minimal, with limited information available on the status and accessibility of such devices in off-grid and weak-grid healthcare facilities. Most available insights focus on vaccine cold chain devices, leaving significant gaps in understanding the broader landscape of medical equipment within these contexts such as autoclaves and oxygen concentrators.

To bridge this gap, CLASP and SEforALL assessed how energy efficient medical equipment can enhance the planning and execution of health facility electrification initiatives. This study also informs the design and implementation of optimally sized energy systems tailored to healthcare facility needs.

The report identifies key challenges and uncovers opportunities to enhance energy efficiency in clinical settings, aligning with WHO guidelines that advocate for the use of low-energy, durable, and environmentally safe medical devices capable of performing in resource-limited

contexts. It further integrates insights from real-time data, including on-site testing and remote metering, to present a grounded perspective on energy performance.

By examining the energy consumption and efficiency of medical equipment across these varied healthcare levels, this report emphasizes the importance of:

- Improving procurement decisions and processes.
- Identifying opportunities for design enhancements and efficiency improvements across systems, infrastructure, and technologies.
- Establishing performance baselines to develop performance standards and, ultimately, a quality assurance framework for off-grid and weak-grid medical equipment in Africa, similar to WHO's performance, quality and safety test protocols.

With inputs from 20 stakeholders and technical evaluations, the report highlights Africa's growing healthcare demand and investment landscape, positioning the region as a strategic frontier for energy-efficient medical equipment deployment. Through this lens, the report underscores how integrating efficient medical devices not only reduces power demand and operational costs but also enhances the feasibility of adopting renewable energy solutions, particularly solar PV, while advancing universal health coverage and contributing to Sustainable Development Goals.

1.3 Methodology

To gain a comprehensive understanding of the medical equipment landscape in off-grid and weak-grid settings, this study's multi-faceted research approach included site visits, remote metering, and stakeholder consultations. These efforts explored the types of medical equipment in use, their performance, and the challenges associated with their acquisition and operation. The findings offer critical insights into the energy demand of healthcare facilities and the barriers to adopting energy-efficient technologies.

To achieve the objectives, the research employed a combination of complementary methods:

- **Stakeholder interviews** conducted with 20 stakeholders from the private sector, the government and academia, from both the energy access and health sectors actively involved in healthcare electrification initiatives from October 2024-December 2024 (see Annex 1).
- **Desk research** including extensive review and analysis of relevant policy documents and existing literature on healthcare electrification and medical equipment efficiency.
- **Health facility surveys** carried out in 29 healthcare facilities in Kisumu County, Kenya, in October 2024. The site visits entailed power and energy data logging for medical devices over a 15-minute period, comprehensive walkthroughs of the facilities, and interviews with hospital staff (Annex 4) to understand energy utilization and challenges faced in the facilities related to medical appliances and power supply. All health facilities visited were connected to the national grid (Annex 2).
- **Additional power and energy data logging of oxygen concentrators, infant warmers and autoclaves (Annex 3)** over an extended period of time in select healthcare facilities in Kisumu County, Kenya, for a period of 15 days from 5th April to 19th April 2025. Box 1

provides definitions and useful information for each of the three appliances tested, including commonly found brands and models, their rated power consumption and the usage pattern in the health facilities visited.

BOX 1: Information on the appliances tested

Autoclave

An autoclave is a medical device used to sterilize surgical instruments and other equipment by applying high-pressure saturated steam, ensuring the elimination of harmful microorganisms

MODEL	RATED POWER CONSUMPTION	USAGE IN THE FACILITIES
Tuttnauer 3870 ELVBH-D85 liters capacity	3600W	Not common
Vertical autoclave LS -120LJ	6000W	Used in level 6
All American X75	1650W	Commonly used in all facilities
NUVE NC 40M 40litres	2500W	Not common

Oxygen concentrator

An oxygen concentrator is a device that extracts and delivers concentrated oxygen from ambient air, commonly used to support patients with respiratory conditions by providing a steady supply of medical-grade oxygen

MODEL	RATED POWER CONSUMPTION	USAGE IN THE FACILITIES
J-10 Oxygen Concentrator	880W	Most used
Germany-Europe SU 305	440W	Only used in one facility
CANTA Heavy Duty Oxygen concentrator	300W	Used in a few facilities

Infant warmer

An infant warmer is a specialized unit combining a radiant warmer and resuscitation equipment, used primarily in neonatal care to stabilize newborns immediately after birth.

MODEL	RATED POWER CONSUMPTION	USAGE IN THE FACILITIES
Okuman OKM 730	700W	Commonly used model in the facilities
FXQ-3	800W	Only used in one facility, level 5
HKN 93	700W	Commonly used model in the facilities

The field research was conducted in Kenya, complemented with key informant interviews with stakeholders operating at a global level. Kenya was selected for the field research since it has achieved remarkable progress in expanding electrification. According to the United Nation (UN) SDG7 tracking report (IEA, IRENA, UNSD, World Bank, WHO, 2024), Kenya achieved an impressive annual growth rate of electrification of 4.8 percent, reaching 76 percent electricity access as of 2022.

Kisumu County was selected as the sample area due to its unique context and relevance to this research. Kisumu County has set an ambitious goal with its 100% Renewable Energy (RE) Roadmap (ICLEI, 2024). Energy efficiency is a core focus of the roadmap, demonstrating the feasibility and economic benefits of integrating RE solutions and efficiency measures in healthcare facilities. Additionally, Kisumu County's mortality rate, which exceeds the national average (Kisumu County, 2018-2022),

The analysis covers a range of healthcare facilities, from primary health centers (level 3), serving as the first point of care in local communities, to county and national hospitals, which cater to broader populations and offer advanced medical services (level 6). Table 1 provides detailed definitions of each healthcare facility category as defined by Kenya's Ministry of Health (MoH).

TABLE 1: Definition of health facility levels in Kenya

LEVEL	FACILITY	KEY SERVICES
1	Community Health Units	Basic healthcare, vaccinations, child medical care, sanitation.
2	Dispensaries and Clinics	Outpatient care for simple ailments like malaria and skin conditions.
3	Health Centers	Comprehensive primary care with preventive services like vaccinations
4	Sub-County Hospitals	Primary care hospitals offering more comprehensive treatment options.
5	County Referral Hospitals	Specialized healthcare services for larger populations.
6	National Referral Hospitals	Advanced and specialized medical services.

The selection criteria for the healthcare facilities to be visited were the following:

- **Connectivity to the electricity grid**: Only facilities that are connected to the national electricity grid were selected. Grid connectivity was essential as it increases the likelihood of having operational medical appliances that rely on stable power, such as diagnostic equipment, sterilization units, and vaccine refrigerators.
- **Administrative representation**: To ensure comprehensive coverage and inclusion of different regional contexts, at least two facilities were selected from each sub-county.
- **Availability of medical equipment**: Selected facilities were required to have key medical appliances that are critical for service delivery and energy consumption, such as oxygen concentrators, autoclaves, and refrigerators used for storing vaccines and other temperature-sensitive supplies. This was important to assess how energy access impacts the functionality and use of such equipment.
- **Facility level mix**: The sample included a range of facilities from Level 3 to Level 6. This range was chosen to capture differences in service delivery complexity, energy demands, and medical equipment usage across the healthcare system. Level 1 and Level 2 facilities were deliberately excluded, as they primarily offer basic outpatient services, often lack advanced medical equipment, and in many cases are not connected to electricity or have only limited access through solar lanterns or other basic means.

CHAPTER TWO

Challenges

Healthcare facilities in SSA experience various electricity-related demand and supply challenges, including electricity fluctuations, grid power unreliability, and poor suitability of medical devices for resource-constrained contexts. Appliance under-resourcing, the disconnect between equipment donors and the local context, and health facility understaffing pose further challenges. Issues such as outdated medical appliances, lack of innovation, and burnout among nurses are also common. Because of this, healthcare workers are subjected to a vicious cycle of high workload leading to reactive care, which further increases the workload. These issues are expounded in detail in the subsequent sections.

2.1 Healthcare electrification and medical equipment challenges

Although SSA's medical devices market has grown significantly in recent years as awareness of healthcare needs grows (Orisakwe, 2023), **progress remains limited in off-and weak-grid areas, in part due to insufficient financial solutions**. As of 2023, the market value for medical devices in Africa was $4.49 billion, with the market projected to grow to $7.79 billion by 2032 (Dey, 2025). This growth is propelled by the escalating prevalence of chronic illnesses, such diabetes, increasing investments in healthcare infrastructure, and the urgent need for improved healthcare services. However, this progress is not reflected in weak-grid areas, not only due to technical incompatibility but also because of the lack of appropriate financing mechanisms. This disparity underscores the urgent need for innovative solutions tailored to meet the energy demands of SSA, especially given that it carries 24% of the global disease burden (Ssekitoleko, et al., 2021) but has access to only 1% of the world's financial resources and 3% of its human capacity (WHO, 2008). Bridging this gap requires not only technological innovation but also robust, context-driven financial solutions that can scale access to life-saving medical devices while reinforcing resilient energy systems.

BOX 2: Muhoroni County Hospital

In Muhoroni County Hospital, power outages are a common occurrence, *"being experienced 40-50% of the day"* according to the Facility in Charge. Although the hospital has two diesel generators as backup power sources, rising fuel costs remain a significant concern. Notably, the facility acquired a second, larger generator four years ago, following an energy audit conducted by the Kisumu County Government in 2018. However, this larger generator is rarely used due to its high fuel consumption. Instead, the hospital primarily relies on the older, smaller generator during outages, as it is more economical to operate. The larger generator is only activated when the smaller unit is non-functional. The hospital is currently exploring alternative clean energy options to power its operations more sustainably.

The energy gap in health facilities remains high, undermining the delivery of quality healthcare services across Sub-Saharan Africa. In Kenya, for example, only 15% of healthcare facilities have access to reliable electricity (PREO, 2020). Grid connection does not guarantee reliable power, highlighting the urgent need to address these energy gaps to improve healthcare outcomes. The complete lack of power access, especially in rural health facilities, is attributed to the fact that it is not economically viable to extend the grid in such settings characterized by low demand for energy with low revenues and high cost of building and maintaining electrical infrastructure.

Survey results from 29 grid-connected facilities revealed that nearly half of healthcare facilities surveyed in Kisumu County experience power outages at least once a week, with over half of the facilities indicating that each outage lasts more than seven hours (Figure 1 and Figure 2). The situation is even more dire in more rural facilities, such as Muhoroni County Hospital and Nyakach County Hospital, which reported that they must occasionally cancel or postpone a medical procedure due to lack of power. This lack of reliable electricity is not unique to Kisumu, but rather symptomatic of the broader infrastructural weaknesses affecting many health systems in SSA (WHO, 2023). The power disruptions are particularly dangerous in maternal care, emergency services, diagnostics, and cold chain management for vaccines and blood products.

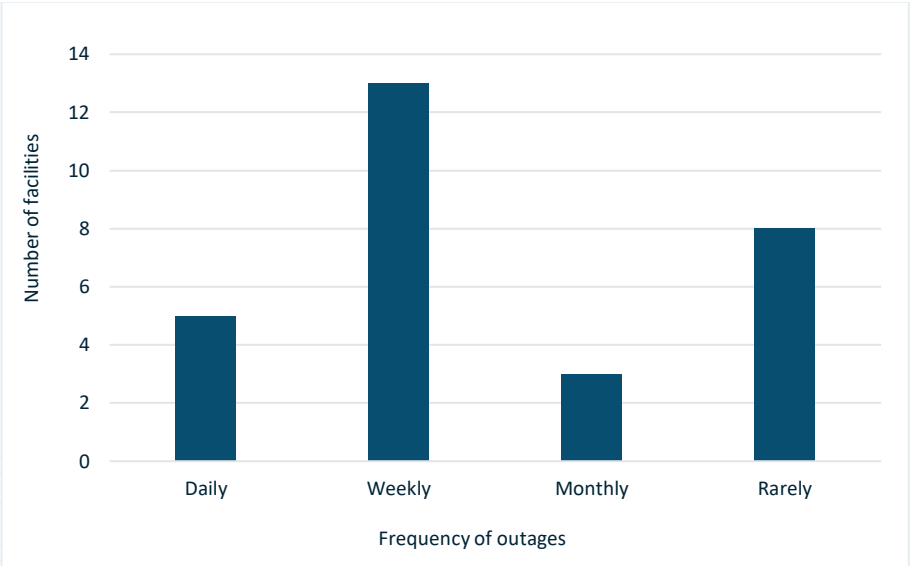

FIGURE 1: Frequency of power outage in healthcare facilities visited
Source: Own analysis

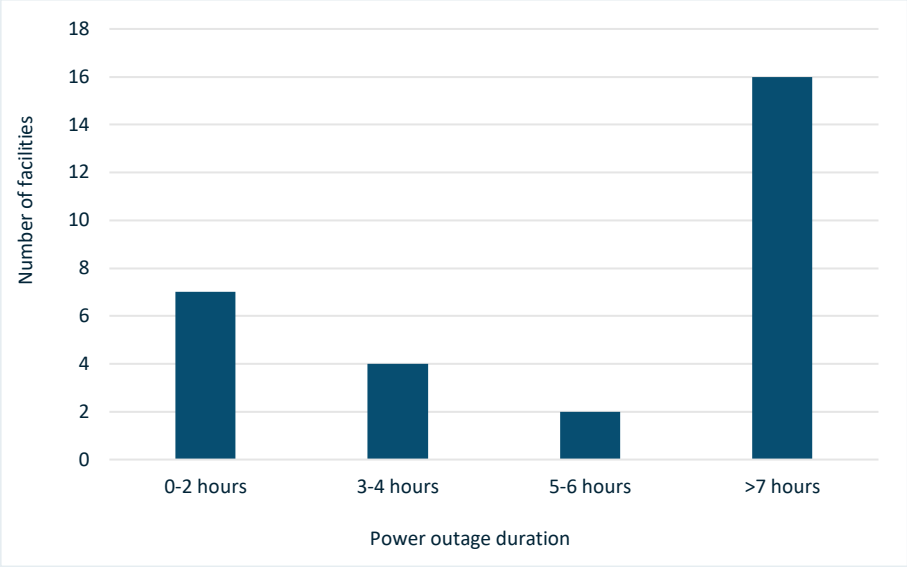

FIGURE 2: Average duration of power outage in healthcare facilities visited
Source: Own analysis

Diesel generators remain the predominant solution for backup power in health facilities. Nearly half of the health facilities surveyed in Kisumu County reported relying on diesel generators as their primary alternative power backup source (Figure 3), sometimes coupled with a PV system. While a genset backup is used to cover the electric needs of the whole facility when the main grid is down, solar PV systems are usually connected to critical loads such as the maternity ward, laboratories and pharmacies. Some facilities use a stand-alone PV system to power the vaccine fridges.

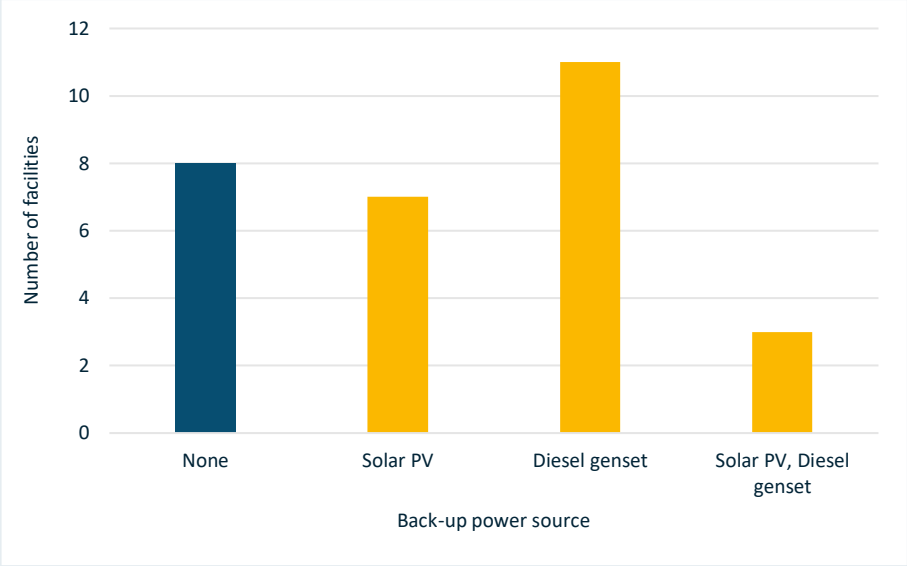

FIGURE 3: Power back-up solutions for healthcare facilities visited
Source: Own analysis

While widespread, these generators are far from a reliable or sustainable solution. Operational challenges, such as frequent breakdowns, lack of routine maintenance, and most critically, the inability to consistently afford fuel for the generator, often render these systems ineffective when power is most needed. In resource-constrained settings, budget limitations frequently force facility

managers to ration fuel or leave generators idle, which severely disrupts the continuity of medical services, thus presenting a great opportunity to explore decentralized energy systems.

Poor sector coordination results to health facility electrification initiatives that do not consider the demand side of facility such as medical appliances. Oftentimes these electrification initiatives target clinics that do not have any form of demand and electricity update only takes place when another donor supplies the facility with medical appliances. Coupling supply and demand in one project could solve the problem of matching energy supply and demand needs but poses challenges, as the energy service companies that supply health facilities with power systems do not have the necessary skills and expertise to procure, deploy and maintain medical appliances.

A lack of consistent and adequate energy access is responsible for many of the mortalities witnessed in SSA. Approximately 55% of the global deaths among children under five years and 70% of maternal mortalities occurred in SSA in 2023 (UNICEF, 2025). These high mortality rates are often driven by health facilities' inability to power critical medical equipment when they are most needed. Lower-tier health facilities, especially those in rural and remote regions, are particularly vulnerable due to lack of any form of power backup. For example, cases of critically ill newborns passing away shortly after birth due to the absence of electricity to power incubators/infant warmers are common (Mohammed & Akuoko, 2022), (Diaconu, et al., 2017).

Cognizant of the severity of this issue, health practitioners in health facilities in two health centers visited refer pregnant women to other facilities when there is no power, which are often further away and may also experience similar power challenges. These systemic challenges compromise both emergency care and routine health services, underscoring the need for reliable electricity, well-designed and functioning appliances to deliver quality healthcare. Understanding the causes of morbidity and mortality is crucial as it helps healthcare systems adapt and respond effectively to the causes as well as trigger responses from the relevant sectors.

Inconsistent availability of electricity leads to the frequent spoilage of vaccines. According to (Soto, et al., 2022), 50% of vaccines imported to LMICs are lost due to improper refrigeration during storage. This not only results in substantial financial losses but also undermines public health efforts, as spoiled vaccines lose their efficacy and increase the risk of preventable diseases spreading within the community leading to the erosion of public trust in immunization programs.

A single outage of a few hours, as witnessed during multiple facility visits, can cause vaccine refrigerator temperatures to rise above the recommended 2–8°C range, rendering stored vaccines unusable. This challenge is mostly noted in facilities where backup power solutions, such as diesel generators or solar PV systems, are either unavailable or insufficiently maintained. Figure 4 shows the grade of impact of power outages on vaccines reported during field work. Forty percent of the facilities visited experience severe frequent spoilage of vaccines due to power cuts, while less reported moderate or no impact (28% and 31% respectively). The consequences are severe: not only are immunization campaigns compromised, but preventable diseases such as measles, polio, and tetanus risk resurging in already vulnerable communities. (WHO, 2008).

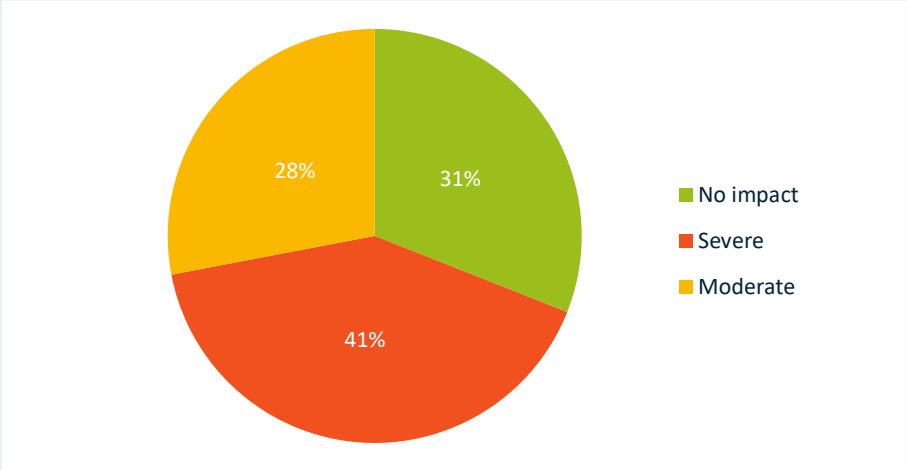

FIGURE 4: Impact of power outages on vaccines
Source: Own analysis

2.2 Design and suitability of medical equipment

Autoclaves, infant warmers and oxygen concentrators, as well as fridges and freezers, are the most common medical appliances in Kisumu County facilities visited, highlighting their crucial role in providing healthcare services (

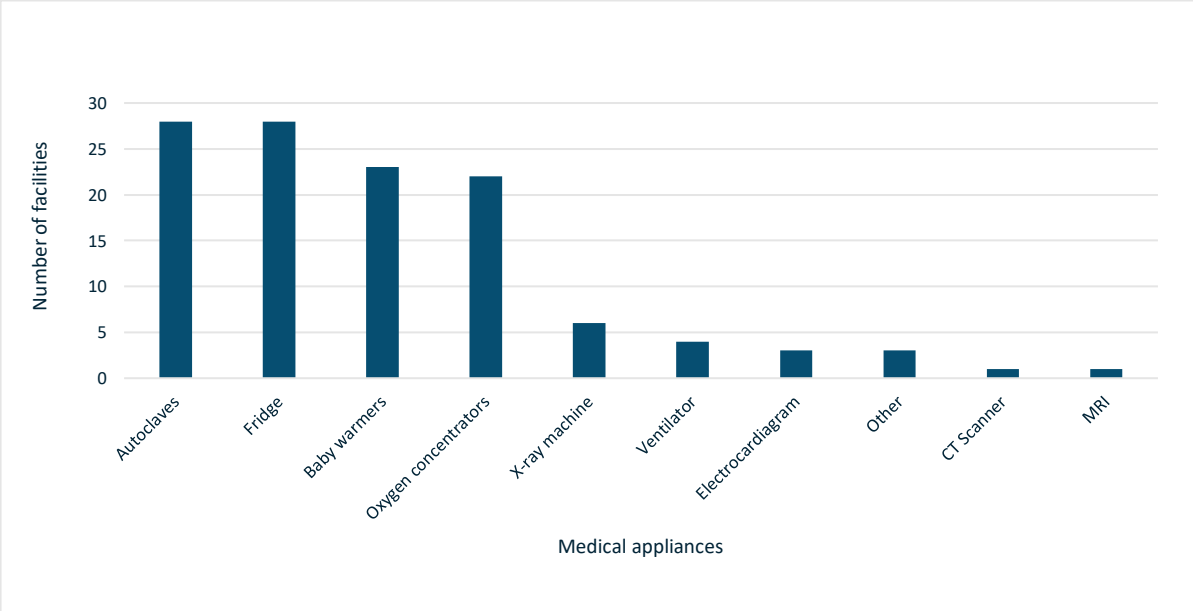

FIGURE 5). However, availability of medical appliances does not automatically translate to use. Medical appliances are essential components of modern healthcare, driven by innovative technologies that have revolutionized the medical device landscape (Garg, 2024). However, in many healthcare facilities in SSA, medical appliances often remain unused despite their potential to significantly improve healthcare delivery. This observation arises from a range of interconnected challenges that hinder the effective deployment and operation of such equipment. According to (Marks, et al., 2019), medical devices are often designed for high income countries (HIC's) with robust electrical infrastructure and access to skilled biomedical engineers for regular maintenance. When such devices are donated or imported into LMICs, they frequently fail to perform as intended

due to unreliable electricity, poor maintenance systems, limited technical expertise, and other operational challenges.

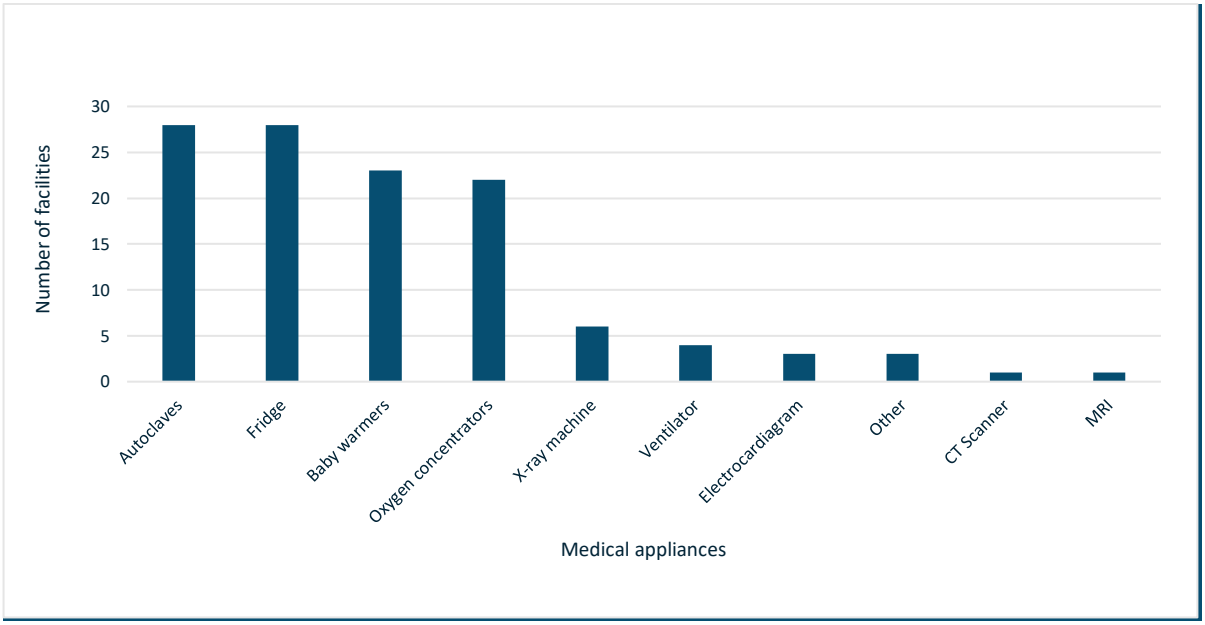

FIGURE 5: Availability of medical appliances in health facilities visited
Source: Own analysis

The effectiveness of the appliances depends on proper and consistent use. With proper maintenance, the Jay-10 oxygen concentrator is designed to last about 5 years or up to 20,000 hours of operation (Longfian, n.d.). However, despite it being the most commonly available model, it remained largely unused in many of the visited facilities. For instance, in two facilities visited, the oxygen concentrators were often kept in storage and rarely operated. Instead, these facilities showed a preference for using oxygen cylinders over concentrators. This could be attributed to the fact that oxygen cylinders do not rely on electricity and are simple to operate, therefore offering a more reliable solution. While oxygen concentrators are efficient and cost-effective, their dependence on consistent power limits their practicality in such environments (Ibrahim, et al., 2025).

Power instability, high energy consumption, and difficulties in sourcing spare parts contributed to the underutilization of appliances like the autoclaves. Many of the higher tier healthcare facilities visited had more than one autoclave model. However, in many cases, only one smaller model was actively used for reasons linked to electricity consumption or power stability, as illustrated in

. Obtaining components, even minor ones, can be extremely challenging with delays observed of over a year. The failure to design and integrate medical devices for weak and off grid-settings, as recommended by WHO, continues to result in inadequate healthcare, disproportionately impacting vulnerable populations.

BOX 3: Reasons attributed to lack of use of autoclaves in select health facilities in Kisumu County

i. Level 4 facility – "*One big sterilizer is not used due to power instability and high electricity consumption*".
ii. Level 6 facility – "*One big autoclave has not been functioning for the last 6 months as there were no spare parts*".
iii. Level 4 facility – "*The autoclave hasn't been used since it was donated because of fear of energy consumption*".
iv. Level 4 facility – "*We have a large autoclave that has not been used for almost a year*".

Usage pattern of appliances depends on the level of facilities.
Figure 6 shows the total use of oxygen concentrators, infant warmers and autoclaves in the Kisumu County facilities over a period of 15 days. The infant warmer model HKN 93 was the most frequently and consistently used medical appliance, with significantly longer usage periods compared to other devices. This trend was particularly evident in the county referral hospitals (Kisumu County Referral Hospital and Lumumba Sub-County Hospital), which conduct a greater number of childbirth-related procedures than smaller or lower-tier facilities. As such, the demand for neonatal resuscitation equipment is naturally higher, reflecting the essential role these devices play in maternal and child healthcare services in more advanced health centers.

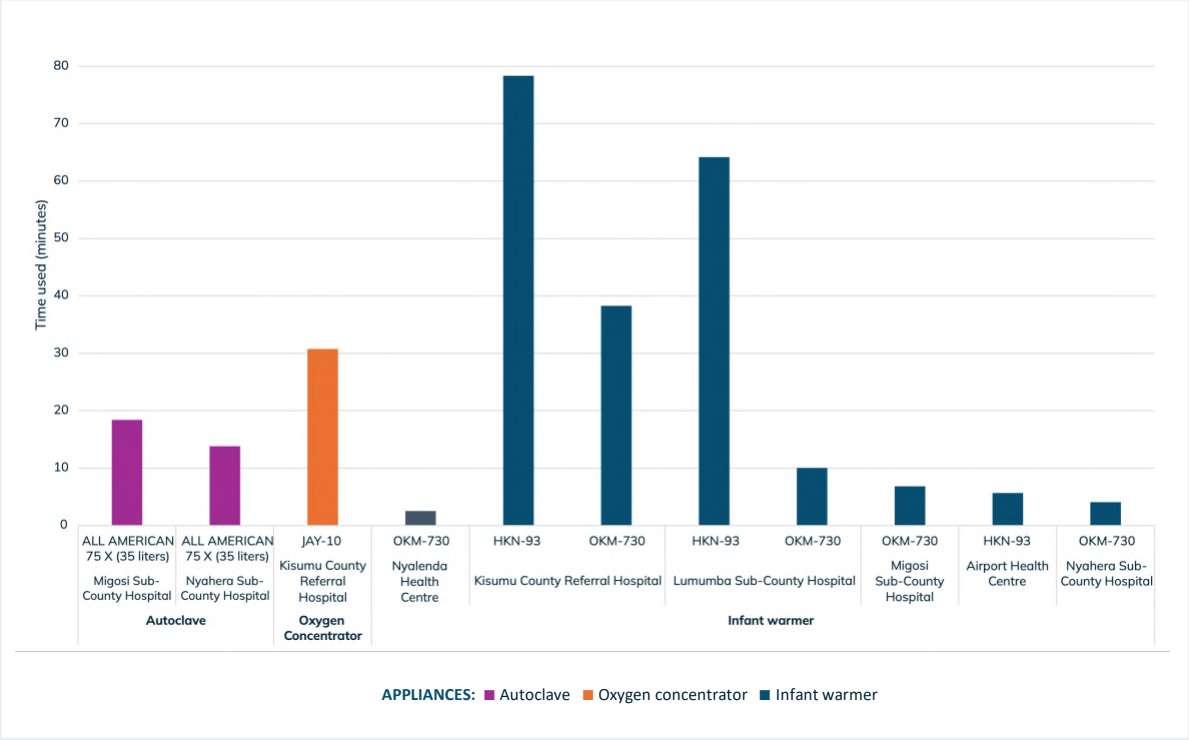

FIGURE 6: Appliances tested in health facilities and total use over the 15-days testing period
Source: Own analysis

Autoclaves were only measured in smaller facilities, where sterilization of medical equipment using the autoclave is carried out only once every fortnight, as opposed to daily or weekly use as in better-equipped hospitals. This infrequent use can be attributed to several factors: first, many of the facilities surveyed lacked a consistent power source or the high energy load required to operate the autoclave regularly. Secondly, the patient load in some smaller facilities may not justify more frequent sterilization cycles. In some cases, facilities relied on centralized sterilization services or shared equipment across departments, further limiting direct autoclave use. Additionally, the reliance on single-use consumables and the use of basic disinfection methods like boiling in lower-tier facilities reduced dependence on autoclaves.

Real energy and power consumption of appliances differs from manufacturer ratings—either exceeding or falling below expected values—raising concerns about equipment reliability and energy system compatibility. Energy monitoring data revealed that the average tested power consumption during the measurement period was either consistently higher or lower than the manufacturer's rated power (Figure 7). For example, equipment such as the two tested infant warmer brands recorded higher power values than the manufacturer's rated values. This mismatch exacerbates the inefficiency of healthcare delivery in energy constrained settings as vital equipment, sometimes brand-new medical equipment, are left idle, compromising patient care and wasting valuable resources in already underfunded health systems. Although both infant warmer brands have the same rated power, real-use data showed that the OKM-73 model was more efficient than the HKN-93 model. The real power consumption deviated from the appliance's rated power by a minimum of -45% to a maximum of +56%.

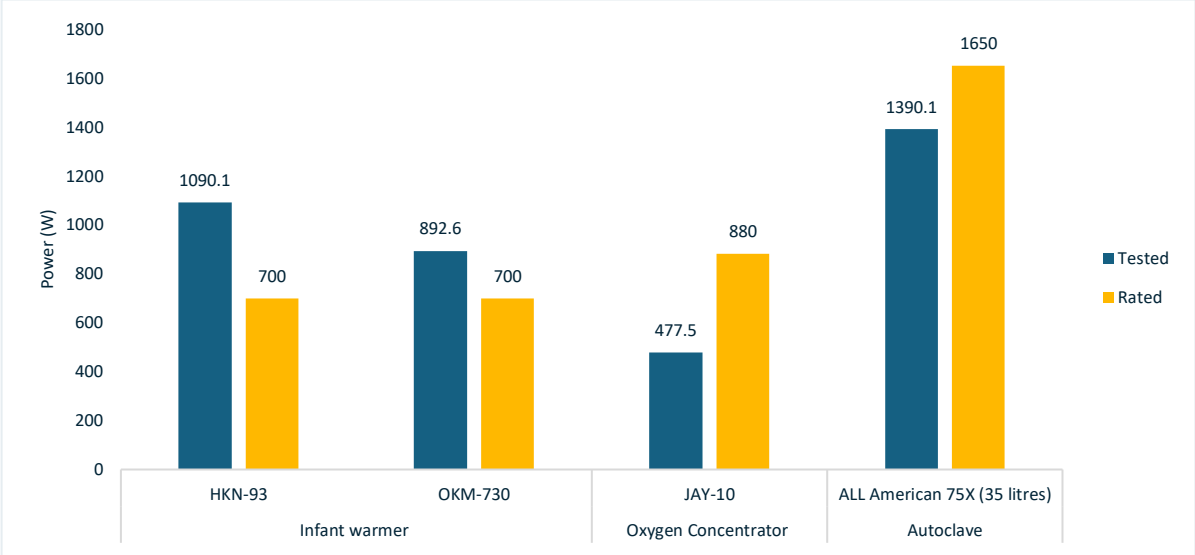

FIGURE 7: Manufacturer's rated power vs tested power consumption
Source: Own analysis

While donation of medical appliances to energy-constrained settings is often used as a strategy to resolve existing disparities or a way to be seen 'doing good', it becomes unsustainable both in the short and long-term. Despite donations accounting for up to 70% of medical appliances in sub-Saharan Africa, only 10–30% becomes functional, raising concerns about the cost-effectiveness and impact of such aid (Marks, et al., 2019) . In 2022, over 90% of medical devices used in Africa were imported (Insight, 2024). A study across 43 LMICs primarily from Africa, Latin America and Asia, revealed that up to 33% of medical equipment donations were made without prior consultation (Mullally & Frinze, 2008). High-cost, low-priority items like ultrasound and laparoscopic equipment were often donated without considering local needs or support infrastructure. Additionally, the Catholic Health Association reported that 60% of donors gave out non-functional equipment, placing a significant burden on hospital staff to sort and dispose of it (Marks, et al., 2019). For instance, University Hospital Wishaw recently donated to Medical Aid International two vanloads of medical appliances "no longer fit for use within NHS Lanarkshire" to be used in African hospitals (International, 2021).

In weak grid settings, voltage often falls below standard levels, causing medical appliances to underperform by drawing less power, not due to efficiency, but because of insufficient power supply. Based on the manufacturer's specifications, the All American 75X model autoclave has a power rating of 1650W. However, when comparing the load profiles of the same model at two different facilities, the recorded power readings varied (Figure 8). (Suhlrie, et al., 2018) asserts that facilities with poor-quality electricity supply often experience reduced functionality in energy use, regardless of their type, management, region, or whether they are in urban or rural areas. As a result, their ability to deliver effective health services is likely to be limited. Power quality issues are increasingly becoming critical as modern medical equipment relies on microprocessors. The extensive use of such appliances in hospitals demands higher-quality power supply. Power quality disturbances, like electrical surges, can cause microprocessors or controllers to malfunction, leading to data processing errors or changes to stored data and settings (Buzdugan & Bălan, 2012). Voltage transience can also significantly impact performance leading to equipment downtime, inability to replicate findings, distorted displays, inaccurate diagnostics, system lockups, and alarm or control failures. While minor disruptions like a flickering monitor may seem trivial,

failures in critical devices like ventilators or infusion pumps can be life-threatening. Since power quality issues are cumulative, even small, unnoticed events can lead to potential medical errors, and ultimately, loss of life.

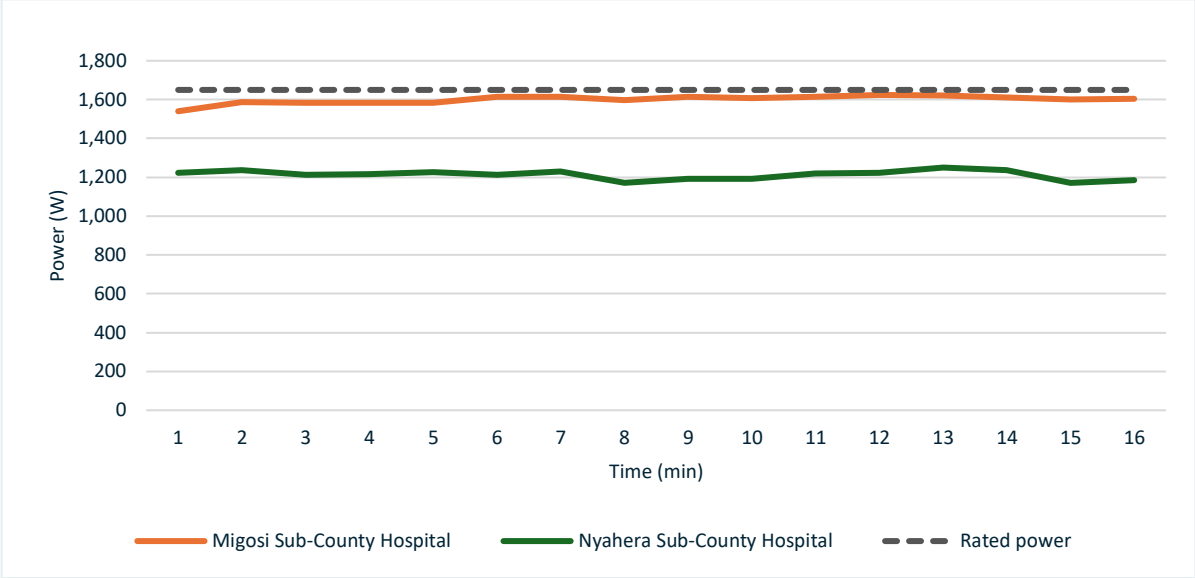

FIGURE 8: Load profile of an autoclave All American 75x (35ltrs) tested
Source: Own analysis

Medical appliances are not always compatible with the local electrical systems of health facilities. Almost 45% of health facilities visited reported that medical appliances available were not suitable for use in resource-constrained settings (Figure 9). This reflects a significant mismatch between the appliances' energy efficiency, power compatibility, and reliability under fluctuating conditions, and the actual energy capacities of the facilities. The survey findings revealed that many donated appliances, including lighting fixtures, are incompatible with local electrical systems. For example, many of the donated lighting fixtures are unable to withstand power fluctuations and have required replacement. Additionally, the tight voltage requirements of these devices often lead to equipment damage and increased electricity costs. For example, one facility visited experienced a problem with its autoclave that has remained unused for almost one year. Although the coil was replaced, it malfunctioned again within six months.

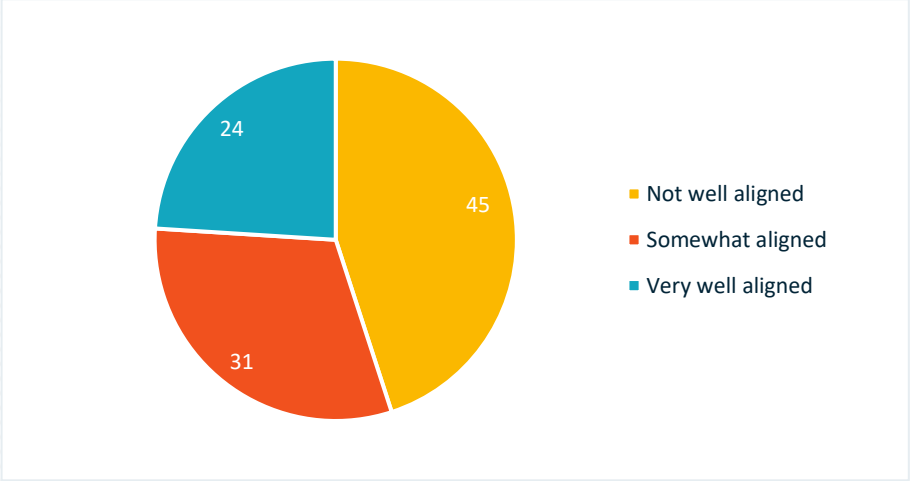

FIGURE 9: Alignment of medical appliance power requirements with available power supply in the visited healthcare facilities

Source: Own analysis

Power outage and voltage fluctuations are responsible for many of the appliance issues. Unreliable power is more than an inconvenience; it is a threat to life-saving medical equipment. The survey results showed that power outage was the main reason contributing to appliance damage (66%) closely followed by lack of effective maintenance (Figure 10). Many life-saving devices—such as autoclaves, oxygen concentrators, and diagnostic machines—are designed to operate on a stable power supply. When deployed in areas with frequent outages or voltage instability, especially without built-in protection, these devices are prone to malfunction or complete failure.

Field visits to facilities in Kisumu County highlighted real-world consequences: autoclaves with faulty plugs, failed coils, and burnt enamel—failures strongly suspected to have resulted from high voltage surges and prolonged blackouts. Stakeholder consultations further underscored that, beyond power quality, inadequate product specifications also contribute to equipment breakdown. These challenges not only compromise healthcare delivery but also increase the operational burden on healthcare workers.

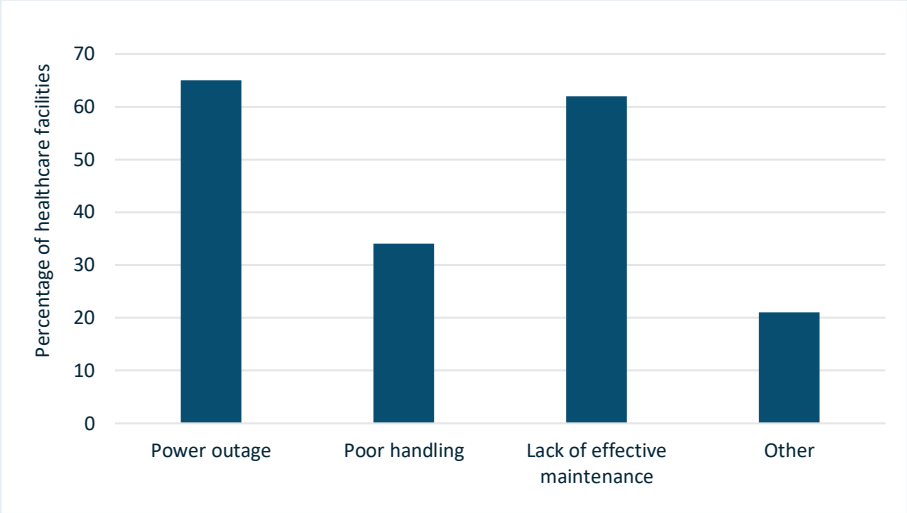

FIGURE 10: Factors contributing to medical appliance breakdown (based on interviews)
Source: Own analysis

The knowledge gap in medical equipment procurement, usage, and maintenance is costing healthcare facilities. This leads to poor purchasing decisions, equipment misuse/damage and underutilization. Power requirements are often overlooked during the procurement process, where cost tends to be the primary consideration. This highlights a knowledge gap at the point of procurement on the operational needs of medical devices, including power consumption and expected lifespan. Energy efficiency considerations are often neglected during procurement–primarily due to limited awareness and understanding of their long-term benefits–unless they have a clear and immediate impact on reducing operational costs. The survey revealed that over half of respondents found it difficult to maintain medical equipment. The issues range from basic issues to software-related problems, with the latter being more common. Nevertheless, healthcare practitioners have inadequate knowledge to an extent that they cannot effectively detect if an equipment has a problem. This limited understanding hinders their ability to identify when an appliance has malfunctioned. So, while appliance damage is often attributed to issues of power, lack of knowledge is also a significant contributing factor. Bridging this knowledge gap is essential

to improving the long-term effectiveness and sustainability of medical equipment in healthcare facilities (Diaconu, et al., 2017).

Most of the health facility electrification initiatives target greenfield facilities with no or only a few appliances present, hence, the PV/storage system design is normally informed by a theoretical set of medical appliances as per the national standards. Medical appliances are acquired at a later stage, usually from another donor's activity. This leads to the deployment of energy systems that cannot support the load requirement of most of the medical equipment used in energy constrained setting**s** (CLASP, 2021). A study conducted by (Pakravan & Johnson, 2021) in healthcare facilities found out that 40% of failures in the current solar PV systems result from poor system design and installation. As a result, electrical faults become the norm, which causes the malfunction of equipment. The scenarios mirror the situation in many parts of Sub-Saharan Africa. The implications are profound: essential equipment fails to function consistently, and healthcare workers are forced to rely on manual methods or delay care altogether. Such incidents not only render critical equipment unusable, but also create additional costs and downtime for repairs or replacements. It is imperative to ensure that an inventory is done on the energy consumption of all medical equipment, to guide the installation of appropriately sized energy systems.

Inefficient appliances add to the high OPEX and CAPEX cost for running and electrifying health facilities. Many healthcare facilities rely on old, outdated appliances that are inefficient and consume excessive amounts of electricity. Healthcare facilities often struggle to pay electricity bills due to the high energy consumption of many medical appliances, leading to significant operational costs. A major challenge is that many medical devices are not energy-efficient, and there is generally low awareness about energy efficiency among healthcare practitioners. As a result, factors such as wattage and energy consumption are frequently overlooked. **It is therefore essential for newly designed medical equipment to incorporate energy-efficient features.** Replacing inefficient appliances with efficient ones can cut the energy needs of a health facility down, thus decreasing the CAPEX needs for electrifying health facilities. From the survey, nearly all of the respondents believed that it is very important for new medical equipment to have energy-efficient features to reduce power consumption and maintain functionality during outages (Figure 11). If adopted, energy-efficient medical appliances can help healthcare facilities in resource-constrained environment save significant energy or money that could be channeled to other productive uses. Data generated by SELCO Foundation has shown that replacing the existing inefficient medical appliances with energy-efficient ones can save 55%, 53%, and 75% of energy for blood bank refrigerators, baby warmers, and oxygen concentrators respectively (WHO, SEforALL, IRENA, World Bank, 2023). Such advancements not only reduce energy consumption and operational costs but also enable the installation of decentralized energy systems to power these devices, that would not have been financially or technically feasible, ensuring sustainable healthcare delivery in energy-constrained environment. With the adoption of energy-efficient medical devices, the overall cost of installing decentralized renewable energy (DRE) technologies can be reduced by half, and in the process, the problem of unreliable power is addressed as well (Abagi, et al., 2019).

> ”
>
> We assemble all appliances and sterilize them after every 2 weeks because of the fear of energy consumption. That way we can control energy consumption. The fear of energy consumption is hereditary.
>
> **Facility in charge in a level 3 facility**

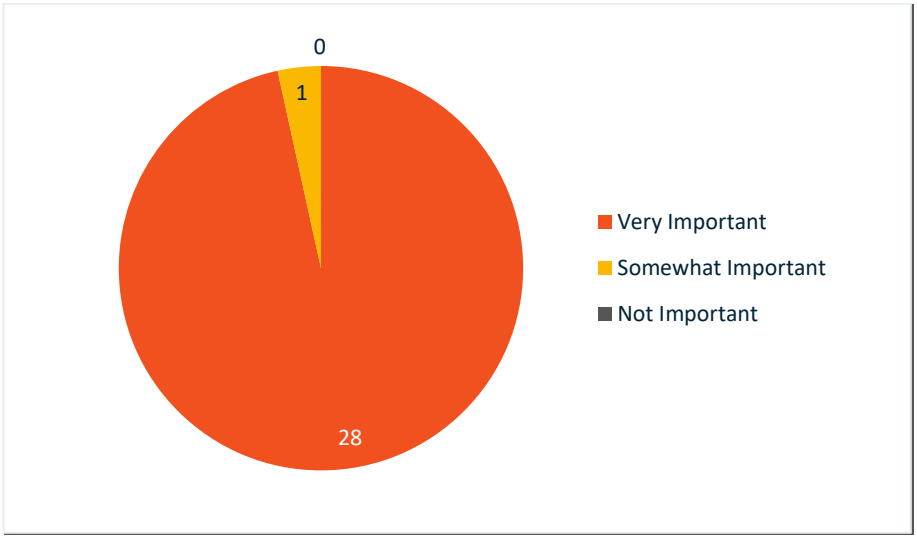

FIGURE 11: Respondent perceptions of the importance of energy efficient features in new medical appliances
Source: Own analysis

Inefficient medical appliances place additional strain on already scarce energy resources. In weak-grid settings, such strain can cause recurring power disruptions and force staff to prioritize the equipment to power or choose alternatives that do not consume energy if possible. Data logging analysis showed that oxygen concentrators were the most energy-intensive appliances consuming 7.3 kWh/day on average (Figure 12). Although autoclaves have higher rated power due to the high heat and pressure required for sterilization, the oxygen concentrator is a low-power, but long-duration appliance, leading to overall high energy consumption. Furthermore, a detailed analysis of the energy consumption of the two infant warmer models tested shows that OKM-730 is somewhat more energy-efficient than HKN-93. However, despite its lower efficiency, HKN-93 was used more frequently, which additionally contributed to the higher overall energy consumption observed.

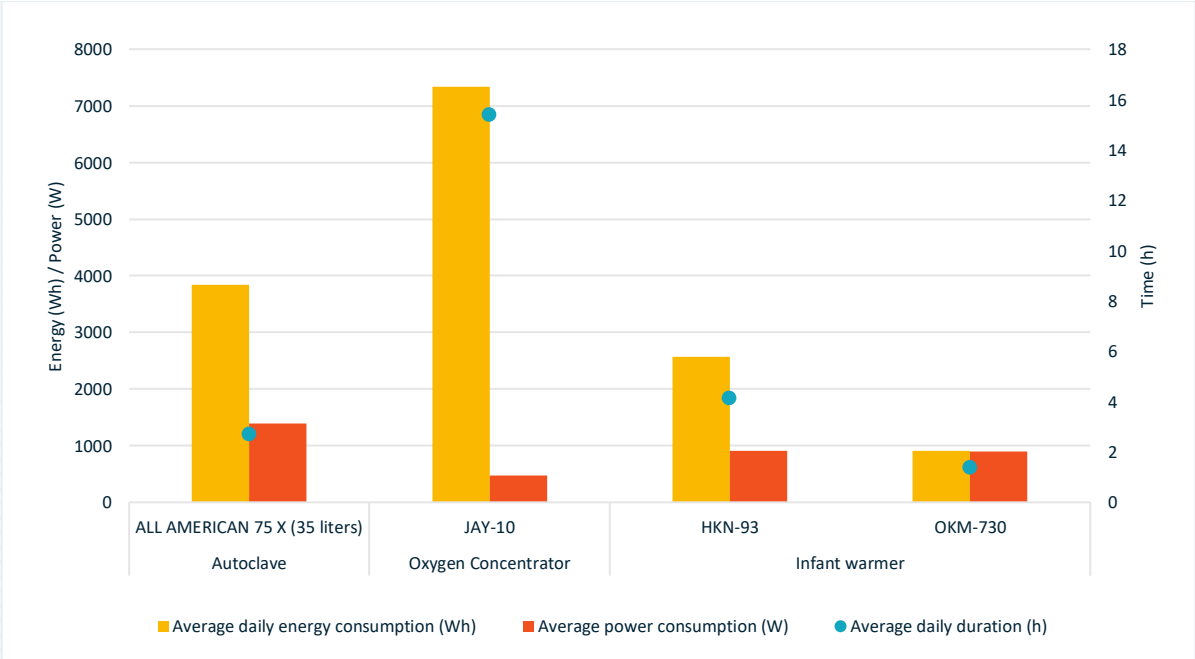

FIGURE 12: Average daily energy consumption, power consumption and daily usage per appliance and model.
Source: Own analysis

Standby energy consumption, when medical or other devices continue drawing electricity even when turned off but still plugged in, might be considerable and accounted for during the sizing of any power supply. A study conducted by (Anselm & Schick, 2022) revealed that anesthesia machines in standby and paused modes can consume significant power, up to 127W, compared to just 10.6W when switched off. Furthermore, research showed that power consumption of anesthesia workstations in standby is equal to 90% of the power consumption during operation, while when switched off, power consumption drops to 7% to 25% depending on the appliance (Drinhaus, et al., 2024).

Portability is a major challenge for many appliances as they cannot be moved easily from one area to another. While considerable advancements have been made in the development of portable medical devices (Soto, et al., 2022), many crucial medical appliances are still large and stationary, which restricts their accessibility and effectiveness, particularly in resource-limited environments. Devices such as traditional X-ray machines, autoclaves, and some types of oxygen concentrators are typically designed for stationary use, requiring fixed power sources, ventilation, or specific environmental conditions. Although there have been advancements in developing more compact and mobile medical technologies—such as handheld ultrasound scanners and battery-operated monitors—many essential devices still lack the design features needed for easy transport, such as wheels, lightweight materials, modular power sources, or shock-resistant casings. This restricts their usability and reach, particularly in low-resource or rural areas where health services are often delivered in temporary clinics, mobile units, or under variable infrastructure conditions. In such environments, flexibility and adaptability are critical, and non-portable equipment limits the ability to respond efficiently to patient needs across varying locations.

2.3 Product growth challenges

BOX 4: Mutsimoto Motor Company

Mutsimoto Motor Company is one local firm that experienced challenges while developing locally manufactured medical equipment in Kenya, specifically the ventilator "Pumuaishi 3.0," which was created during the COVID-19 pandemic. Despite its certification by the Kenya Bureau of Standards (KEBS) and collaboration with local experts, including biomedical engineers, doctors, and programmers, the project faced insurmountable obstacles. A case of bureaucratic barriers were encountered that hindered progress. Without external funding and with the government prioritizing imported ventilators over local innovation, the Mutsimoto team had to halt production, despite the ventilator's potential for local and export markets. In most African countries, the regulatory environment makes it extremely difficult for local innovators to succeed.

The lack of regulatory frameworks and policies around medical devices limits access to energy-efficient appliances for weak-off grid settings. Innovations in medical technology are complex and typically take 12 to 15 years to enter a market, as they must undergo rigorous validation for safety, effectiveness, and quality. This process is even more challenging in LMICs due to limited product testing facilities and weak institutional support, which undermine efforts to systematically assess and verify innovation quality leading to products of poor standards (Dutta & Dhar, 2024). The WHO Africa region has more countries lacking regulatory frameworks or national regulatory authorities (NRAs) for medical devices compared to other regions (Nasir, et al., 2023). According to WHO, 40% of countries in the African region lack medical device regulations; 32% have only partial regulations, and 28% lack sufficient data on this issue. Even where NRAs are available,

challenges exist that hinder effective regulation. Moreover, it is unclear how NRA-approved medical devices are adopted in health facilities or governed beyond national-level processes (Nasir, et al., 2023). As a result, there is a risk that medical devices enter African markets with minimal pre-market regulation and inadequate or no safety testing. However, devices for disease-specific programs like HIV, TB, and malaria undergo strict regulation, likely due to international organizations' involvement, though the exact reasons remain unclear. Stakeholder consultations showed that specific regulatory frameworks for medical equipment are lacking in countries like Kenya with only international standards based on performance being used, highlighting a regulatory gap that leaves the local market unstructured and vulnerable. This regulatory gap poses significant risks, including the proliferation of low-quality medical devices and limited access to reliable healthcare technologies for patients in these underserved areas, underscoring the urgent need for action.

Lack of government support is a major impediment to the growth of local medical device markets in African countries. Stakeholder consultations revealed that the main obstacle for local medical device development in SSA is not a lack of innovation, but rather government procurement practices. Local startups in the medical device sector have not been effectively supported nor benefited from an enabling environment, either due to lack of knowledge or policies. Moreover, product manufacturers often experience frustration with slow government processes. Issues such as difficulties in obtaining the "Conformité Européenne" (CE) certification, the initial cost of hardware, procurement guidelines and the need for more patient engagement in the process, and the lengthy process of tapping into government funds contribute to frustration. Product implementation only becomes easier when the government shows interest in supporting innovative technologies.

Implementing systems in complex environments is challenging due to their unpredictability, the need to coordinate multiple stakeholders, and interconnected factors that impact outcomes, underscoring the importance of effective communication among stakeholders. The medical appliance landscape has a lot of vertically hierarchical processes from procurement to use and it becomes difficult to ascertain whether the problems encountered such as the improper use of appliances is a result of limited capacity or other contributing factors. It is therefore crucial to identify the actual issue; otherwise, efforts may be directed at solving the wrong problem. Additionally, stakeholders may attend conferences abroad and encounter systems they believe would be beneficial for their own country, even though that may not actually be the case. Should such systems be implemented without proper guidance from the manufacturers, it will reflect poorly on them if the system fails for any reason and tarnishes their reputation, with buyers likely forgetting the advice that was provided.

To avoid such issues, there is a need for locally specific guidance on medical appliance implementation. Remote areas may require simpler systems due to a limited workforce. Consequently, understanding the total cost of ownership and the importance of selecting equipment proven to work in similar settings is crucial.

Developing medical equipment compatible with unreliable power sources is a promising solution but involves navigating a complex and often bureaucratic approval process. Such equipment must meet stringent regulatory, safety, and performance standards, often requiring approval from both national and international bodies. This process can be slow, opaque, and resource-intensive, with limited institutional capacity and unclear guidelines in many settings. As a result, only a few well-resourced organizations are able to successfully navigate these hurdles, limiting the availability and deployment of appropriate medical technologies in energy-constrained health facilities.

CHAPTER THREE

Addressing Challenges

3.1 Healthcare electrification and medical equipment

Addressing the energy-healthcare nexus challenges requires more than just expanding the grid. It demands a systemic approach involving the deployment of decentralized renewable energy solutions, energy-efficient medical technologies, and robust maintenance systems tailored to off-and weak-grid settings. Up to 60% of failures in solar PV systems are attributed to inadequate operation and maintenance (O&M) practices (Pakravan & Johnson, 2021) which highlights the critical importance of implementing effective O&M strategies to enhance system reliability and performance. Investment in solar PV systems with battery storage, supported by innovative financing models, is increasingly recognized as a pathway to strengthening healthcare resilience in off grid and weak grid regions (UNDP, 2025).

Transitioning to decentralized renewable energy systems, particularly solar PV solutions paired with battery storage, presents a transformative opportunity to enhance the resilience and sustainability of healthcare infrastructure. Appropriately sized off-grid solar PV systems coupled with energy-efficient medical appliances offer a quick and affordable way of electrifying rural healthcare facilities and can significantly reduce the total energy demand of a facility. Moreover, the continued cost reduction of solar PV and battery technology renders off-grid solar solutions a more viable option given that battery prices declined by 73% while the cost of PV modules has dropped by over 80% since 2009 (SEforALL, 2022). When used with energy-efficient medical devices, the cost of installing off-grid solar systems can further be reduced by 25% (Abagi, et al., 2019), making solar-powered systems more economically viable than ever (REN21, 2024).

Clean energy solutions such as solar PV help alleviate the financial burden of energy costs in hospitals. Unreliable and costly grid electricity has consistently diverted funds away from essential medical services, placing significant financial strain on hospitals. Medical superintendents reported

that they frequently faced a dilemma in attempts to manage the limited funds allocated each quarter. Given the importance of reliable power for operating essential medical equipment, covering electricity costs competes with procurement of vital medicines. This may partly explain the common scenario in many public health facilities where diagnostics tools are available, but essential medications are missing. Nevertheless, diagnosis without guaranteed access to appropriate medications can put patients in difficult situations, especially when many cannot afford the prescribed over-the-counter drugs. Similar scenarios were observed in nearly all the facilities surveyed, except the Airport Health Centre which operates entirely on solar power (BOX 5).

BOX 5: Case study: Impact of solarizing health facilities on health services

Relying on a solar PV system with battery storage, the Airport Health Centre has experienced no issues with power fluctuations or equipment damage. The system comprises a battery with an approximate capacity of 24V, 1818Ah (43,632Wh), a 5kW inverter, and a 6kWp photovoltaic array. The grid is used solely as a backup and only on rare occasions during the rainy season. Since the solar PV system was installed by NICCO Japan volunteers in 2021, the facility has consistently kept its grid electricity costs below $3.9 per month. This suggests that the facility has greater financial flexibility to invest in essential medicines and medical supplies. The positive impact of this transition is reflected in the high patient turnout, with many seeking care at the facility. In contrast to other Level 3 hospitals visited, this hospital was notably busy and able to provide comprehensive services including free ultrasound scans for pregnant women.

Reliable electricity in healthcare facilities plays a significant role in lowering neonatal and maternal deaths and uninterrupted operation of life-saving equipment is vital to positive outcomes, as it enables timely delivery of essential medical interventions during emergencies. According to (Mohammed & Akuoko, 2022), improved access to electricity is linked to a significant reduction in infant mortality; a 10% rise in electricity access reduces infant mortality by 5.4 deaths/1,000 live births. Among the three key appliances studied, the infant warmer emerged as the most frequently used, underscoring its critical role in efforts to reduce neonatal mortality. WHO advises using infant warmers for unstable or low-birth-weight babies under 2,000g (Kyokan, et al., 2023). Infant warmers and incubators regulate body temperature and prevent hypothermia, a serious risk for preterm or low-birth-weight newborns. Hypothermia is a key contributor to neonatal deaths and illness, especially among preterm infants, where it's linked to up to 80% of the mortalities (Kyokan, et al., 2023). To minimize the serious risks that hypothermia poses to newborns, ensuring proper thermal protection is a critical aspect of neonatal care (Singer, 2022). A study conducted by (Ouedraogo & Schimanski, 2018) found out that the use of electric incubators in Kenyan health facilities lowered neonatal mortality rates to 28% from 40%. According to (Soto, et al., 2022), providing access to basic lighting and electricity for surgical equipment can reduce maternal mortality by 70%. Better results are obtained when infant warmers/incubators are paired with oxygen concentrators.

A newborn receiving treatment for hypothermia and asphyxia at Kisumu County Referral Hospital

Birth asphyxia, inability to initiate breathing at birth, a condition that occurs when a newborn is deprived of adequate oxygen before, during, or immediately after birth, can be remedied using oxygen concentrators. According to WHO, birth asphyxia is among the main causes of early neonatal death, contributing to approximately 900,000 mortalities annually (Wudu, et al., 2025). In Ratta Health Centre, for example, most of the hospital referrals were due to neonatal asphyxia. The facility lacked all the medical appliances relevant to the study and reported that power outages could last up to three days. Although oxygen cylinders were available, they were not in use. A study conducted by (Lawubah, et al., 2023) equally revealed that birth asphyxia was the leading direct cause of neonatal mortality, accounting for 39.6% of the deaths in Grand Kru County, Liberia, underscoring the critical role of functioning oxygen concentrators in saving lives.

BOX 6: Spectrum Africa

Spectrum Africa has introduced an AI and machine learning solution called emPower. The emPower aims to efficiently manage power by allocating the right power source based on the facility's energy needs, reduce peak demand, and store surplus energy for later use. This will involve installing solar-powered rechargeable stations at healthcare facilities, which would also provide clean water and cooling chambers for pregnant mothers, underscoring the potential for energy savings and the reduction of greenhouse gas (GHG) emissions. The solution also includes a smartphone-based app to monitor and adjust power usage and hence could be particularly beneficial for healthcare facilities in Kenya that experience frequent power outage. The strategy strives to improve energy efficiency, which includes conducting energy audits, optimizing equipment scheduling, and implementing smart meters and sub-metering, “it is important to monitor and control energy consumption in real-time to adjust peak demand.” The company is to explore the potential of solarization and the use of battery storage solutions as well as the potential to lease energy-efficient equipment and the possibility of earning carbon credits.

According to (Khogalia, et al., 2022), oxygen delivery systems powered by solar have been linked to decreased infant fatalities and shorter hospital stays. Improved access to electricity in Africa can significantly reduce maternal mortality (per 100,000 live births), with each unit increase in electricity access associated with a decline of approximately 5.64 maternal deaths (Dominic, et al., 2019).

Efficient power management plays a crucial role in addressing health electrification challenges by optimizing equipment use. Innovative solutions using AI and machine learning are emerging to optimize power allocation, manage peak demand, and store excess energy for future use. These approaches often include solar-powered infrastructure that can support additional services like clean water access and cooling facilities, contributing to both health outcomes and environmental sustainability. Mobile applications are also being used to enable real-time monitoring and control of energy consumption, which is particularly valuable in areas with frequent power outages. Broader strategies include energy audits, equipment scheduling, smart metering, and exploring solar and battery storage solutions. There is also growing interest in models that support leasing energy-efficient equipment and generating carbon credits to enhance sustainability and affordability.

BOX 7: Off-grid vaccine carrier innovations

Drop Access has developed VacciBox, a solar-powered vaccine carrier tailored for low-resource clinics that comes with a 2-year warranty. It is lightweight, easy to transport on motorbikes, and designed with built-in power storage to maintain temperatures for over 24 hours. Drop Access has piloted the VacciBox in rural parts of Kenya, offering a scalable, context-relevant cold chain innovation that supports equitable vaccine access even during blackouts. Black Frog Technologies has equally introduced portable medical-grade vaccine carriers that use thermoelectric cooling and are particularly suited for last-mile delivery in rural and hard-to-reach areas in India. These units provide a temperature-stable environment for up to 12 hours and are equipped with IoT-enabled temperature monitoring, enhancing real-time tracking and accountability.

Maintaining the cold chain for vaccines in energy constrained settings is crucial to ensuring that no one is left behind in the fight against preventable diseases, making equitable healthcare access a reality for all. Innovative technologies have been developed that can preserve vaccines at safe temperatures for several days or even weeks without relying on electricity. For instance, these innovations show how tailored, energy-efficient technologies can significantly improve cold chain reliability, reduce vaccine wastage, and enhance immunization coverage in weak and off grid areas.

3.2 Design and suitability of medical devices

Well-designed, context-appropriate medical equipment ensures functionality in areas with unreliable electricity. Medical devices appropriate for resource constrained settings, with compounding contextual factors such as power availability and local technical capacity, can strengthen health systems sustainably. Energy efficiency considerations have to be factored into the design process, and devices need to meet minimum requirements, i.e. available power whether it is from grid or solar. For instance, Delft University of Technology has designed MRI machines that are tailored to work with low power supply in energy-constrained settings with a few MRI machines that run purely on solar, a technology already available in Uganda. These designs do not adhere to European frameworks, as these are not suitable for resource-constrained settings. Instead, they consider factors such as power availability and repairability. To address the issue with donated medical appliances that often become obsolete after breakage, Delft University of Technology is exploring different business models, including a cheaper device model and subscription-based services to ensure longevity. The argument behind this is that "if they can afford it, they can afford the cost of repair."

Energy efficiency is a critical factor that must be prioritized during medical equipment procurement in under-resourced settings. It is crucial to establish guidelines that prioritize the acquisition of energy-efficient medical devices for public hospitals. Although energy-efficient equipment may involve higher initial costs, the long-term advantages of decreased operating expenses and enhanced environmental sustainability provide significant value. As illustrated in Chapter 2, governments and procurement agencies should incentivize manufacturers to redesign frequently used and energy-intensive appliances in the selected healthcare facilities, prioritizing autoclaves, HKN-93 infant warmer and new life oxygen concentrator which has the highest energy consumption to maximize overall savings. By focusing on these high-consumption devices, healthcare facilities can substantially reduce energy consumption and overall service cost.

Harnessing AI for medical applications like diagnosis can increase robustness of products. AI-driven medical technologies are crucial for strengthening healthcare delivery in low-resource settings with limited electricity and medical personnel.

BOX 8: Delft Imaging

Delft Imaging specializes in AI-powered medical imaging tailored for low-resource settings, addressing context-specific challenges rather than adopting high-income country models. Its AI-enabled ultrasound technology determines gestational age and detects pregnancy risks, while its AI-integrated X-ray systems identify TB-related lung abnormalities, currently deployed in over 85 countries. A key innovation, Delft Light, is a battery-operated, ultra-portable X-ray system designed for decentralized TB screening, compatible with solar or grid power. Delft's solutions are built to be energy-efficient and resilient, ensuring functionality even in settings with unstable electricity. All systems meet WHO standards and are supported by a global help desk and local partners, with funding facilitated through The Global Fund's three-year country proposal cycle.

Integrated solutions such as patient monitoring systems can be transformative in low-resource settings. By combining reliable hardware, intuitive software, and power backup features, these systems help address critical challenges such as staff shortages, limited training, and unstable electricity. Their success lies not only in the technology itself but also in the ecosystem of support services—ranging from training and maintenance to data connectivity and supply management. Backed by grants, philanthropic funding, and sustainable service models, such solutions have demonstrated significant improvements in patient outcomes, including reduced child and neonatal mortality rates, while easing the workload of healthcare workers. Their expansion across several countries highlights the value of comprehensive, system-level approaches over isolated interventions.

BOX 9: Goal3 and the Impala System

GOAL3, an organization dedicated to helping hospitals shift from reactive to proactive care, has developed a comprehensive model that extends beyond electricity to address the wider needs of healthcare facilities. The company has introduced the Impala system, a patient monitoring system designed for low-resource settings, which includes durable hardware components, intuitive software, and a 6-hour battery life to address power fluctuations and blackouts. Post-sale services are also provided, including troubleshooting, retraining, and maintenance. This was made possible through grants from organizations like Gates and ELMA Foundation, as well as support from effective altruism programs. Recurring revenue from hospitals and governments for the rendered services also ensures sustainability. GOAL3 provides service contracts to ensure the availability of spares and consumables, as well as ongoing training and support. The company partners with organizations like Signalytic that offer solar power and servers for communication and stock management, emphasizing the importance of system solutions rather than single solutions to tackle healthcare issues.

The Impala System is a patient monitoring system that was developed for use in low-resource settings. The system was designed to reduce child mortality rates by providing continuous monitoring, easing the workload of nurses and clinical officers, and improving patient outcomes. The system has been successfully implemented in public hospitals in various countries, with initial costs covered by grants and private donations. The system has shown impressive results, with pediatric mortality rates having reduced by 42% and neonatal mortality rates by 27% in some hospitals with 92% of staff reporting reduced workload. The success of the system is attributed to its ability to monitor patient health, provide insights for decision-making, and improve overall quality of care as well as its potential to automate tasks at lower-level healthcare facilities and its integration with solar power solutions to address electricity constraints. Because of this, the system has seen exponential growth in countries such as Malawi, Tanzania, and Rwanda.

Portable and IoT-enabled medical equipment is essential for extending healthcare access, ensuring that healthcare can reach patients whether in remote clinics, mobile outreach units, or emergency settings and therefore significantly help improve healthcare delivery in underserved communities. These technologies enable healthcare providers to bring medical services directly to patients, reducing the need for extensive travel. Portable diagnostic devices facilitate on-site testing and immediate results, allowing for quicker diagnoses and treatment plans, and decreasing the necessity for multiple trips to distant facilities. IoT-enabled devices allow for continuous remote monitoring of patients' conditions, ensuring timely interventions and reducing the need for patients

to travel for routine check-ups. This combination of portability and connectivity transforms healthcare delivery, making it more convenient, efficient, and accessible for underserved populations, and ultimately improving health outcomes by providing timely and consistent care closer to home.

3.3 Sector growth

With the evolution of medical technology, it becomes increasingly important to prioritize the upskilling and training of biomedical engineers. Currently, biomedical engineers in SSA have limited knowledge on innovative appliances and lack versatility. Therefore, training is necessary for staff to be resourceful and capable of working with various equipment brands and addressing issues. Exposing biomedical engineers to advanced technologies by empowering them to troubleshoot and adapt when new equipment is introduced should take precedence over hiring specialized technicians, which tends to be a more costly option. Furthermore, it is essential to prioritize enhancing the department's skills before investing in new equipment, as their expertise can offer valuable input during both the procurement and maintenance stages. Considering that maintaining and powering medical equipment in various countries can be very challenging, training and capacity building exercises ought to be conducted regularly. To address challenges such as high staff turnover, organizations can implement trainings like Delft Imaging, which conducts initial for its clients and refresher training 3 times a year. The training sessions are conducted in person, in collaboration with local organizations, to help overcome language barriers. Capacity building on the importance of energy efficiency should also be conducted to influence their purchasing decisions.

Transdisciplinarity is key to bridging the research, policy, and industry gap due to its ability to transcend the scope of any single discipline or sector. Transdisciplinary approaches foster collaboration among academia, policymakers, industry stakeholders, and communities, enabling the co-creation of knowledge and solutions that are both scientifically robust and practically applicable (Lah, 2025). Long-term partnerships can help define energy efficiency in local contexts while supporting the design and testing of appropriate technologies. In Kenya for example, limited capital has led to foreign dominance in the medical device startup space, highlighting the need for government and investor support to boost local innovation. Financial incentives and non-monetary support from organizations like GET.invest can help local businesses become investment ready.

Government commitment is also essential in covering both the upfront and operational costs of energy-efficient devices, as well as in establishing procurement guidelines prioritizing locally-sourced devices and supporting maintenance and management. Engaging with public health partners and local innovators through inclusive procurement processes can drive adoption of new technologies, such as the active vaccine carriers from Drop Access and Black Frog (see **BOX 7**). To further encourage local manufacturing, policies should promote the procurement of locally made devices and support integration with renewable energy systems. According to Africa Centre for Disease Control and Prevention (CDC), African leaders pledge to increase the share of vaccines, medicines, and diagnostics locally manufactured in Africa to 60% by 2040. To support sustainable local manufacturing of medical equipment in SSA, it is essential to establish national and regional policies and legal frameworks that foster an enabling environment.

Governments can incentivize local manufacturing by providing serviced land, implementing tax holidays for start-ups, and granting duty exemptions on imported raw materials and equipment. Strengthening health financing strategies within the framework of universal health coverage will help create market certainty, while preferential local procurement schemes and pooled procurement mechanisms can ensure consistent demand for locally produced equipment. Establishing manufacturing hubs in regional economic zones for priority health products can promote economies of scale and reduce competition with national manufacturers.

Local companies should equally be encouraged to produce effective devices that meet global standards through partnerships with objective third-party quality assurance initiatives like VeraSol. Competitions and innovation challenges can further inspire local manufacturers to achieve international recognition, but also international manufacturers by making knowledge openly available. It is also vital to design programs with a systemic lens and integrate them over a long period of time to avoid short-term projects that often lie unused or unutilized. Relying on multilateral partners for short-term, siloed projects can hinder the integration of new collaborators. When initial initiatives are designed without inclusive, long-term strategies, they may fail to demonstrate sustainable impact, causing prospective partners to question their effectiveness and hesitate to participate.

Building champions in the procurement process for medical equipment who have bought into the narrative of health system strengthening, is crucial. Given that evidence alone is not enough to sway government decisions, these champions play a pivotal role in ensuring that procurement decisions align with the overarching objectives of enhancing healthcare delivery and achieving universal health coverage. Thus, there is a need to organize cross-learning workshops and forums to help create and influence champions while educating suppliers about the relevant medical standards. For effective interventions, the correct audience must be invited to these discussions, not just anyone.

Healthcare facilities must adopt innovative and adaptable business models. Traditional procurement approaches that depend on large upfront capital investments often limit access to reliable energy solutions and essential medical technologies in weak-grid and off-grid settings. A shift towards service-based models can enable these healthcare facilities to access solar energy systems, battery storage, and critical medical equipment through contracts that include installation, maintenance, and performance guarantees, reducing the burden of ownership. Financing mechanisms like results-based financing (RBF), climate-health adaptation funds, and blended finance, including grants, concessional loans, and guarantees can help mobilize the estimated USD 5 billion required to close the energy gap by 2030. Moreover, partnerships with social enterprises offering pay-as-you-go (PAYG) or lease-to-own models can make energy and equipment solutions more accessible to clinics in rural or peri-urban areas. These models not only lower financial barriers but also ensure long-term functionality and reliability of medical equipment, ultimately strengthening the delivery of health services in weak-grid and off-grid regions.

CHAPTER FOUR

Upcoming Trends in Healthcare Electrification and Medical Equipment

Decentralized renewable energy (DRE) has vast potential to transform healthcare in low-resource communities. It can help democratize healthcare by shaping energy systems around the needs of communities, especially those relying on primary care, driving a shift in service delivery (IRENA, 2025). The shift toward decentralized energy systems in healthcare is driven by a combination of technological factors, financial incentives, and the growing recognition of the significance of resilience in unstable operating conditions. With the declining costs of renewable technologies, decentralized renewable energy systems such as solar PV panels paired with battery storage have emerged as affordable and rapidly deployable solutions for health facilities electrification, especially in remote or underserved areas. Providing reliable electricity through solar PV to approximately 100,000 currently unelectrified or poorly healthcare facilities in SSA would require an estimated upfront investment of $2.5 billion, while close to $4.9 billion are required to close the electrification gap of health facilities globally (WHO, SEforALL, IRENA, World Bank, 2023). According to (Moner-Girona, et al., 2021), electrifying these facilities could reduce the travel time of 281 million people by almost one hour.

DRE systems not only provide primary power where grid access is lacking but also serve as reliable backup sources in grid-connected facilities facing frequent outages or high electricity costs (WHO, SEforALL, IRENA, World Bank, 2023). By reducing dependence on diesel fuel, DRE systems enhance the resilience of health systems, lower air pollution, and contribute to climate action. Integrating sustainability and climate considerations into healthcare electrification efforts is thus essential for building robust, low-carbon health systems worldwide.

BOX 10: Chitwan Medical College Teaching Hospital in Nepal

Chitwan Medical College Teaching Hospital (CMCTH), one of Nepal's largest hospitals, faced high energy costs and unreliable grid power, relying on expensive diesel generators. To avoid upfront investment in solar, the hospital partnered with Gham Power through an innovative Power Purchase Agreement (PPA), paying $0.10/kWh, a rate lower than the national utility (Soler, et al., 2020). Gham Power fully funded the $140,655, 200kWp grid-tied solar system and retains ownership for 15 years, after which CMCTH takes over. The system now reduces 800kWh of daily load, powers critical equipment, and saves around 196 tons of CO_2 emissions annually. It is supported by trained local operators and digital monitoring tools for maintenance and performance, ensuring sustainability and long-term savings estimated at $197,092

Energy-as-a-Service (EaaS) is a growing trend in healthcare, providing dependable and sustainable energy solutions for facilities, especially in LMIC's with limited electricity access. It marks a transition from conventional, high-cost energy infrastructure to more adaptable, subscription-based or pay-per-use models (IRENA, 2025). It meets the urgent demand for reliable power to support vital medical equipment and services. When equipped with remote monitoring features, these systems enable real-time tracking and quick resolution of technical issues, ensuring solar systems remain fully functional. Remote monitoring effectively tackles the frequent challenge of solar systems becoming non-functional due to inadequate maintenance, avoiding the typical donor model where systems fail due to lack of long-term planning. The EaaS model guarantees sustained power for at least 10 years, supporting better healthcare delivery and demonstrating the value of reliable electricity. This could prompt governments and relevant ministries to fund service fees, ensuring reliable electricity for rural health facilities. As an example, SolarAid, in partnership with WWF Zambia, is currently piloting an EaaS model at the Hofmeyr Zonal Rural Health Centre located in Zambia. Through this model, the facility pays a fixed monthly fee that covers ongoing operation and maintenance of the solar power system (Ollvid, 2024).

Industry 4.0, marked by the convergence of IoT, cyber-physical systems and cloud computing, is expected to revolutionize medical device manufacturing. Amid staff shortages and rising patient demand, healthcare providers globally are rethinking care delivery while increasingly prioritizing sustainability (Philips, 2024). Cutting-edge innovations are being blended with patient-centered solutions (Singh, 2025). Advances in AI, wearable devices, internet of medical things (IoMT), robotics, augmented reality (AR), and blockchain technologies are redefining the medical equipment landscape, transforming healthcare delivery through better outcomes, greater efficiency, and wider accessibility (Junaid, et al., 2022). Of all these innovations, AI and IoMT are most promising due to their transformative capabilities in healthcare. AI enhances data interpretation through machine learning and predictive analytics, enabling more accurate diagnoses and personalized treatments (Akkaoui, et al., 2024). IoMT connects devices for real-time monitoring and data analysis, enhancing care efficiency. However, challenges like data privacy, cybersecurity, infrastructure limitations, and system interoperability must be addressed. Besides, these advanced technologies facilitate smart manufacturing processes that improve efficiency and scalability medical appliances. AI-powered analytics enhance quality control by detecting defects early, while IoT-enabled systems allow real-time monitoring to ensure consistency and regulatory compliance. AI further strengthens operations by offering remote training and visual guidance. When combined with 3D printing, AI and IoT enables the production of personalized medical

devices like custom prosthetics and implants, greatly improving patient care and outcomes. Africa is gradually establishing its presence in the global tech landscape, with countries like South Africa, Egypt, and Morocco leading the way. Morocco is making notable progress in healthcare technology, reflecting a strong commitment to scientific research and innovation. These developments are driving technological growth and positioning African nations as emerging players in the global healthcare innovation arena.

Point-of-Care (PoC) devices are emerging to be game-changers, bringing critical care to the patient's bedside and transforming health delivery in low-resource settings. Technological advancements have led to the development of smaller, more portable Point-of-Care Testing (POCT) devices. These compact appliances enable immediate testing at the site of patient care, removing the need to transport samples to centralized labs (Shah, 2025). As a result, healthcare providers can conduct tests swiftly and efficiently at the bedside, in emergency settings, ambulances, or remote areas, supporting quicker diagnosis and more timely treatment decisions. Despite their benefits, POCT devices face challenges such as reduced accuracy due to user error, environmental factors, and technological limits, which can lower demand compared to traditional lab tests. Their cost-effectiveness is also a concern, especially in low-resource settings, as well as complex, region-specific regulations that pose additional hurdles (Anon., 2024). Enhancing POCT devices' accuracy, affordability, and speed while ensuring economic feasibility could boost adoption. The industry could drive growth by integrating smart technologies, partnering with tech innovators, and focusing on improved diagnostics for non-communicable diseases and conditions requiring continuous monitoring, provided clinical standards are met.

CHAPTER FIVE

Recommendations

To address the challenges identified in this report and enable sustainable healthcare delivery in weak- and off-grid settings, a coordinated and multi-faceted approach is necessary**. This approach must bridge the gap between energy access and healthcare outcomes by focusing on the procurement, deployment, and maintenance of energy-efficient, context-appropriate medical equipment**. The following recommendations offer a pathway for medical device manufacturers, policymakers, donors, suppliers, and practitioners to improve the availability, usability, and longevity of medical devices in resource-constrained environments.

5.1 National governments

There is an urgent need to develop and implement energy performance standards for medical devices. In the absence of standardized benchmarks, health planners and procurement officials are often unable to assess or compare the energy requirements of equipment options, leading to the deployment of high-consumption devices that strain health facility energy systems. Establishing minimum energy performance standards for commonly used appliances—such as autoclaves, oxygen concentrators, and infant warmers—would provide a foundation for better procurement decisions and allow governments to incentivize the uptake of energy-efficient technologies. These standards should be harmonized across regions and aligned with global initiatives such as the WHO's performance, quality and safety protocols, while also accounting for local operational conditions.

Innovative technologies are emerging as critical enablers of effective healthcare delivery. These technologies can reduce dependence on unreliable power sources, lower operational costs, and enhance the quality, continuity, and reach of healthcare services. To realize their full potential, governments, donors, and implementing partners should establish supportive policies and funding

mechanisms that encourage local innovation and context-specific adaptation, integrate performance-based procurement models that emphasize energy efficiency and reliability, promote cross-sector collaboration between health, energy, and ICT actors, and ensure alignment with decentralized renewable energy systems. Embedding these technologies into national health strategies and procurement frameworks will help build more resilient, efficient, and inclusive health systems.

Governments should encourage local manufacture of medical equipment to minimize reliance on imports, decrease production and procurement costs, generate local employment, and improve the availability of essential medical devices in hard-to-reach or underserved communities. Governments and donors should support early-stage product development through targeted grant schemes, innovation challenges, and tax incentives. Additionally, regional collaboration through platforms like the African Medicines Agency (AMA) can help streamline regulatory approval processes and encourage the scale-up of locally validated technologies.

A broader, cross-sectoral coordination mechanism is needed to align stakeholders across health, energy, finance, and technology sectors. National and subnational governments should institutionalize joint planning processes and interministerial coordination to ensure that health facility electrification is approached as a holistic system investment rather than as a series of disconnected infrastructure upgrades. Development partners and donors should likewise coordinate their investments and technical assistance to avoid duplication and build on existing knowledge and networks.

5.2 Healthcare facility electrification planners

Healthcare facilities should adopt integrated budgeting and planning approaches that prioritize energy efficiency of medical equipment alongside clinical needs. Given the financial pressures and structural constraints many facilities face, targeted support, such as incentives, technical assistance, and awareness-raising, can help demonstrate the value of energy efficiency. Embedding energy performance considerations early in facility design and procurement processes can reduce long-term costs and improve overall resilience, even in weak-grid and off-grid settings.

It is essential to integrate energy efficiency considerations into health facility planning, procurement processes, and equipment specification guidelines. Electrification efforts must be directly informed by the power requirements of medical devices to be used in a facility and standby power. Standby power consumption plays a crucial role in sizing DRE systems and should be minimized during the product design phase. This requires closer collaboration between health and energy sectors during planning stages to ensure that energy systems are correctly sized and capable of powering essential equipment. Pre-deployment energy audits and load assessments should be institutionalized as a standard part of electrification programs. Moreover, public procurement frameworks should explicitly require energy efficiency as a criterion in equipment tenders to help shift market demand toward more sustainable products.

Establish comprehensive training and competency programs for both healthcare workers and biomedical technicians. These programs should include structured, ongoing training on the correct use, handling, and basic troubleshooting of medical devices, provided at the time of installation and regularly thereafter. Simultaneously, investments should be made in building the diagnostic

and maintenance capacity of technicians through targeted certification and refresher courses, potentially in partnership with vocational institutions and development partners. Standardized diagnostic protocols and checklists should be introduced to guide accurate assessment of equipment functionality, reducing instances where functional devices are incorrectly deemed faulty.

5.3 Development partners and donors

Development agencies and governments should explore innovative business models like EaaS for the provision of an electrification system and adequate medical appliances. Traditional procurement models that rely on large upfront capital outlays often limit access to essential technologies in low-resource settings. Instead, service-based models can be adopted. These models allow healthcare facilities to access modern energy systems and medical devices including solar power, battery storage, and cold chain units through service-based contracts that include maintenance and performance guarantees. Results-based and climate-health financing mechanisms can be leveraged, particularly where healthcare resilience overlaps with climate adaptation goals. Facilities may also partner with social enterprises or cooperatives that provide PAYG solutions tailored to these contexts. By adopting these flexible and sustainable financing options, healthcare facilities can overcome financial barriers, ensure reliable energy for critical services, and strengthen their ability to maintain functional, appropriate equipment over time.

There is a need to systematically evaluate the effectiveness of current medical equipment donation guidelines and how they are applied in practice, particularly in off-and weak-grid contexts. Collaborative needs assessments are essential to align donor-funded health interventions and equipment with local priorities, ensuring relevance, sustainability, and effective integration. This will help address the issue of misaligned donor priorities and promote demand-driven donations by allowing hospitals to identify and prioritize their most critical needs. Donors must encourage efforts that empower health facilities to communicate their needs, including the right to decline unsuitable donations.

In parallel, donors should critically assess their own practices against established guidelines, such as the WHO guidelines, and ensure that energy requirements and infrastructure compatibility are explicitly considered before donations are made. Embedding these practices into donation protocols can significantly reduce the mismatch between donated equipment and real-world operating conditions of health facilities, helping ensure that donations are appropriate, sustainable, and impactful.

The initial stage of medical equipment donation should involve establishing bilateral and equitable partnerships between donors and recipients. Leaders on both sides are required to be partnership coordinators, and local clinical leads, biomedical engineering departments, suppliers and health ministries should be consulted in the development of a formal, agreed donation plan. Inclusion of hospital procurement managers, who may be better informed on local equipment policy and needs, may help donations to succeed.

Investing in data infrastructure and knowledge-sharing mechanisms is key to strengthening the evidence base for future interventions and technology development. Informed decision-making must also be underpinned by robust data systems. Remote monitoring tools and IoT-

enabled devices can provide real-time visibility into equipment performance and energy consumption, facilitating predictive maintenance and optimal resource allocation. Open-access databases that catalogue appliance energy profiles, failure rates, and field performance under different conditions would be invaluable to planners and developers.

5.4 Medical equipment suppliers and manufacturers

To address the unavailability of spare parts and challenges posed by obsolete medical equipment in LMIC's, it is essential to develop local spare part supply chains and implement standardized and sustainable procurement practices. This will necessitate engagement with private sector actors and the promotion of circular economy models—such as refurbishment and recycling—to reduce e-waste and enhance equipment longevity. Regional maintenance hubs will need to be established, with procurement and donations limited to equipment models with assured parts available as well as local technical support. Long-term service contracts with manufacturers or third-party providers should be prioritized to ensure access to spare parts over the equipment's lifecycle.

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Annex

ANNEX 1: Stakeholders consulted

No.	NAME	DESIGNATION	ORGANISATION
1	George Nyongayo	Assistant Director Renewable Energy	State Department for Energy, Kenya
2	Norah Magero	CEO	Drop Access
3	Huda Jaffer	Director	SELCO Foundation
4	Yue Cui	Director	Signify Foundation
5	Caroline Wangamati	Team Lead	Coalition of Blood for Africa
6	Asit Shah	Director	Mutsimoto Motor Co Limited
7	Joao Pedro	Business Development Manager	Delft Imaging
8	Florent Geerts	Managing Director	Delft Imaging
9	Janharmen Drost	Commercial & Business Development Lead	GOAL3
10	Raoul Ilahibaks	Director	Bazaruto Renewables
11	Peter Ejimudo	Co-Founder	Vanpeux Global Synergy Ltd
12	Justus Ogando	Director	Spectrum
13	Keziah Khalinditsa	Senior Project Specialist	ABT Alliance
14	Shedrick Otieno	BioMedical Engineer	Kisumu County and Referral Hospital
15	Dr. Muthoni Ntonjira	Director	Philips East Africa
16	Andrew Amadi	Energy Transition Expert	UNEP CCC
17	Dr. Karlheinz Samejo	Co-Director	Delft University of Technology
18	Gladys Ngeno	Health Systems & Climate Change and Health Specialist	Dutch Embassy
19	Pamella Odolo	Director	Bright Dada
20	Dan Mbingo	Research Scientist	Kenya Institute for Research and Development

ANNEX 2: Facilities visited in Kisumu County

No.	FACILITY	FACILITY LEVEL
1	Ober Kamoth Sub County Hospital	Level 4
2	Chulaimbo County Hospital	Level 4
3	Hongo Ogosa Health Centre	Level 3
4	Airport Health Centre	Level 3
5	Nyakach County Hospital	Level 4
6	Rabuor Sub-County hospital	Level 4
7	Muhoroni County Hospital	Level 3
8	Nyalenda Health Centre	Level 3
9	Nyang'oma Sub-County hospital	Level 3
10	Ratta Health Centre	Level 3
11	Sango Rota Health Centre	Level 3
12	Kibigori Health Centre	Level 3
13	Sigoti Health Centre	Level 3
14	Migosi Sub-County hospital	Level 4
15	Lumumba Sub-County Hospital	Level 4
16	Nyahera Sub-County hospital	Level 4
17	Sondu Sub-County hospital	Level 4
18	Ojolla Health Centre	Level 4
19	Bodi Health Centre	Level 3
20	Chemelil Gok Health Centre	Level 3
21	Katito Sub-County hospital	Level 4
22	Gita Sub County hospital	Level 4
23	Kowino Dispensary	Level 3
24	Kombewa District Hospital	Level 4
25	Ahero County Hospital	Level 4
26	Kisumu County Referral Hospital	Level 5
27	Jaramogi Oginga Odinga Teaching and Referral Hospital	Level 6
28	Kuoyo Health centre	Level 3
29	Nyalunya Health centre	Level 3

ANNEX 3: Medical appliances tested

No.	APPLIANCE	MODEL
1	Infant warmer	OKM-730
2	Infant warmer	HKN-93
3	Oxygen Concentrator	JAY-10
4	Oxygen Concentrator	NEWLIFE
5	Autoclave	ALL American 75X

ANNEX 4: Healthcare facility representatives interviewed during the site visits

No.	NAME	DESIGNATION	FACILITY
1	Pamela Olilo	Clinician	Lumumba Sub-County Hospital
2	Milicent Anyango Orwa	Nursing officer	Migosi Sub-County Hospital
3	Irene Akello	Clinician	Kuoyo Health Centre
4	Enosh Nyakiti	Clinician	Kowino Dispensary
5	Triza Ogam	Clinician	Nyalenda Health Centre
6	Mercy Omondi	Nurse	Nyalunya Health Centre
7	Edwin Ondiek Opiyo	Clinician	Jaramogi Oginga Odinga Teaching and Referral Hospital
8	James Okoth	Clinician	Hongo Ogosa Health Centre
9	Elizabeth Anyango	Clinician	Rabuor Sub-County hospital
10	John Agalo Ndege	Bio Medical Engineer	Ahero County Hospital
11	Charles Otieno	Nursing Officer in Charge	Katito Sub-County Hospital
12	Nelson Okinda Odhiambo	Lab Technician	Sango Rota Health Centre
13	Abraham Abuto	Health Administrator	Nyakach County Hospital
14	Esther Oboge	Enrolled Nurse	Sigoti Health Centre
15	Naom Kerubo	Nursing Officer	Sondu Sub-County Hospital
16	Lucy Odimo	Registered Nurse	Kibigori Health Centre
17	Victor Olang'	Clinician	Chemelil Gok Health Centre
18	Aloyce Ouma Mbuya	BioMedical Engineer	Muhoroni County Hospital
19	Everlyne Awuor Ogollah	Health Administrative Officer	Nyahera Sub-County Hospital
20	Josephine Odhiang	Nursing In charge	Nyang'oma Sub-County Hospital
21	Luke Ombewa	Clinical Officer	Chulaimbo County Hospital
22	Adeline Vera	Clinician	Ojolla Health Centre
23	Loice Owino	Clinician	Ratta Health Centre
24	Rollene Odego	Nursing Officer Incharge	Kombewa District Hospital
25	Godfred Ochinga	Clinician	Bodi Health Centre
26	Victor Omondi Ajumbo	Clinician	Ober Kamoth Sub County Hospital
27	Hellen Mbogo	Health Records & Information Officer	Gita Sub County Hospital
28	Naboth Kowala	Clinician	Airport Health Centre
29	Alex Ochieng	Senior Health Administrative Officer	Kisumu County Referral Hospital


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