Energy access in Malawian healthcare facilities: consequences for health service delivery and environmental health conditions

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Abstract

Many healthcare facilities (HCFs) in low-income countries experience unreliable connectivity to energy sources, which adversely impacts the quality of health service delivery and provision of adequate environmental health services. This assessment explores the status and consequences of energy access through interviews and surveys with administrators and healthcare workers from 44 HCFs (central hospitals, district hospitals, health centres and health posts) in Malawi. Most HCFs are connected to the electrical grid but experience weekly power interruptions averaging 10 h; less than one-third of facilities have a functional back-up source. Inadequate energy availability is associated with irregular water supply and poor medical equipment sterilization; it adversely affects provider safety and contributes to poor lighting and working conditions. Some challenges, such as poor availability and maintenance of back-up energy sources, disproportionately affect smaller HCFs. Policymakers, health system actors and third-party organizations seeking to improve energy access and quality of care in Malawi and similar settings should address these challenges in a way that prioritizes the specific needs of different facility types.

Keywords: Energy access in healthcare facilities, Sustainable Development Goal 7, maternal and child health, Malawi, energy and environmental health
Introduction

Sufficient, reliable energy is fundamental for safe and effective patient care in healthcare facilities (HCFs) (WHO and World Bank, 2015). Electricity enables many functions essential to healthcare services, among them, lighting, refrigeration, sterilization and powering medical devices (Ouedraogo and Schimanski, 2018). However, many HCFs in low- and middle-income countries (LMICs), especially in sub-Saharan Africa, have no access to electricity or face unreliable electrical services that impact patient and provider safety and health service delivery (Adair-Rohani et al., 2013). A study of 78 LMICs found about 60% of HCFs lacked reliable electricity, defined as electricity supply without prolonged interruptions in the preceding week (WHO and World Bank 2015; Cronk and Bartram, 2018).

The United Nations (UN) Sustainable Development Goal Seven calls for ‘access to affordable, reliable, sustainable and modern energy for all’ (UN, 2015). The UN Secretary General referred to energy as the ‘golden thread’ that connects many social, economic and environmental goals (UN, 2012). Energy, for example, is linked to the provision of adequate water and sanitation services (WaSH), captured by Goal Six (Mccollum et al., 2018).

Adequate environmental health conditions including WaSH are important for safe patient care (Adams et al., 2008). Energy is necessary for continuous safe water supply, proper sterilization of reusable medical equipment and functional waste disposal. Although few data concern hospital-acquired infections in LMICs, inadequate environmental health conditions, such as a lack of regular safe water supply, contribute to nosocomial infections and may be associated with higher infant and maternal death rates (WHO, 2009; Borg, 2010; Moffa et al., 2017).

Despite the importance of reliable energy access and adequate environmental health conditions in health settings, few studies document the relationship between sufficient, reliable energy and the availability of basic environmental health conditions in HCFs. Among the few systematic analyses, most examine WaSH service levels and exclude energy (e.g. Guo et al., 2017; Huttlinger et al., 2017). Of the studies that do address energy access, most examine household settings; data on energy access in HCFs are rarely collected systematically and comprehensively (Adair-Rohani et al., 2013; Sustainable Energy Transitions Initiative, 2018). There is a need for evidence responding to this void that includes more robust energy metrics such as capacity, reliability, affordability and sustainability (WHO and World Bank, 2015). We addressed these aspects of energy access in HCFs using a novel conceptual framework to describe the characteristics of available energy sources, their use within HCFs, and their effects on health service delivery and environmental health conditions within facilities (Suhlrie et al., 2018). We describe the status of energy access in 44 HCFs in Malawi; and triangulate quantitative and qualitative data to investigate linkages between inadequate energy access, facility outputs and environmental health conditions.

Methods

Study setting: Malawi

Malawi is a landlocked country in southeastern Africa that contains Lake Malawi, which generates over 90% of Malawi’s electricity (Randson et al., 2013). Household access to electricity is among the lowest in the world—4% and 42% among rural and urban populations, respectively. The population of over 19 million is growing 2.9% annually, with the largest percentage of the population in the Southern and Central regions (UNICEF, 2018). In 2014, Malawi had 1060 private and government-run HCFs (Malawi Ministry of Health and ICF International, 2014). Malawi’s maternal mortality ratio, 634 per 100 000 live births, and neonatal mortality rate, 22 per 1000 births, are among the highest in the world (UNICEF, 2018); its per capita healthcare expenditure $39.20 is among the lowest (UNICEF, 2016).

Study sample

Quantitative and qualitative data were collected from 44 government-run HCFs in the Northern, Central and Southern regions of Malawi (Table 1). Fourteen of Malawi’s 28 districts were selected to ensure that the number of districts in each of the three regions corresponded to the relative population. Spatial clustering was used to select districts to ensure that the sample covered the geographic area of each region (Figure 1). Jointly with the Malawi Ministry of Health, researchers from UNC-Chapel Hill and UNC Project-Malawi selected one health centre and one health post or dispensary within the catchment area of each of the 14 district hospitals. The sole central hospital in each of the north and central regions was selected, as well as one of the two central hospitals in the southern region (Supplementary Table S2).

Data collection

Survey development

The energy assessment was conducted as part of a larger study of environmental health conditions in HCFs. A mobile mixed-methods survey instrument was developed using the following tools: WHO’s Essential Environmental Health Standards in Health Care, Soap Box Collaborative WASH and CLEAN Toolkit, WHO and UNICEF’s Water and Sanitation for Health Facility Improvement Tool, Clean and Safe Health Facilities Audit Tool from the Medical Services Directory in Ethiopia, Service Delivery Indicator Survey from Kenya, WHO’s Service Availability and Readiness Assessment, WHO’s ‘Monitoring WASH in Birth Settings’ and Malawi’s Service Provision Assessment (SPA) (Adams et al., 2008; ICF International,
Survey questions were extracted from each source document to construct a comprehensive assessment of the principal environmental health components, comprising: water quality, water quantity, water access, sanitation, wastewater disposal, healthcare waste disposal, cleaning, laundry, food storage and preparation, vector control, building design, hygiene promotion and energy access.

Additional energy-related questions captured attributes of electricity supply identified in the WHO's 'Access to Modern Energy Services for Health Facilities in Resource-Constrained Settings' and Suhlrie et al.’s (2018) conceptual framework, including sources of power, electricity duration and reliability, power capacity and seasonal variations in energy access (WHO and World Bank, 2015). Questions were validated using selection criteria and panellist review (Schwemlein et al., 2016).

Questions were organized into three surveys: a general facility survey, an outpatient department survey and a maternity ward survey (Supplementary Materials). All questions were uploaded to the mWater Mobile Application (New York, NY, USA) in English and piloted at a health centre in the central region of Malawi.

Interview guide development
Semi-structured interview guides were developed for HCF administrators and healthcare workers (HCWs) (Supplementary Materials). Questions explored environmental health conditions in the facility (practices related to water, sanitation and waste management, infection prevention behaviours) and HCW experiences and satisfaction. Energy-related questions, informed by the conceptual framework, explored the impact of energy availability and reliability on facility outputs such as working conditions, health service delivery and staff satisfaction.

Implementation
Data were collected between June and August 2017, the dry season in Malawi. Several authors and colleagues spent 2 days collecting data at each central hospital, 1 day at each district hospital; and 1 day was spent assessing both a health centre and a health post or dispensary within a given district. If a facility sampled was closed or misclassified, in-country officials identified an alternative. Researchers recorded daily field notes. These were compiled weekly in Microsoft Word and shared with research team members.

Survey administration
All facilities were assessed using the general facility survey, administered to the administrator or the ‘in-charge’—the administrator that doubled as the lead healthcare provider at health centres and health posts. In cases \( n = 10 \), where the administrator was unavailable or the in-charge was attending patients, a facility-level environmental health official, nursing officer or maintenance supervisor responded to the survey (Supplementary Table S1).

The general facility survey was the only survey administered at health posts and dispensaries. At central hospitals, district hospitals and health centres, the maternity and outpatient ward surveys were also administered to the appropriate HCW in each ward.

Surface swab samples were collected in maternity wards at central hospitals, district hospitals and health centres. Swabs of sink handles, delivery mattresses, light switches and forceps from sterile delivery packs were immediately analysed using a Hygiena UltraSnap™ ATP meter (Hygiena Camarillo, CA, USA). UltraSnap is an adenosine triphosphate (ATP) assay used to assess cleaning practices rapidly as ATP is a reliable indicator of the presence of microorganisms (Carling and Bartley, 2010).

Information was collected on respondents’ job title and educational background, but no other personal identifying information was obtained from respondents.

Qualitative interviews
Interviews were conducted by the first and second authors with administrators and HCWs who had been working at the facility for
at least 6 months to ensure sufficient knowledge of facility conditions. To reduce participant time burden, particularly in settings where a medical assistant served as the facility’s administrator and sole healthcare provider, the survey and interview questions were administered in a single session. All interviews were conducted in English and audio recorded.

Data analysis
We organized our analysis according to five components (energy types, energy supply characteristics, energy uses, facility outputs, and environmental health conditions), for which data from surveys and in-depth interviews were available, derived from the conceptual framework for the role of modern energy in HCFs proposed by Suhlrie et al. (2018) (Figure 2).

Quantitative data analysis
Survey data were exported and cleaned in Stata (V13, StataCorp, College Station, TX, USA), and organized by the five components of the simplified energy framework. Energy access in HCFs was characterized by connection to the electrical grid, availability and functionality of back-up sources, duration, frequency, predictability of electrical interruptions and energy uses in HCFs. Summary statistics were calculated, and Fisher’s exact test was used to explore relationships between availability of a back-up energy source with facility environmental health conditions.

Transcription and coding
English audio recordings of interviews with HCF administrators and HCWs were transcribed. A preliminary codebook was developed using field notes prepared by the data collection team and the five components of the energy framework. The codebook was structured to allow themes to emerge from the data. Transcripts were categorized by actor and region. Dedoose (Dedoose, Los Angeles, CA, USA) was used to code the interview transcripts.

Additional codes emerged during the first round of coding. The codebook was finalized at the end of the first round and applied during the second round of coding (Supplementary Materials). Coders were assigned a different set of transcripts in the second round.

Thematic analysis
The first author examined excerpts within groups of codes to identify energy-related themes present in the data and to provide detailed insight on quantitative findings. Code analysis tools in Dedoose were used to examine co-occurrences of codes related to ‘energy access’, ‘energy maintenance’, ‘back-up source’, ‘energy use’, ‘insufficiency’, ‘challenge’, ‘working conditions’ and ‘safety’. Additional themes related to energy supply reliability, capacity, conditions in delivery wards and effects on health service delivery were explored. Descriptor tools were used to examine energy challenges that emerged across the four facility types.

Results
Primary energy source types and uses
Malawian HCFs are either connected to the electrical grid served by the Electricity Supply Corporation of Malawi (ESCOM) as their primary source or have an off-grid primary source, such as solar panels or a fuel-based generator. A source was considered primary if it was
used consistently to power a necessary HCF function, such as lighting, refrigeration or electrical medical equipment. Facilities had zero, one or more than one primary energy source. The electrical grid was the predominant primary energy source at assessed facilities (82%) (Table 2).

The grid powered the following energy uses in at least 10 facilities: lights, communication devices, refrigerators, sterilizers, medical devices, computers, fans, air conditioning units, cooking equipment, water pumps and internet devices. Eleven facilities used photovoltaic (solar) systems for lights and water pumps, and four used solar for charging cell phones. Other energy sources such as wood and gas provided power to sterilizers, refrigerators and cooking equipment at 10 facilities.

Energy supply characteristics

Energy ‘reliability’ (frequency and duration of interruptions) was poor at most HCFs. Less than half of the HCFs reported that their primary source had always worked when needed in the past week, and none reported the source had always worked when needed in the past 6 months (Table 2). Electrical interruptions, or ‘black-outs’, lasted on average 9 h each in the past week, and 11 h each in the past 6 months.

Black-outs on both time scales were predominantly ‘unpredictable’, meaning the facility had not expected an electrical interruption (Table 2). Only 14 of 44 (32%) facilities had an ‘available’ and ‘functional’ back-up source (Table 3). Back-up sources among grid-connected facilities were generators (56%) and solar systems (8%).

‘Capacity’ (source’s ability to run all required appliances) of back-up generators was poor. Most small generators were incapable of supplying sufficient power to all energy-dependent facility services. In surveys, 85% of facilities reported prioritizing certain energy-dependent services such as pharmacies, maternity wards, laboratories and major surgery wards during electrical interruptions, causing other energy-dependent services to suffer. Respondents in 65% of HCFs reported that electrical interruptions had constrained health service delivery in the past week; this rose to 80% in the preceding 6 months (Table 3).

Survey data could not be collected for all supply characteristics; those not included in survey results are addressed in qualitative findings and discussion.

In-depth interviews
Twenty-seven out of 42 (64%) administrators, and 23 out of 39 (59%) HCWs cited poor grid reliability, including frequent and lengthy black-outs. Two district hospital HCWs said, ‘Black-outs are so frequent, every two days we have a blackout of maybe eight hours’, and, ‘They could be two hours, maybe one hour thirty minutes. But the weekend ones, they take time, maybe 24 h…’ A health post administrator summarized the countrywide problem, ‘[T]his is not the only facility experiencing problems, it is the whole country. We are [all] experiencing interrupted power supply’.

Only at the central level, two administrators of the three central hospitals cited being ‘spared’ from electrical interruptions because they receive advance warning from the energy utility regarding scheduled electrical interruptions, allowing them to make preparations such as filling water storage containers or acquiring fuel for generators. One administrator said, ‘Here we are being spared as a hospital. Sometimes we are given notice. If we are given notice, the [black-out] can last the whole day’. Other facility types were excluded from the alerts, including district hospitals, which provide many of the same services as central hospitals.

Health centres and health posts experienced delays in energy system repairs lasting several days to months—some generators and solar panels had been non-functional for over a year. These facilities rely on district maintenance teams, housed at district hospitals. Repair delays were most commonly attributed to insufficiencies in maintenance staff, funding for supplies procurement and transport from the district to the facility. One health post in-charge remarked, ‘When there is a problem we always call [the district], but the response is always devastating. You cannot keep calling someone and see that nothing is being done. The response we get is just the same, “we don’t have funds…”’

Eight of the 20 facilities (40%) with generators, referred to locally as ‘gen-sets’, lacked sufficient fuel for the generator. Administrators and HCWs from all HCF types partially attributed this to competition between vehicles and generators for fuel from a shared fuel ‘pool’. No facilities had fuel designated exclusively for generators. Other reasons for insufficient generator fuel were specific to HCF type—respondents from health centres and health posts reported that the district health office, which manages the budget for fuel supply, had insufficient funding, and that facility actors lacked transportation to collect generator fuel from the district. Many district hospitals had large generators that they could not afford to fuel and instead used multiple smaller generators. One HCW explained, ‘[W]e had the gen-set which… was catering for all the hospital, but because of the shortages of oil, we had so many problems. So, we just decided to have the two small ones’.

Thirteen administrators (39%) discussed insufficient capacity of their back-up fuel-based generators. One central hospital administrator said of the facility’s energy supply, ‘I am not satisfied… Not all the departments are connected to the generator. So sometimes we have power interruptions and you find that some of the departments are experiencing black-outs’. Another district hospital administrator explained only being able to fulfil some of the facility’s energy-dependent services during black-outs. ‘We need power in the lab since you cannot take X-rays without electricity. The theater as well needs power. We have a big generator but it is not functioning, [so] we have small ones positioned in some areas… the ones which are more critical’.

Insufficient back-up sources coupled with frequent electrical interruptions adversely affected service provision to patients. Poor energy conditions impede sufficient lighting necessary for routine healthcare services. HCWs from out-patient care at seven facilities reported difficulty correctly diagnosing patients and carrying out routine procedures, such as administering fluids intravenously and suturing wounds, under poor lighting conditions.

Poor energy conditions also hinder functionality of electrical medical equipment. In extreme cases, this led to deaths. One administrator said, ‘The electricity that we are supplied is not constant, as a result, we are bringing in alternates. Not even these are giving us satisfaction. There were times that we lost lives because the gen-set did not pick up as early as we thought’. A handful of nurses linked unreliable energy access to poor neonatal and maternal health outcomes. One nurse noted: ‘[Some] babies need oxygen, but because of the black-out, most of the babies die during these periods’.

Energy access repercussions for facility outputs
We identified three ways that sufficient, reliable energy supply is intertwined with facility outputs: hours of operation, sufficient birth facility lighting and HCW perception of personal safety.

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## Table 2: Primary energy source type, reliability, predictability and impact on service delivery in the last week and 6 months before data collection

<table>
<thead>
<tr>
<th>Category</th>
<th>Central (C) (n = 3)</th>
<th>District (DH) (n = 14)</th>
<th>Health centre (HC) (n = 14)</th>
<th>Health post (HP) (n = 13)</th>
<th>Total (n = 44)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary energy source type (facilities could have none, one or more)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid</td>
<td>3 (100%)</td>
<td>14 (100%)</td>
<td>13 (93%)</td>
<td>6 (46%)</td>
<td>36 (82%)</td>
</tr>
<tr>
<td>Photovoltaic (solar) system</td>
<td>0 (0%)</td>
<td>3 (21%)</td>
<td>3 (21%)</td>
<td>5 (38%)</td>
<td>11 (25%)</td>
</tr>
<tr>
<td>Other (wood, coal, gas)</td>
<td>0 (0%)</td>
<td>3 (21%)</td>
<td>4 (29%)</td>
<td>3 (23%)</td>
<td>10 (23%)</td>
</tr>
<tr>
<td>Fuel-based generator</td>
<td>0 (0%)</td>
<td>1 (7%)</td>
<td>1 (7%)</td>
<td>1 (8%)</td>
<td>3 (7%)</td>
</tr>
<tr>
<td>No energy access</td>
<td>0 (0%)</td>
<td>0 (%)</td>
<td>0 (%)</td>
<td>1 (8%)</td>
<td>1 (2%)</td>
</tr>
<tr>
<td><strong>Primary energy source reliability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Always worked when needed</td>
<td>3 (100%)</td>
<td>6 (43%)</td>
<td>2 (18%)</td>
<td>0 (0%)</td>
<td>17 (40%)</td>
</tr>
<tr>
<td>Didn't always work</td>
<td>0 (0%)</td>
<td>8 (57%)</td>
<td>9 (62%)</td>
<td>3 (100%)</td>
<td>26 (60%)</td>
</tr>
<tr>
<td><strong>Duration of electrical interruptions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average (h)</td>
<td>9.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electrical interruptions predictability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictable</td>
<td>0 (0%)</td>
<td>1 (20%)</td>
<td>3 (18%)</td>
<td>1 (33%)</td>
<td>5 (11%)</td>
</tr>
<tr>
<td>Unpredictable</td>
<td>0 (0%)</td>
<td>4 (80%)</td>
<td>2 (71%)</td>
<td>2 (67%)</td>
<td>7 (16%)</td>
</tr>
<tr>
<td><strong>Energy breakdown impact on service delivery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected service</td>
<td>0 (0%)</td>
<td>3 (60%)</td>
<td>4 (67%)</td>
<td>2 (67%)</td>
<td>11 (26%)</td>
</tr>
<tr>
<td>Did not affect service</td>
<td>0 (0%)</td>
<td>2 (40%)</td>
<td>1 (20%)</td>
<td>1 (33%)</td>
<td>4 (9%)</td>
</tr>
</tbody>
</table>

\(n\) varies based on survey skip-logic based on answers to previous questions.
Fourteen birth facilities (45%) had lighting characterized by electrical disturbances that were weekly or more frequent. Five HCWs also had a photovoltaic (solar) system with insufficient capacity to power lights throughout the birth facility. A district hospital midwife described the challenges of having a single solar-supplied lamp, ‘When there is no [grid] electricity, [the lamp] cannot light the other lamp and you are suturing someone, you will suture yourself’. All 14 facilities with an available, functional back-up source were among the HCFs offering 24-h services. Facility staff may be more confident in remaining open for 24 h knowing that back-up energy sources are available in the event of primary source failure during the night. They are more likely to attend deliveries if they know there will be sufficient lighting to handle emergencies.

Sufficient lighting in the birth facility

Twelve of thirty-one (39%) facilities that offered delivery services had regular, sufficient lighting in the birth facility (Supplementary Table S4). Fourteen birth facilities (45%) had lighting characterized by electrical disturbances that were weekly or more frequent. Five facilities (16%) had entirely irregular, insufficient or absent lighting. Unreliable grid service contributes to insufficient delivery room lighting at grid-connected HCFs. However, several maternity wards also had a photovoltaic (solar) system with sufficient capacity to power lights throughout the birth facility. A district hospital midwife described the challenges of having a single solar-supplied lamp, ‘When there is no [grid] electricity, [the lamp] cannot light the other bed. This is okay to conduct [a] delivery, but if the mother has got a tear or is bleeding, it is very difficult to handle that case’. HCWs, particularly from health centres, reported that solar energy rarely lasted through the night and was unavailable altogether during the rainy season. Others reported that solar lights were completely non-functional due to unfulfilled district maintenance requests.

Health service delivery was often compromised when sufficient lighting was not available to provide care to women with complications related to pregnancy and delivery. Necessary procedures were often delayed until sufficient lighting was available, or the woman was transferred to a different facility. A district hospital nurse explained, ‘If you want to do a caesarean section, you can’t because there is no electricity’. Another HCW recalled a specific incident, ‘We were about to go to the theater to operate on a pregnant woman and then we had a black-out before we started the procedure, so we had to wait for an hour. Had it been we had already started operating on the patient and then had [the] black-out, there would have been chaos’. Anticipating poor lighting at night, nurses at six HCFs said they instruct pregnant mothers to bring candles when coming to give birth. Ten nurses (32%) recalled using cell phones, flashlights or candles as alternative light sources.

Healthcare worker safety

During interviews at over one-third of facilities, HCWs of both genders said insufficient energy availability and poor lighting threatened their safety while working in the facility at night. Some worried about outsiders, or animals such as stray dogs, wandering into the facility in the dark. Others felt unsafe walking through unlit areas. A district hospital nurse said, ‘The corridor itself is not fully lighted . . . so whenever you are transferring a patient from here to theater, you are walking between the building in total darkness’. Others worried about handling needles and sharp medical equipment in the dark. One HCW said, ‘If we don’t have [power supply] it is very difficult because we don’t have any back-up to see where, for example, a sharp is. To work with sharps at night when we don’t have any power becomes difficult’.

Energy access repercussions for environmental health conditions

We identified two ways that sufficient, reliable energy supply is intertwined with basic environmental health conditions in HCFs: regular access to safe water and sterility of reusable medical equipment.

Regular supply of safe drinking water

Nearly three-fourths of HCFs had a primary water source that required pumping into the facility. The majority (86%) of water sources were functional on the day of the visit, but 6 out of 10 facilities had at least one breakdown in the last 6 months (Supplementary Table S5). During interviews, electrical breakdown was the most common reason cited for water unavailability. The respondent at the only HCF with no energy access defined the facility’s biggest challenge as securing sufficient water and linked this to the absence of a primary energy source.

More than half of respondents reported that water shortages were more common in September, October and November, corresponding to the hot, dry season in Malawi (Supplementary Table S5). Facilities also reported using their back-up energy source most frequently in the dry season (Table 3). Since Malawi is predominantly powered by hydroenergy, the hot, dry time of year could explain both water and energy shortages.

### Table 3 Back-up energy source types, functionality, capacity and seasonality

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of facilities (percentage of facilities)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back-up energy source type ((n = 37)^a)</td>
<td></td>
</tr>
<tr>
<td>Fuel-based generator</td>
<td>20 (54)</td>
</tr>
<tr>
<td>No back-up source</td>
<td>14 (37)</td>
</tr>
<tr>
<td>Solar</td>
<td>3 (8)</td>
</tr>
<tr>
<td>Back-up energy source status ((generator, n = 20))</td>
<td></td>
</tr>
<tr>
<td>Functional</td>
<td>13 (65)</td>
</tr>
<tr>
<td>Non-functional</td>
<td>7 (35)</td>
</tr>
<tr>
<td>Back-up energy source functionality ((solar, n = 3))</td>
<td></td>
</tr>
<tr>
<td>Functional</td>
<td>1 (33)</td>
</tr>
<tr>
<td>Non-functional</td>
<td>2 (67)</td>
</tr>
<tr>
<td>Capacity of back-up energy source ((n = 20))</td>
<td></td>
</tr>
<tr>
<td>Back-up source can power all required appliances</td>
<td>3 (15)</td>
</tr>
<tr>
<td>Back-up source cannot power all required appliances</td>
<td>17 (85)</td>
</tr>
<tr>
<td>Season when back-up source is used more frequently ((n = 17))</td>
<td></td>
</tr>
<tr>
<td>Dry season</td>
<td>8 (47)</td>
</tr>
<tr>
<td>Wet season</td>
<td>4 (24)</td>
</tr>
<tr>
<td>Equal in both</td>
<td>5 (29)</td>
</tr>
</tbody>
</table>

\(^a\)Twenty-four hours of operation

All HCFs are supposed to provide healthcare services for 24 h. In central and district hospitals, this includes all services. In health centres, health posts and dispensaries, 24-h care includes basic services, namely deliveries and emergency out-patient care. In our assessment, 93% of HCFs offered 24-h services (Supplementary Table S3).

Several factors hindered smaller facilities from operating for 24 h, including inadequate night-long energy access. Five HCWs from health centres and health posts reported that they were unable to continuously provide necessary services, including deliveries and minor outpatient procedures. Their facilities lacked reliable energy access and a back-up energy source. One nurse said, ‘There were frequent episodes of blackouts [and] unfortunately this facility doesn’t have a generator; that [has] proven a challenge’. She went on to explain that 24-h services cannot be provided. ‘Suppose there is no light and you are suturing someone, you will suture yourself’. All 14 facilities with an available, functional back-up source were among the HCFs offering 24-h services. Facility staff may be more confident in remaining open for 24 h knowing that back-up energy sources are available in the event of primary source failure during the night.
(Power Africa, 2018). One nurse noted, ‘When the water gets lower in Lake Malawi, the [utility] complains that the water table has gone down. During that time . . . we have the most frequent blackouts and water problems’. Yet approximately one-third of facilities did not view water shortages and electrical interruptions as seasonal, suggesting that these challenges at some HCFs are not confined to a single season. One district hospital administrator remarked, ‘When it is [the] rainy season, you wouldn’t expect to have many challenges because the streams have filled, and you could consequently think that the major source of water that drives the turbines, would rise. [And] logically one would expect we wouldn’t have black-outs as frequently. But ironically, that’s when [some] black-outs are experienced’.

During water shortages, actors such as cleaners and patient guardians, often family or close friends, fetch water from a borehole which may be on or off the facility premises. Collected water is often carried and stored in open buckets. This practice is associated with a higher probability of water contamination compared with acquiring water directly from the tap (Shields et al., 2015). Respondents also reported that water shortages adversely affected their ability to administer oral drugs, and to ensure good sanitation and cleaning practices.

**Safe reuse of sterilized medical equipment**

Facilities used a combination of techniques to clean and sterilize medical equipment such as forceps used during deliveries (Supplementary Table S6). All facilities that offered delivery services used chlorine to disinfect equipment; 90% also used soap and water to clean, and 81% also used an electric autoclave to sterilize.

Results from ATP testing of swabs of forceps from sterile birth packs were ‘passing’ if the relative light units (RLU) value was <30 on the Hygiena UltraSnap™ (Hygiena Camarillo, CA, USA). Six of 31 (20%) forceps ‘failed’ (RLU value of >30).

Facilities with a functional back-up energy source were significantly less likely to have forceps with high levels of contamination ($P = 0.029$) (Table 4). While we cannot draw causal links between back-up energy source availability and equipment sterility, back-up sources allow facilities to sterilize equipment properly during grid black-outs.

Facilities with a functional main water source were also significantly less likely to have forceps with high levels of contamination ($P = 0.016$) (Table 4). Similarly, while we cannot draw causal links between water availability and equipment safety, available and reliable energy improves access to both water and safe, reusable equipment in delivery wards.

During electrical interruptions, electric autoclaves are non-functional and equipment cannot be sterilized properly. One district nurse said, ‘If there is no energy, there is no sterilization [and] no infection prevention’. HCWs reported that, in such instances, sterilization is sometimes performed at facilities in nearby towns that are able to sterilize during black-outs.

HCWs reported that when unable to access sterilization elsewhere, they were more likely to have insufficient sterile birth packs and to use equipment that had not been properly sterilized. The use of non-sterile equipment leads to a higher risk for maternal infection, and clean birth kits are essential to ensuring safe deliveries in HCFs (WHO, 2006).

### Table 4 Water source functionality, back-up energy source availability and ATP swab fluorescence for forceps in sterilized birth packs

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pass (RLU &lt; 30)</th>
<th>Fail (RLU ≥ 30)</th>
<th>Condition totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main water source</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional</td>
<td>24</td>
<td>3</td>
<td>27 (87%)</td>
</tr>
<tr>
<td>Non-functional</td>
<td>1</td>
<td>3</td>
<td>4 (13%)</td>
</tr>
<tr>
<td>Fisher’s exact test</td>
<td></td>
<td></td>
<td>0.016*</td>
</tr>
<tr>
<td>Back-up power source</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional</td>
<td>20</td>
<td>2</td>
<td>22 (73%)</td>
</tr>
<tr>
<td>Non-functional</td>
<td>4</td>
<td>4</td>
<td>8 (27%)</td>
</tr>
<tr>
<td>Fisher’s exact test</td>
<td></td>
<td></td>
<td>0.029*</td>
</tr>
<tr>
<td>Pass/fail totals</td>
<td>25 (81%)</td>
<td>6 (19%)</td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 95% confidence level.

**Discussion and implications**

Energy enables many functions essential to healthcare services and plays an important role in ensuring adequate environmental health conditions, which are important for safe patient care. Our mixed methods research in 44 public Malawian HCFs describes the status of energy access in these facilities, reinforces knowledge of how energy is essential to healthcare and suggests important relationships between energy access and environmental health conditions.

The majority of Malawian HCFs are connected to Malawi’s electricity supply company (ESCOM). However, unreliable grid-supply, coupled with insufficient back-up sources, contributes to inadequate energy access. Inadequate energy access is associated with an irregular water supply and unsatisfactory sterilization of critical medical equipment; adversely influences healthcare worker and patient safety; and contributes to poor lighting and working conditions. Further challenges vary across facility type: health centres and health posts often lack a back-up energy source and experience delays in energy system maintenance; district and central hospitals lack sufficient generator fuel. As a result, essential energy-dependent services suffer.

**Comparison to related work**

Some previous works analyse data from Sub-Saharan African countries’ SPAs. These provide an overview of a country’s health service delivery (Ouedraogo and Schimanski, 2018; Suhlrie et al., 2018). A recent analysis of Malawi’s 2013–14 SPA found that 69% of all facilities were grid-connected and 9% had no electricity; for government-run facilities, these percentages were 54% and 13% (Suhlrie et al., 2018); in our study, we found 82% and 2%. Among grid-connected facilities, less than one-third had a back-up source; we found this proportion to be nearly double.

Our study differs from SPA-based analyses in having a smaller sample size and excluding private facilities. Nevertheless, the consequences of poor energy access that we identify are consistent with these works, including insufficient power for energy-dependent laboratory and maternal services equipment (Ouedraogo and Schimanski, 2018). Larger sample sizes permit in-depth quantitative explorations of associations between the source and continuity of electricity and different energy uses; Suhlrie et al. find that energy uses such as electric sterilization devices were less likely to be
Table 5 Summary table of energy challenges, by facility type

<table>
<thead>
<tr>
<th>Facility type</th>
<th>Services provided</th>
<th>Energy challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central hospital (n = 3)</td>
<td>In-patient services Delivery services Out-patient care</td>
<td>Unreliable service from energy utility Insufficient fuel available for generators</td>
</tr>
<tr>
<td>District hospital (n = 14)</td>
<td>In-patient services Delivery services Out-patient care</td>
<td>Unreliable service from energy utility Insufficient fuel available for generators No advance warnings of blackouts from the utility</td>
</tr>
<tr>
<td>Health centre (n = 14)</td>
<td>Delivery services Out-patient care</td>
<td>Unreliable service from energy utility Insufficient fuel available for generators No advance warnings of blackouts from the utility Insufficient meter units for grid access Lack of a back-up energy source</td>
</tr>
<tr>
<td>Health post/dispensary (n = 13)</td>
<td>Out-patient care</td>
<td>Unreliable service from energy utility Insufficient fuel available for generators No advance warnings of blackouts from the utility Insufficient meter units for grid access Lack of a back-up energy source Slow district response to energy system breakdowns Solar systems non-functional during rainy season</td>
</tr>
</tbody>
</table>

Analyses of SPA or census-like data provide greater breadth of statistics from a nationally representative sample of HCFs but lack qualitative insight into challenges posed to HCWs. Our in-depth interview findings are similar to the experiences of nurses in other resource-constrained settings. A 2012 report from interviews with 122 Ugandan HCWs discussed challenges maternity nurses face in attending childbirths in the dark (The Coalition for Health Promotion and Social Development & VSO Uganda, 2012).

Still, survey data are needed to quantify the status of energy access and provide a baseline for future monitoring and impact assessments. Our mixed-method approach both contributes to the data needed to quantify the status of energy access and provides a baseline for future monitoring and impact assessment; it also allows for a deeper understanding of causes and consequences of inadequate energy access in HCFs thereby informing recommendations for policymakers and other involved actors.

**Limitations**

To assess our sample of 44 HCFs in Malawi, the health centre and health post/dispensary in each district were surveyed on the same day; thus, health centres and health posts with close proximity to one another were chosen. In some instances, the health centre surveyed in each district was also located near the district hospital. Given this sampling approach, remote HCFs are likely to have been undersampled. However, the results reflect four facility types across all three regions of Malawi.

Our data set relies on participants’ memories of the recent history of facility water and energy systems. At smaller HCFs, one respondent frequently served as the medical provider and HCF administrator. Therefore, data from these facilities depend heavily on one respondent’s knowledge of the facility’s environmental health conditions and ability to recall events such as water and energy system breakdowns. To address this, respondents were not asked to recall events longer than 6 months ago. Recall inaccuracies are less of a concern in central and district hospitals where a range of actors was interviewed.

**Implications for policy and practice**

Countrywide energy matters are in the *de jure* purview of Malawi’s Ministry of Natural Resources, Energy and Environment. However, other involved actors such as Malawi’s Ministry of Health (MoH), facility actors and non-governmental organizations are closer to energy challenges in healthcare settings. Building on knowledge of how energy needs vary by facility classification (Franco et al., 2017), we recommend that these actors consider the challenges specific to each facility type to improve energy access, environmental health and working conditions in HCFs.

**Grid unreliability**

Facilities of all sizes experience grid unreliability—blackouts are frequent, sustained and unpredictable. Central hospitals are most likely to receive advance warning from Malawi’s energy utility regarding scheduled electrical interruptions. While district hospitals provide many of the same services, they rarely receive such notices. Health centres and health posts lack these warnings. The MoH and facility-level actors should advocate for HCF exemption—or advance warning if exemption cannot be achieved—from scheduled grid black-outs and for increased communication with ESCOM to ensure more reliable connectivity. This may reduce adverse effects on health service delivery and allow smaller facilities to prepare for water shortages and schedule equipment sterilization. Electricity utility-level examinations may lead to better understanding of how grid infrastructure and utility practices could be improved to ensure more reliable energy supply.

**Lack of back-up energy sources**

Smaller health facilities are more likely to lack a back-up source. Health centres, which provide maternity services, should receive priority for acquiring back-up sources. The MoH and third-party actors whose work focuses on improving health service delivery should provide adequate back-up energy sources at HCFs; this may...
include entities who have worked to ensure safe water supply and other energy-dependent WaSH improvements.

Delayed energy system repairs
Health posts and health centres rely on district maintenance teams to repair generators and solar panels and to supply metre units for grid connectivity. Insufficiencies in maintenance staff, funding for supply procurement and transport lead to repair delays. District health officials responsible for maintenance budget and staffing should define measures to improve the timeliness and efficacy of maintenance practices.

Insufficient generator fuel
Facilities with back-up generators, found most frequently at central and district hospitals and health centres, lack sufficient fuel. Administrators and officials involved in budgetary allocations at the district level should ensure funding to supply sufficient fuel for generators. To address competing use of fuel between vehicles and generators, HCF administrators should make separate fuel allocations. Facility staff may also develop plans for strategic generator placement that prioritizes critical energy-dependent services during blackouts, maximizing benefits of limited generator fuel. Managerial oversight in planning fuel stocks and monitoring energy use can help improve facility energy conditions (Ngounou et al., 2015).

Sustainable, affordable technologies
Nurses and midwives reported that solar panels had insufficient capacity to pump water into the facility or to power lights in the maternity ward, particularly during the rainy season. Nevertheless, photovoltaic systems represent a promising energy source for the Global South and a sustainable option as part of the portfolio for improving energy access in Malawi (Franco et al., 2017). The MoH has partnered with third parties such as the Global Fund to introduce solar power in over 85 facilities (Turner, 2017). It is important that these efforts consider seasonal differences to maximize use of this technology. Energy experts have proposed the use of hybrid solar-diesel systems to ensure reliable energy access; however, their cost is high and innovative financial solutions are needed (WHO and World Bank, 2015; Franco et al., 2017).

Implications for research on energy in HCFs
Previous work calls for broad interagency efforts to advance a framework to measure the dimensions of energy access in HCFs in resource-constrained areas (Adair-Rohani et al., 2013). In light of our use of the framework proposed by Suhrie et al. (2018) and insights gained from the present study, we suggest transportation be added to the energy framework. Fuel availability for vehicles influences an HCF’s ability to transfer patients with complications to higher-level facilities, obtain hospital and cleaning supplies and supply fuel for generators.

Energy criteria have been excluded from most WaSH and environmental health research; a handful of surveys include basic energy access indicators. More research is needed to further understand linkages between energy access and environmental health conditions, particularly those not included in this study, such as energy and waste management. Future surveys and HCF infrastructure assessments conducted by ministries of health, international development agencies and other organizations should use robust metrics to examine energy access, including capacity, reliability, affordability, quality and sustainability. Our inclusion of these metrics, along with triangulation between survey and interview findings, allow in-depth understanding of linkages between energy access, facility outputs and environmental health conditions.

Overall, our research suggests that better energy conditions improve patient outcomes, working conditions and environmental health in HCFs. In the absence of sufficient geographic coverage on energy access in HCFs (Adair-Rohani et al., 2013), this research may prove useful for improving energy conditions in similar healthcare settings in Sub-Saharan African countries with a centralized energy grid, and in understanding challenges faced by HCFs with varying service levels.

Note
1. Minimum lighting requirements for delivery wards are unclear; basic lighting requirements for health clinics are estimated at 162 lux for general and task illumination (WHO and World Bank 2015).

Supplementary data
Supplementary data are available at Health Policy and Planning online.

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Conflict of interest statement. None declared.

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