Health Policy and Planning, 2019, 1–11
doi: 10.1093/heapol/czz118
Original Article

OXFORD

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

Frances Reuland[1,*], Nikki Behnke[1,2], Ryan Cronk [1,2], Ryan McCord[1,3], Michael Fisher[1,2], Lydia Abebe[2,4], Laura Suhlrie[2,5], Lauren Joca[1,2], Innocent Mofolo[6,7], Holystone Kafanikhale[8], Jennifer Mmodzi Tseka[6], Eva Rehfuess[2,5], John Tomaro[1,2], Irving Hoffman[6,7] and Jamie Bartram[1,2]

[1]The Water Institute at the University of North Carolina at Chapel Hill (UNC-CH) Gillings School of Public Health, 4114 McGavran-Greenberg Hall, CB#7431, USA, Chapel Hill, NC 27516, USA, [2]The Department of Environmental Sciences and Engineering at UNC Gillings School of Public Health, 135 Dauer Drive, 166 Rosenau Hall, CB #7431, Chapel Hill, NC 27599, USA, [3]Carolina Population Center at UNC-CH, Carolina Population Center, 123 West Franklin St., Chapel Hill, NC 27516, USA, [4]USAID Bureau for Global Health, Office of Maternal and Child Health and Nutrition, 2100 Crystal Dr, Arlington, VA 22202, USA, [5]Institute for Medical Information Processing, Biometry and Epidemiology at Pettenkofer School of Public Health, LMU Munich, Marchioninistr. 15, 81377 München, Germany, [6]UNC Project-Malawi, Lilongwe, Malawi, [7]The Department of Medicine at UNC-CH, 125 MacNider Hall, Campus Box #7005, Chapel Hill, NC 27599, USA and [8]Malawi Ministry of Health and Population, Lilongwe, Malawi

*Corresponding author. The Water Institute at the University of North Carolina at Chapel Hill (UNC-CH) Gillings School of Public Health, 4114 McGavran-Greenberg Hall, CB#7431, USA, Chapel Hill, NC 27516, USA. E-mail: francesemilyr@gmail.com

Accepted on 6 September 2019

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

Key Messages

- We evaluated environmental health conditions, including energy access, at 44 healthcare facilities (HCFs) in the three regions of Malawi.
- Energy availability in Malawian HCFs is inadequate; the grid provides unreliable access with frequent and sustained 'black-outs'; functional back-up energy sources are rarely available.
- Safe working conditions, adequate lighting and basic environmental health services, such as a regular supply of water, suffer as a result of inadequate energy availability.
- The Malawian Ministry of Health, facility staff and other involved actors should consider facility-type specific measures to improve energy availability and functionality in HCFs.

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; Huttinger *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 uses 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,

Table 1 Number of public healthcare facilities surveyed, by facility type and region in Malawi

Region	Central hospital	District hospital	Health centre	Health post/dispensary	Total
North	1	3	3	3	10
Central	1	5	6	4	16
South	1	6	5	6	18
Total	3	14	14	13	44

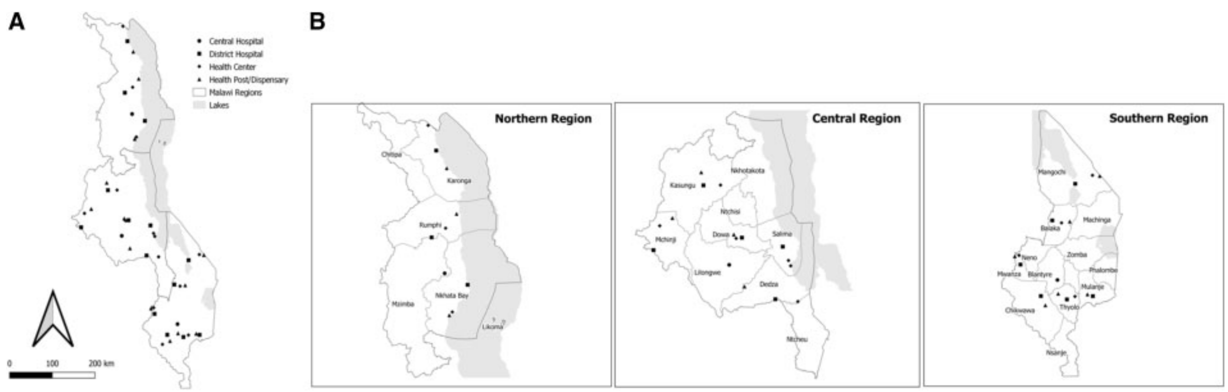

Figure 1 Facilities assessed, by facility type, region (A) and district (B) in Malawi.

2013-14; World Bank Group, 2013; The Soapbox Collaborative, 2014; Ethiopia Ministry of Health, 2015; WHO, 2017a,b). 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^{TM} 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

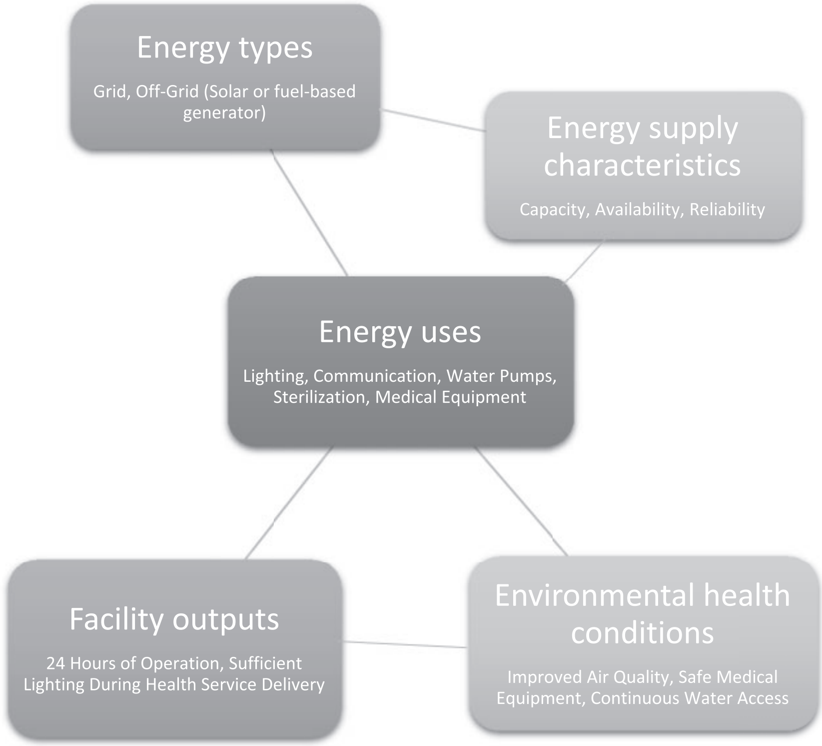

Figure 2 A simplified version of Suhlrie *et al.*'s (2018) conceptual framework characterizing modern energy in HCFs, including energy source types, characteristics, uses and relationships with facility outputs and environmental health conditions. The framework was used in development of survey questions, mixed-methods data analysis and organization of the Results section.

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 supply characteristics include 'availability', 'reliability', 'predictability', 'seasonality', 'affordability', 'functionality', 'sustainability' and 'capacity'.

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 alternatives. 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.

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

Category	Number of facilities (percentage of facilities)									
Primary energy source type (facilities could have none, one or more)	Central (C) ($n=3$)	District (DH) ($n=14$)	Health centre (HC) ($n=14$)	Health post (HP) ($n=13$)	Total ($n=44$)					
Grid	3 (100%)	14 (100%)	13 (93%)	6 (46%)	36 (82%)					
Photovoltaic (solar) system	0 (0	3 (21%)	3 (21%)	5 (38%)	11 (25%)					
Other (wood, coal, gas)	0 (0%)	3 (21%)	4 (29%)	3 (23%)	10 (23%)					
Fuel-based generator	0 (0%)	1 (7%)	1 (7%)	1 (8%)	3 (7%)					
No energy access	0 (0%)	0 (%)	0 (0%)	1 (8%)	1 (2%)					
	Central	District	Health centre	Health post	Total	Central ($n=3$)	District ($n=14$)	Health centre ($n=14$)	Health post ($n=12$)	Total ($n=43$)
Primary energy source reliability	In the past week ($n=42$, $n_{C}=3$, $n_{DH}=14$, $n_{HC}=14$, $n_{HP}=11$)[a]					In the past 6 months ($n=43$)				
Always worked when needed	3 (100%)	6 (43%)	6 (43%)	2 (18%)	17 (40%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Didn't always work	0 (0%)	8 (57%)	8 (57%)	9 (82%)	26 (60%)	3 (100%)	14 (100%)	14 (100%)	12 (100%)	43 (100%)
Duration of electrical interruptions	In the past week ($n=17$)					In the past 6 months ($n=43$)				
Average (h)	9.1					11.1				
Electrical interruptions predictability	In the past week ($n=17$, $n_{C}=0$, $n_{DH}=5$, $n_{HC}=5$, $n_{HP}=7$)					In the past 6 months ($n=43$)				
Predictable	0 (0%)	1 (20%)	0 (0%)	2 (29%)	3 (18%)	1 (33%)	1 (7%)	1 (7%)	1 (8%)	4 (9%)
Unpredictable	0 (0%)	4 (80%)	5 (100%)	5 (71%)	14 (82%)	2 (67%)	13 (93%)	13 (93%)	11 (92%)	39 (91%)
Energy breakdown impact on service delivery	In the past week ($n=16$, $n_{C}=0$, $n_{DH}=5$, $n_{HC}=5$, $n_{HP}=6$)					In the past 6 months ($n=43$)				
Affected service	0 (0%)	3 (60%)	4 (80%)	4 (67%)	11 (69%)	2 (67%)	11 (79%)	12 (86%)	10 (83%)	35 (81%)
Did not affect service	0 (0%)	2 (40%)	1 (20%)	2 (33%)	5 (31%)	1 (33%)	3 (21%)	2 (14%)	2 (17%)	8 (19%)

[a] *n* varies based on survey skip-logic based on answers to previous questions.

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

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

[a] *n* varies based on survey skip-logic based on answers to previous questions.

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.

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).[1] 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 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 beds. 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 light ... 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

(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).

Energy-related challenges vary by facility type

We summarize energy challenges faced by Malawian HCFs (Table 5). Some, such as grid unreliability, are common across all HCFs, while others, such as lack of a back-up energy source, are specific to smaller facility types. Health centres and health posts face a broader range of challenges.

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

Condition	Pass (RLU < 30)	Fail (RLU ≥ 30)	Condition totals
Main water source			
Functional	24	3	27 (87%)
Non-functional	1	3	4 (13%)
Fisher's exact test		0.016[a]	
Back-up power source			
Functional	20	2	22 (73%)
Non-functional	4	4	8 (27%)
Fisher's exact test		0.029[a]	
Pass/fail totals	25 (81%)	6 (19%)	

[a]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

Facility type	Services provided	Energy challenges
Central hospital ($n = 3$)	In-patient services Delivery services Out-patient care	Unreliable service from energy utility Insufficient fuel available for generators
District hospital ($n = 14$)	In-patient services Delivery services Out-patient care	Unreliable service from energy utility Insufficient fuel available for generators No advance warnings of blackouts from the utility
Health centre ($n = 14$)	Delivery services Out-patient care	Unreliable service from energy utility Insufficient fuel available for generators No advance warnings of blackouts from the utility Insufficient metre 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
Health post/dispensary ($n = 13$)	Out-patient care	Unreliable service from energy utility Insufficient fuel available for generators No advance warnings of blackouts from the utility Insufficient metre 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

functional with lower quality electricity supply but point to a lack of information on several variables, most notably the use of back-up sources, functionality of solar systems and impacts of energy on health services, which are present in our study.

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 Suhlrie *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.

Acknowledgements

The Water Institute and the Institute of Global Health and Infectious Diseases at UNC-Chapel Hill thank members of UNC Project-Malawi and the Malawi Ministry of Health for their in-country organization and guidance that made this work possible. We thank Tasila Zuzu, Chrissie Chilima and Pearson Mmodzi, who transcribed the interviews. We also thank Katie Connolly, Rachel Beardsley, Kirsten Miner, Hemali Oza, and Griffin Bell for their contributions to survey preparation, coding, data analysis and figure construction. This work was funded by P&G Children's Safe Drinking Water Program and the Office for Undergraduate Research at UNC-Chapel Hill.

Conflict of interest statement. None declared.

Ethical approval: All facility actors surveyed and interviewed provided verbal and written consent. Ethical approval was received from the Malawi Health Sciences Research Committee (approval number 16/7/1624) and the University of North Carolina at Chapel Hill's Office of Human Research Ethics (approved non-biomedical research, project 16-1682).

References

Adair-Rohani H, Zukor K, Bonjour S *et al*. 2013. Limited electricity access in health facilities of sub-Saharan Africa: a systematic review of data on electricity access, sources, and reliability. *Global Health: Science and Practice* **1**: 249–61.

Adams J, Bartram J, Chartier Y. 2008. Essential environmental health standards in health care. *Bulletin of the World Health Organization* **57**: 27–52.

Borg MA. 2010. Prevention and control of healthcare associated infections within developing countries. *International Journal of Infection Control* **6**: 1–3. doi:10.3396/IJIC.V6I1.4356.

Carling PC, Bartley JM. 2010. Evaluating hygienic cleaning in health care settings: what you do not know can harm your patients. *American Journal of Infection Control* **38**: S41–50.

Cronk R, Bartram J. 2018. Environmental conditions in health care facilities in low- and middle-income countries: coverage and inequalities. *International Journal of Hygiene and Environmental Health* **221**: 409–22.

Ethiopia Ministry of Health. 2015. *Clean and Safe Health Facilities (CASH) Audit Tool*. https://www.washinhcf.org/fileadmin/user_upload/CASH-Audit-Tool.pdf, accessed 17 April 2017.

Franco A, Shaker M, Kalubi D, Hostettler S. 2017. A review of sustainable energy access and technologies for healthcare facilities in the Global South. *Sustainable Energy Technologies and Assessments* **22**: 92–105.

Guo A, Bowling JM, Bartram J, Kayser G. 2017. Water, sanitation, and hygiene in rural health-care facilities: a cross-sectional study in Ethiopia, Kenya, Mozambique, Rwanda, Uganda, and Zambia. *The American Journal of Tropical Medicine and Hygiene* **97**: 1033–42.

Huttinger A, Dreibelbis R, Kayigamba F *et al*. 2017. Water, sanitation and hygiene infrastructure and quality in rural healthcare facilities in Rwanda. *BMC Health Services Research* **17**: 517.

ICF International, Ministry of Health; USAID; ICF. 2014. *Malawi Service Provision Assessment (SPA)*. **414**. https://dhsprogram.com/pubs/pdf/SPA20/SPA20%5BOct-7-2015%5D.pdf, accessed 16 March 2018.

Malawi Ministry of Health and ICF International. 2014. *Malawi Service Provision Assessment Survey 2013-14: Key Findings*. https://dhsprogram.com/pubs/pdf/SR217/SR217.pdf, accessed 17 April 2017.

Mccollum DL, Echeverri LG, Busch S *et al*. 2018. Connecting the sustainable development goals by their energy inter-linkages. *Environmental Research Letters* **13**: 033006.

Moffa M, Guo W, Li T *et al*. 2017. A systematic review of nosocomial waterborne infections in neonates and mothers. *International Journal of Hygiene and Environmental Health* **220**: 1199–206.

Ngounou GM, Gonin M, Gachet N, Crettenand N. 2015. Holistic approach to sufficient, reliable, and efficient electricity supply in hospitals of developing countries—Cameroon Case Study. In: Hostettler, S, Gadgil A, Hazboun E (eds). *Sustainable Access to Energy in the Global South*. Cham: Springer, 59–74. doi:10.1007/978-3-319-20209-9_6.

Ouedraogo NS, Schimanski C. 2018. Energy poverty in healthcare facilities: a 'silent barrier' to improved healthcare in Sub-Saharan Africa. *Journal of Public Health Policy* **39**: 358–71.

Power Africa. 2018. *Malawi: Energy Sector Overview*. https://www.usaid.gov/sites/default/files/documents/1860/MalawiPACFSDEC20175.508.pdf, accessed 23 March 2018.

Randson R, Mwadiwa PP, Lapukeni PGJ. 2013. *The Republic of Malawi Country Report*. https://eneken.ieej.or.jp/data/5006.pdf, accessed 23 March 2018.

Schwemlein S, Cronk R, Bartram J. 2016. Indicators for monitoring water, sanitation, and hygiene: a systematic review of indicator selection methods. *International Journal of Environmental Research and Public Health* **13**: 333.

Shields KF, Bain RES, Cronk R, Wright JA, Bartram J. 2015. Association of supply type with fecal contamination of source water and household stored drinking water in developing countries: a bivariate meta-analysis. *Environmental Health Perspectives* **123**: 1222.

Suhlrie L, Bartram J, Burns J *et al*. 2018. The role of energy in health facilities: a conceptual framework and complementary data assessment in Malawi. *PLos One* **13**: e0200261.

Sustainable Energy Transitions Initiative. 2018. *Energy as the Golden Thread: What Do We Know? New Research Sheds Light on Connections among United Nations Sustainable Development Goals and Highlights Critical Knowledge Gaps*. http://www.efdinitiative.org/sites/default/files/energy_and_development_a_systematic_review.pdf, accessed 23 March 2018.

The Coalition for Health Promotion and Social Development & VSO Uganda. 2012. *Our Side of the Story, Ugandan Health Workers Speak Up*. http://www.ivoindia.org/Images/VSO-Our-side-of-the-story_Ugandan-health-workers-speak-u_tcm78-35533.pdf, accessed 23 March 2018.

The Soapbox Collaborative. 2014. *WASH & CLEAN Toolkit*. 2014. http://soapboxcollaborative.org/? page_id=3232, accessed 17 April 2017.

Turner C. 2017. *Solar Power in Malawi Aids Health Facilities. The Borgen Project*. 2017. https://borgenproject.org/solar-power-in-malawi-aids-health/, accessed 23 March 2018.

UNICEF. 2016. *Health Budget Brief*. http://apps.who.int/nha/database/ViewData/, accessed 23 March 2018.

UNICEF. 2018. *Malawi Maternal and Newborn Health Disparities*. https://data.unicef.org/wp-content/uploads/country_profiles/Malawi/countryprofile_MWI.pdf, accessed 23 March 2018.

United Nations (UN). 2012. *Secretary-General to Global Development Center: 'Energy Is the Golden Thread' Connecting Economic Growth, Social Equity, Environmental Sustainability. Meetings Coverage and Press Releases*. 2012. https://www.un.org/press/en/2012/sgsm14242.doc.htm, accessed 23 March 2018.

United Nations (UN). 2015. *Goal 7: Sustainable Development Knowledge Platform*. 2015. https://sustainabledevelopment.un.org/sdg7, accessed 23 March 2018.

World Bank Group. 2013. *Service Delivery Indicators: Kenya*. https://openknowledge.worldbank.org/bitstream/handle/10986/20136/903710WP0Box380IC00SDI0Report0Kenya.pdf? sequence=1&isAllowed=y, accessed 17 April 2017.

World Health Organization (WHO). 2006. *Opportunities for Africa's Newborns Practical Data, Policy and Programmatic Support for Newborn Care in Africa*. http://www.who.int/pmnch/media/publications/oanfullreport.pdf, accessed 23 March 2018.

World Health Organization (WHO). 2009. WHO guidelines on hand hygiene in health care: first global patient safety challenge clean care is safer care. *World Health* **30**: 270.

World Health Organization. 2017a. *WHO. Water and Sanitation for Health Facility Improvement Tool (WASH FIT)*. World Health Organization. http://www.who.int/water_sanitation_health/publications/water-and-sanitation-for-health-facility-improvement-tool/en/, accessed 17 April 2017.

World Health Organization. 2017b. *WASH in HCF Monitoring Webinar*. https://www.washinhcf.org/documents/Webinar-160622-Monitoring-WASH-in-HCF_one-year-since-EGM.pdf, accessed 17 April 2017.

World Health Organization and World Bank. 2015. *Access to Modern Energy Services for Health Facilities in Resource-Constrained Settings*. http://apps.who.int/iris/bitstream/handle/10665/156847/9789241507646_eng.pdf? sequence=1, accessed 23 March 2018.