

Building power-ful health systems: the impacts of electrification on health outcomes in LMICs

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ABSTRACT

Critical disparities threaten health care in developing countries and hinder progress towards global development commitments. Almost a billion people and thousands of public services are not yet connected to electricity – a majority in sub-Saharan Africa. In economically fragile settings, clinics and health services struggle to gain and maintain their access to the most basic energy infrastructure. Less than 30% of health facilities in LMICs report access to reliable energy sources, truncating health outcomes and endangering patients in critical conditions. While ‘universal health coverage’ and ‘sustainable energy for all’ are two distinct SDGs with their respective targets, this review challenges their disconnect and inspects their interdependence in LMICs. To evaluate the impact of electrification on healthcare facilities in LMICs, this systematic review analysed relevant publications up to March 2021, using MEDLINE, Embase, Scopus, CENTRAL, clinicaltrials.gov and CINAHL. Outcomes captured were in accordance with the WHO HHFA modules. A total of 5083 studies were identified, 12 fulfilled the inclusion criteria of this review – most were from Africa, with the exception of two studies from India and one from Fiji. Electrification was associated with improvements in the quality of antenatal care services, vaccination rates, emergency capabilities and primary health services; with many facilities reporting high-quality, reliable and continuous oxygen supplies, refrigeration and enhanced medical supply chains. Renewable energy sources were considered in six of the included studies, most highlighting their suitability for rural health facilities. Notably, solar-powered oxygen delivery systems reduced childhood mortality and length of hospital stay. Unavailable and unreliable electricity is a bottleneck to health service delivery in LMICs. Electrification was associated with increased service availability, readiness and quality of care – especially for women, children and those under critical care. This study indicates that stable and clean electrification allows new heights in achieving SDG 3 and SDG7 in LMICs.

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Introduction

Electricity consumption commonly signifies economic growth, productivity and poverty reduction (Ouedraogo et al., 2021). Universal access to reliable, affordable and sustainable energy for all is the seventh target of the Sustainable Development Goals (SDGs), yielding unanimous support from 193 UN member states (Irwin et al., 2020). Despite global progress, over 770 million people had no access to electricity in 2019, 75% residing in sub-Saharan Africa (Apenteng et al., 2018). Further, it is an issue that is commonly confined to one sector, blinding policymakers from its implications on wider government services like education, food provision and healthcare services.

While electricity shortages are well documented in residential areas, the detrimental impacts on public services are not. Outages are particularly apparent in low- and middle-income countries (LMICs), commonly disrupting essential health services (Kushner et al., 2010; WHO, 2019). Outages are associated with increased all-cause mortality and hospitalisations, especially for patients reliant on electrical medical devices (Casey et al., 2020). Access to electricity does not mean it is reliable (Irwin et al., 2020). For example, while only a quarter of health facilities lack access to electricity in sub-Saharan Africa, 72% of surveyed facilities reported unreliable electricity (Adair-Rohani et al., 2013). Unreliable electricity leads to insufficient use of health technologies, vaccine spoilage, increased fuel costs and waste for health facilities – limiting healthcare capabilities in already disadvantaged areas (WHO, 2018). Electricity shortages can be life-threatening.

This review examines the impact of electrification on healthcare facilities, prioritising evidence of impact on service provision, health outcomes and quality of care in LMICs. It further considers the comparative advantages of clean electrification. With increasing commitments towards the SDGs, Paris Agreement and COP26 resolutions, clean electrification of public health services is a global priority. Despite the shifts towards ‘solar for health’, adaptive technologies and rising fossil fuel costs, little is known about healthcare electrification using renewable energy. Though limited by existing literature, this review bridges the gap between healthcare delivery and the infrastructure that underpins it.

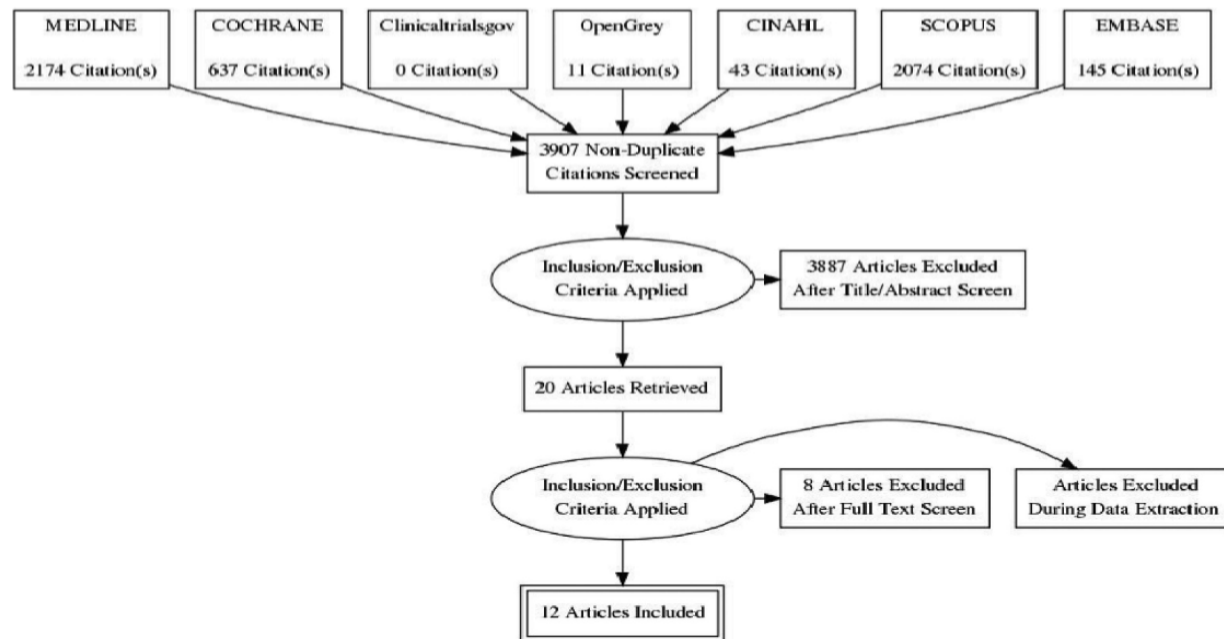
Methods

A protocol for this systematic review was published in the PROSPERO register (Ibrahim et al., 2021). To systematically investigate the impact of electrification, the harmonised health facility assessment (HHFA) modules were used as a gold standard (WHO, 2021). The systematic online search navigated the following databases: MEDLINE, Embase, Scopus, CENTRAL, clinicaltrials.gov and CINAHL. The search strategy is detailed in Table 1. No restriction was applied to the date of records publication. Only records in English language and from LMICs were included. OpenGrey was also used to retrieve relevant grey literature.

Inclusion criteria: Studies investigating the outcomes or impact of electricity supply on healthcare facilities in LMICs (as defined by the World Bank; The World Bank, 2022). Studies with incomplete data and those from high-income countries were excluded. The last search was done on 2/3/2021. Three independent

Table 1. Search strategy for database searches.

Strategy	Keywords
Strategy #1	electrification OR electricity OR renewable energy OR clean energy OR solar energy OR solar power OR solar electricity OR photoelectric cells OR solar technology OR wind energy OR windmills
Strategy #2	health OR healthcare delivery OR health services OR access to health services OR maternal health OR Emergency Obstetric Care (EmOC) package OR child health OR vaccination OR health facilities OR quality of care OR COVID-19
Strategy #3	Strategy #1 AND strategy #2

**Figure 1.** PRISMA flowchart of the study selection process.

reviewers screened abstracts of retrieved records for potential inclusion, then independently reviewed record full-texts for final inclusion. Any disparities between them were resolved by discussion and consensus. The study selection was in line with the Preferred Reporting Items for Systematic Reviews and MetaAnalyses (PRISMA) guidelines (Moher et al., 2009), as demonstrated in Figure 1.

A data extraction sheet encapsulated relevant findings from included studies. This includes the study type, location, electrification technology used (Grid, Mini-Grid and off-grid), source of electrification energy used (carbonised, clean and mixture of both), level(s) of healthcare facilities affected by electrification (primary, secondary and tertiary), HHFA modules reported and any changes in their indicators before and after electrification. Possible effects of electrification on COVID-19 vaccination were also extracted. Finally, the Cochrane risk-of-bias assessment tool was used to assess the quality of evidence for experimental studies (Higgins et al., 2011); similarly, the Newcastle Ottawa scale evaluated the risk of bias for observational studies (Stang, 2010).

Results

Selection and study characteristics

Out of 5083 records identified through the search process, 12 fulfilled the inclusion criteria of this review. Most of the included studies were from Africa, two from India and one from Fiji. Out of the 10 studies conducted in Africa, six were from Uganda. Five studies were experimental (including four quasi-experimental and one randomised control trial); the rest varied in methods (including four cross-sectional surveys, two retrospective surveys and one case-control study). The studies varied in the facility grading (primary, secondary and tertiary) and setting (urban vs. rural). [Table 2](#) shows the characteristics of the included studies, and [Tables 3 and 4](#) show the risk of bias assessments. Most of the studies, except for Swanson et al. study, were of good quality of evidence (Swanson et al., 2017).

Outcome measures

The HHFA modules were used to evaluate health facilities relative to their level of electrification (WHO, 2021). The four key underpinnings include service availability, service readiness, quality of care and safety and management and finance. This paper evaluates the impact of health system electrification on each dimension, with deliberate attention to the availability of sustainable energy sources where evidence is available.

Service readiness

Five studies spoke to the effect of electrification on service readiness, with most focusing on oxygen supplies, antenatal care, vaccine infrastructure, illumination and water supply systems. Findings suggest that electrification may provide cost-effective oxygen supplies compared to conventional oxygen cylinders with demanding supply-chain prerequisites. Building on assessments across the Gambia and Fiji, Howie et al. further elaborate that solar-based energy storage systems were successful in delivering oxygen at standard levels to hypoxemic patients (an output of $\geq 82\% \pm 3\%$ oxygen concentration, in 100% of 1–2 weekly measurements over 12 months of assessment). Users, including staff, rated the system positively (90% rated it as very good or excellent), indicating its ease of use (Howie et al., 2020). Turnbull et al. complemented these results with findings from Uganda, signifying comparative improvements in blood oxygenation in patients receiving solar-powered oxygen. With the presence of solar-powered oxygenation systems, oxygen saturation in critically ill patients increased by an average of 12%, with significant improvements in their clinical profiles (Turnbull et al., 2016). In six African countries, facilities with central electricity supplies were more likely to provide optimal quality of antenatal care (AOR = 2.19; 95% CI, 1.81–2.65, P-value ≤ 0.001 ; Owili et al., 2019). One study also reported increased probabilities of functioning deep freezers, ice-lined refrigerators, cold boxes and vaccine carriers with reliable electrification (Chen et al., 2019). Electrification was also associated with improved access to water pumps, prompting improvements in sterilisation of medical equipment and signifying protection against nosocomial infections. This reinforces the link between health, water and hygiene – with electricity as a mediator (Mubyazi et al., 2012).

Table 2. Characteristics of the included studies. N. S: not specified.

Study	Study type	Country(s)	Primary objective(s) of the study	Source of electricity	Type of electrical grid	Health facility(s) level	Rural/ urban/ both	Outcome(s) measured
Chen et al., 2019 (22)	Case-control study	India	Examining the effects of a rural electrification project on the core components of health systems in that area	N. S	N. S	Primary area	Rural	Service Availability Service readiness management and finance
Javadi et al., 2020 (23)	Quasi-experimental study	Ghana and Uganda	Capturing changes in service availability and readiness in health facilities following the implementation of off-grid solar electrification project	Solar	off-grid	primary	Rural	Service Availability quality and safety of care management and finance
Apenteng et al., 2018 (24)	Randomised controlled trial	Uganda	Evaluating a novel strategy, solar-powered oxygen delivery, which concentrates oxygen from ambient air using solar energy compared to the previous method of oxygenation using cylinders	Solar	N. S	Tertiary	urban	Service Availability quality and safety of care
Howie et al., 2020 (25)	Quasi-experimental study	Fiji and Gambia	Development and assessment of the reliability, usability and costs of a newly powered oxygen concentrators	Solar	N.S	Multi-level	N. S	Service readiness management and finance
Kumar et al., 2014 (26)	retrospective survey	India	Exploring the effects of supply-side factors on the volume of delivery care provided at Indian health facilities	N. S	N. S	Primary	rural and urban	Service Availability
Mbonye et al., 2007 (27)	cross-sectional survey	Uganda	Investigating the availability of emergency obstetric care (EmOC) and factors related to maternal deaths, including the availability of electricity, in Uganda	N. S	N. S	Multi-level	rural and urban	Service Availability
Mbonye & Asimwe, 2010 (28)	cross-sectional survey	Uganda	Determining the availability and access to essential maternity care and health system factors related to maternal health in Uganda	N. S	N. S	Multi-level	rural and urban	Service Availability
Morrissey et al., 2015 (29)	quasi-experimental study	Sierra Leone	Assessment of a newly implemented hybrid solar power system to support the electricity needs of a paediatric department in a district hospital in Sierra Leone	Solar	off-grid	secondary	rural	Service Availability Service readiness

(Continued)

Table 2. (Continued).

Study	Study type	Country(s)	Primary objective(s) of the study	Source of electricity	Type of electrical grid	Health facility(s) level	Rural/urban/both	Outcome(s) measured
Mubyazi et al., 2012 (30)	qualitative cross-sectional study	Tanzania	Describing the supply-related drivers of motivation and performance of HWs in administering intermittent preventive treatment of malaria during pregnancy in Tanzania	N. S	N. S	Primary	Rural	Service readiness management and finance
Owili et al., 2019 (31)	Cross sectional study	Kenya, Malawi, Namibia, Rwanda, Tanzania and Uganda	Exploring the determinants of quality of antenatal care in sub-Saharan Africa	N. S	N. S	Multi-level	rural and urban	Quality and safety of care
Swanson et al., 2017 (32)	retrospective survey	DRC	Examining the challenges that arose in implementing an intervention included. The training of health personnel to perform antenatal ultrasound screening and to refer women identified with high risk.	Solar in addition to other sources	N. S	Secondary	Urban	Service readiness
Turnbull et al., 2016 (33)	quasi-experimental study	Uganda	Pregnancies to hospitals for appropriate care Implementing a solar-powered oxygen delivery system for the treatment of paediatric pneumonia.	Solar	Off-grid	Tertiary	Urban	Service readiness management and finance

Table 3. Risk of bias assessment for experimental studies.

Study	Risk of bias domain (High, low, unclear)						
	Random sequence generation	Allocation concealment	Selective reporting	Blinding (participants and personnel)	Blinding (outcome assessment)	incomplete outcome data	Other sources of bias
Javadi et al., 2020 (23)	Low risk of bias	NA	Low risk of bias	N.A	N.A	Low risk of bias	Low risk of bias
Apenteng et al., 2018 (24)	Low risk of bias	Low risk of bias	Low risk of bias	High risk of bias	High risk of bias	Low risk of bias	Low risk of bias
Howie et al., 2020 (25)	High risk of bias	NA	Low risk of bias	NA	NA	Low risk of bias	Low risk of bias
Morrissey et al., 2015 (29)	Unclear	NA	Low risk of bias	NA	NA	Low risk of bias	Low risk of bias
Turnbull et al., 2016 (33)	Unclear	NA	Low risk of bias	NA	NA	Low risk of bias	Low risk of bias

Table 4. Quality assessment for non-experimental studies.

Study	Number of stars				Overall score
	Selection	Comparability	Outcome		
Chen et al., 2019 (22)	4	0	3		7/9 (Good quality)
Kumar et al., 2014 (26)	5	0	3		8/9 (Good quality)
Mbonye et al., 2007 (27)	5	0	3		8/9 (Good quality)
Mbonye & Asimwe, 2010 (28)	5	0	3		8/9 (Good quality)
Mubyazi et al., 2012 (30)	4	0	3		7/9 (Good quality)
Owili et al., 2019 (31)	5	0	3		8/9 (Good quality)
Swanson et al., 2017 (32)	0	0	0		0/9 (Unsatisfactory quality)

Service availability

Seven studies highlighted the effects of electrification on health services availability, particularly for maternal care and emergency services. In India, the probability of receiving the first dose of various vaccines increased significantly following an electrification project – check-ups in the first trimester increased by 10%. Despite gains in perinatal care, the study reports electrification did not influence the number of deliveries in public facilities (Chen et al., 2019). Another study showed increased availability of 24-hr emergency services following electrification (Javadi et al., 2020).

In Uganda, Solar-Powered Oxygen Delivery showed marginal reductions in the duration of hospital stays, from a median of 4.5 days using cylinders to 4.1 days in patients using solar-powered oxygen systems. However, there were no significant changes in mortality rates and the time to discharge. These solar-powered systems faced challenges including battery depletion, the need to switch to the grid or low backup stocks of oxygen when the

system fails (Hawkes et al., 2018). In Sierra Leone, results showed that after 6 months of installing new oxygen hybrid energy system, the mean paediatric mortality was significantly reduced from 3.7% to 1.8% (Morrissey et al., 2015). In India, approximately 62% of maternity care facilities were found to have a regular supply of electricity available. Access to electricity was significantly associated with a higher volume of deliveries (Kumar et al.,

2014). In Uganda, out of 553 facilities, electricity was only available in 16.8% of facilities; availability of electricity was protective against maternal death (OR 0.39, P-value: 0.0001), averting an estimate of 61% of maternal deaths (Mbonye et al., 2007).

Quality of care

Three included studies explored the impact of electrification on the quality of healthcare service provision, focusing on primary health care, maternal and child care, and delivery of oxygen for children. Electrification was evidently critical to the quality of antenatal care in six African countries (Owili et al., 2019). Furthermore, in Ghana and Uganda, community satisfaction of health facilities rocketed after electrification (Javadi et al., 2020), from 10% approval to 95% after health service electrification in Ghana, and from 34% to 96% in Uganda. Emergent patterns include health facility availability at night, improved perceptions around safety, cleanliness and quality of care. This is reinforced by staff reporting adequate lighting to conduct tasks in maternity wards regardless of the time. Despite community satisfaction, there were no significant changes in service uptake at end-line. This suggests other barriers to access. Other studies concluded that solar-powered oxygen may be suitable for low-resource hospitals with paediatric inpatient services, especially those with unreliable supplies of cylinders and electricity (Hawkes et al., 2018).

Management and finance

Four studies spoke of management and financing, highlighting human resources for health, the cost-effectiveness of interventions and improved information systems. In Tanzania, Ghana and Uganda, health workers' motivation increased, partly due to perceived variations in the working conditions, including stable electricity supplies (Javadi et al., 2020; Mubyazi et al., 2012). Respondents in Tanzania, for example, were not fully satisfied with the 'government's endless promises to improve the physical working conditions including staff residential houses, office space, water and electricity supplies' (Mubyazi et al., 2012). Thirty per cent were satisfied with the availability of electricity at health facilities, influencing increased staff motivation.

Clean electrification of health systems may also be cost-effective. Howie et al. found that electricity-dependent oxygen had similar or lower costs than existing cylinder supply systems in modelled standardised facilities (Howie et al., 2020). One barrier to implementation is that the high up-front capital costs in LMICs – donor support may help overcome this hurdle.

Chen et al. studied the effect of reliable electricity implementation on Primary Health Centres (PHCs) in rural India (Chen et al., 2019). They studied the operational capacity, and whilst electrification did not have any effect on general awareness about infectious illnesses, the probability of receiving health information via television increased significantly by 5.7% after electrification of the surrounding areas – indicating improvements in health information.

Discussion

This review interrogates the body of evidence linking electrification to health services and healthcare performance in LMICs. Electricity has widespread positive impacts on health-care provisions; this analysis frames them in relation to global development targets, discussing the impacts of healthcare electrification on SDG3 (good health and well-being), and their relevance in achieving SDG7 (affordable and clean energy).

Electrification accelerates progress towards SDG 3 in LMICS

Energy-supplied health facilities influence maternal and child health

As put by the former Chair of the African Union Commission, Jean Ping: ‘The welfare and the future of our societies depend on our capacity to improve the health of every mother and child’ (United Nations, 2005). With noble advancements in reproductive, maternal, newborn and child health (RMNCH), integrated service delivery has improved their continuum of care. The majority of RMNCH deaths remain preventable or treatable (WHO, 2022) – the results echo this sentiment. Integrated health services are highly effective in reaching women and children in rural communities (Karim et al., 2020; Diaz et al., 2014). The results highlight that RMNCH services are the first to improve with electrification, reflecting its role in facilitating integrated service packages. Further, reports highlighted that women and children in rural areas often endure the double burden of healthcare fragility and lack of energy sources. This is directly reflected through increased maternal and under-five mortality (Mangipudi et al., 2020).

Another major finding is that electrification may increase the capacity to respond to emergencies through improved oxygen supply systems, sterile tools, overnight staff retention and security of facilities, among others. Electrification was shown to provide a basic infrastructure on which emergency facilities can be built. With the exploding burden of acute respiratory illnesses in sub-Saharan Africa, oxygen supply can be key to managing its manifestation due to infectious disease (Troeger et al., 2017). Oxygen supply is often faced with many financial and logistical challenges (Graham et al., 2020; Dondorp et al., 2020), hampering medical capacities to respond to infectious disease endemics. In the COVID-19 pandemic, for example, 19% of clinical cases required oxygen, but only 309 (6.9%) health facilities were found to have the energy source needed to supply oxygen systems out of 4466 facilities across four African countries. It could be argued that restricted access to electricity – and therefore oxygen – worsens health emergencies, especially in LMICs (Mangipudi et al., 2020).

Electrical coverage can be a milestone towards universal health coverage

PHC services often vary between and within countries. In many LMICs, PHC-level facilities provide essential services and medications (Ramírez et al., 2011). The results suggest that the introduction or improvement of electricity at PHC facilities may enhance service availability, readiness and quality. Electrification of PHC facilities can catalyse an improvement of operational capacity. In India, for example, PHC electrification improved essential service provision in operating rooms (Chen et al., 2019); in Mongolia, it further improved surgical and anaesthetic services (Spiegel et al., 2011).

Energy availability is also linked to healthcare workers' performance. Mubyazi et al. noticed differences in staff motivation between public and private healthcare facilities, partially attributing this to perceived variations in the working conditions, including electricity as an important basic right (Mubyazi et al., 2012). Electricity was also associated with improved health worker perceptions towards being posted at newly electrified facilities (Javadi et al., 2020). This highlights a possible route to decentralise health care workers and devolve healthcare coverage to be more inclusive of rural areas.

Electrification of healthcare facilities can catalyse immunisation and global health security

The success of immunisation services is often reliant on the strength of the PHC systems through which they are delivered, e.g., cold-chain capacity and delivery systems (Poore, 1988; Jafflin, 2019). Electrification evidently improved vaccine coverage. In India, electrification resulted in better functioning cold-chain equipment like deep freezers, ice lined refrigerators, cold boxes and vaccine carriers. There was increased uptake of four vaccines in energy supplied facilities: DPT, polio, BCG and measles vaccines (Chen et al., 2019). COVID-19 vaccine delivery is notably stunted where electricity supplies and refrigeration are unstable (Haque & Pant, 2020). While affordability, supply chains and acceptability have been commonly debated as challenges in global vaccine delivery, electrification of health facilities has not received equal attention despite the significantly increased coverage that it allows. Equitable vaccine delivery should recognise that lack of electricity is a major bottleneck.

Healthcare electrification presents opportunities to achieve SDG7

Health facilities can be cornerstones for mini-grid technologies and rural electrification

Most LMICs have uneven population distributions that centralise in urbanised areas (Rodríguez-Pose & Hardy, 2015). To build a cost-effective energy infrastructure accounting for these demographic distributions, Ministries of Energy commonly build central electrical grids that cover high-density areas, prompting remote health facilities and public services to build their own self-sufficient mini-grids, using more diverse sources of energy (Neal et al., 2020; Remson, 2015). Rural PHC electrification efforts can leverage and expand on these disconnected grids to power surrounding residential areas and public services – gaining grounds towards the SDG target 7.1. Despite their expensive capital costs, electrified health facilities could be centres for distributing energy generation locally (WHO & WHO & The World Bank, 2014). Sustainable energy can easily become a core element in health planning (United Nations Foundation, 2019). Furthermore, with advancements in the production and sales of Electric Vehicles (EVs) in the US, EU and China, governments can repurpose retired EV batteries as Stationary Storage of Energy (Baars et al., 2021).

Renewable energy is linked to better health outcomes

Four studies highlighted the role of standalone solar power in health facilities. Their competitive pricing and low long-term costs were also emphasised. Solar-powered oxygen concentrators, for example, were cheaper and low maintenance compared to

cylinders (Graham et al., 2020). The use of solar power, either solely or hybrid with other systems, provided high quality and reliable oxygen, decreased hospital stay time and reduced in-patient paediatric mortality.

Monitoring and evaluation of the energy supply-chains in LMICs

Despite the overwhelming benefits of electrification and its spillover benefits on population wellbeing, several factors need to be evaluated, including the efficacy of renewable energy – especially solar-powered systems – across and within different geographic climates; the logistical capacities of supplying renewable energy to health facilities, particularly in humanitarian areas and regions with underperforming infrastructures (Osman et al., 2021); and where mini-grids are considered, an assessment of their battery requirements, price, maintenance costs and safe disposal. Until these implementation assessments are investigated, backup supplies (like oxygen cylinders) should be considered. Implementation challenges and energy disruptions can be communicated through existing healthcare reporting channels. One study, for example, reported major challenges in antenatal care ultrasound screening, evidently due to an unreliable national grid, the investigators had to set up a hybrid-solar system in order to continue with their program (Swanson et al., 2017).

Conclusion and implications for policy and practice

Electrification was found to improve multiple health system indicators. This study concludes that electrification of healthcare facilities is associated with enhanced service availability, readiness and quality of care. It also ameliorates health facilities management and financing. The electrification of the healthcare services and health sector at large requires robust coordination between different government sectors and ministries in addition to the private and civil society sectors. This will not only enhance sustainability but also ensure synergies across the government. A major limitation of this study was the scarcity of literature around the impact of electrification on health outcomes, and the unclear directionality of impact. The relationship between electrification and health service should be thoroughly investigated in the future. Especially, considering the compelling long-term cost-effectiveness of using renewable energy for healthcare electrification.

Disclosure statement

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References

- Adair-Rohani, H., Zukor, K., Bonjour, S., Wilburn, S., Kuesel, A. C., Hebert, R., & Fletcher, E. R. (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(2), 249–261. doi:10.9745/GHSP-D-13-00037
- Apenteng, B. A., Opoku, S. T., Ansong, D., Akowuah, E. A., & Afriyie-Gyawu, E. (2018). The effect of power outages on in-facility mortality in healthcare facilities: Evidence from Ghana. *Global Public Health*, 13(5), 545–555. <https://doi.org/10.1080/17441692.2016.1217031>
- Baars, J., Domenech, T., Bleischwitz, R., Melin, H. E., & Heidrich, O. (2021). Circular economy strategies for electric vehicle batteries reduce reliance on raw materials. *Nature Sustainability*, 4(1), 71–79. <https://doi.org/10.1038/s41893-020-00607-0>
- Casey, J. A., Fukurai, M., Hernández, D., Balsari, S., & Kiang, M. V. (2020). Power outages and community health: A narrative review. *Current Environmental Health Reports*, 7(4), 371–383. <https://doi.org/10.1007/s40572-020-00295-0>
- Chen, Y. J., Chindarkar, N., & Xiao, Y. (2019). Effect of reliable electricity on health facilities, health information, and child and maternal health services utilization: Evidence from rural Gujarat, India. *Journal of Health, Population and Nutrition*, 38(1), 1–16. <https://doi.org/10.1186/s41043-019-0164-6>
- Diaz, T., Aboubaker, S., & Young, M. (2014). Current scientific evidence for integrated community case management (iCCM) in Africa: Findings from the iCCM Evidence Symposium. *Journal of Global Health*, 4(2), 020101. <https://doi.org/10.7189/jogh.04.020101>
- Dondorp, A. M., Hayat, M., Aryal, D., Beane, A., & Schultz, M. J. (2020). Respiratory Support in COVID-19 Patients, with a Focus on Resource-Limited Settings. *The American Journal of Tropical Medicine and Hygiene*, 102(6), 1191–1197. doi:10.4269/ajtmh.20-0283
- Graham, H. R., Bagayana, S. M., Bakare, A. A., Olayo, B. O., Peterson, S. S., Duke, T., & Falade, A. G. (2020). Improving hospital oxygen systems for COVID-19 in low-resource settings: lessons from the field. *Global Health: Science and Practice*, 8(4), 858–862. <https://doi.org/10.9745/GHSP-D-20-00224>
- Haque, A., & Pant, A. B. (2020). Efforts at COVID-19 vaccine development: challenges and successes. *Vaccines*, 8(4), 739. <https://doi.org/10.3390/vaccines8040739>
- Hawkes, M. T., Conroy, A. L., Namasopo, S., Bhargava, R., Kain, K. C., Mian, Q., & Opoka, R. O. (2018). Solar-powered oxygen delivery in low-resource settings: A randomized clinical noninferiority trial. *JAMA Pediatrics*, 172(7), 694–696. <https://doi.org/10.1001/jamapediatrics.2018.0228>
- Higgins, J. P., Altman, D. G., Gøtzsche, P. C., Jüni, P., Moher, D., Oxman, A. D., Savović, J., Schulz, K. F., Weeks, L., & Sterne, J. A. (2011). The Cochrane collaboration's tool for assessing risk of bias in randomised trials. *Bmj*, 343(oct18 2), d5928–d5928. <https://doi.org/10.1136/bmj.d5928>
- Howie, S. R., Ebruke, B. E., Gil, M., Bradley, B., Nyassi, E., Edmonds, T., Boladuadua, S., Rasili, S., Rafai, E., Mackenzie, G., Cheng, Y. L., Peel, D., Vives-Tomas, J., & Zaman, S. M. (2020). The development and implementation of an oxygen treatment solution for health facilities in low and middle-income countries. *Journal of Global Health*, 10(2), 1–10. <https://doi.org/10.7189/jogh.10.020425>
- Ibrahim, M., Osman, A., Karrar, K., Elsheikh, M., & Sharaf, A. (2021). The impact of electrification on healthcare facilities in lower- and middle-income countries: A systematic review of the literature. *PROSPERO International Prospective Register of Systematic Reviews*. CRD42021234042. https://www.crd.york.ac.uk/prospéro/display_record.php?ID=CRD42021234042
- Irwin, B. R., Hoxha, K., & Grépin, K. A. (2020). Conceptualising the effect of access to electricity on health in low- and middle-income countries: A systematic review. *Global Public Health*, 15(3), 452–473. <https://doi.org/10.1080/17441692.2019.1695873>
- Jafflin, K. (2019). The local and the global in primary health care how global policies and local legacies influenced the success of the expanded programme on immunization. *Sociology of Development*, 5(1), 50–70. <https://doi.org/10.1525/sod.2019.5.1.50>

- Javadi, D., Ssempebwa, J., Isunju, J. B., Yevo, L., Amu, A., Nabiwemba, E., Pfeiffer, M., Agyepong, I., & Severi, L. (2020). Implementation research on sustainable electrification of rural primary care facilities in Ghana and Uganda. *Health Policy and Planning*, 35(Suppl._2), ii124–ii136. <https://doi.org/10.1093/heapol/czaa077>
- Karim, A., Cobos Muñoz, D., Mäusezahl, D., & de Savigny, D. (2020). Thematic areas and complexity of integrated community case management (iCCM) design, implementation, and evaluation: Protocol for a scoping review. *Systematic Reviews*, 9(1), 205. <https://doi.org/10.1186/s13643-020-01454-y>
- Kumar, S., Dansereau, E., & Carlo, W. A. (2014). Supply-side barriers to maternity-care in India: A facility-based analysis. *PloS One*, 9(8), e103927. <https://doi.org/10.1371/journal.pone.0103927>
- Kushner, A. L., Cherian, M. N., Noel, L., Spiegel, D. A., Groth, S., & Etienne, C. (2010). Addressing the millennium development goals from a surgical perspective: Essential surgery and anesthesia in 8 low and middle-income countries. *Archives of Surgery*, 145(2), 154–159. <https://doi.org/10.1001/archsurg.2009.263>
- Mangipudi, S., Leather, A., Seedat, A., & Davies, J. (2020). Oxygen availability in sub-Saharan African countries: A call for data to inform service delivery. *The Lancet Global Health*, 8(9), e1123–e1124. [https://doi.org/10.1016/S2214-109X\(20\)30298-9](https://doi.org/10.1016/S2214-109X(20)30298-9)
- Mbonye, A. K., Mutabazi, M. G., Asimwe, J. B., Sentumbwe, O., Kabarangira, J., Nanda, G., & Orinda, V. (2007). Declining maternal mortality ratio in Uganda: Priority interventions to achieve the millennium development Goal. *International Journal of Gynecology & Obstetrics*, 98(3), 285–290. <https://doi.org/10.1016/j.ijgo.2007.05.019>
- Mbonye, A. K., & Asimwe, J. B. (2010). Factors associated with skilled attendance at delivery in Uganda: Results from a national health facility survey. *International Journal of Adolescent Medicine and Health*, 22(2), 249–256. <https://doi.org/10.1515/IJAMH.2010.22.2.249>
- Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Group, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, 6(7), e1000097. <https://doi.org/10.1371/journal.pmed.1000097>
- Morrissey, B., Conroy, N., & Estelle, A. (2015). G260(P) Effect of solar panels on in-patient paediatric mortality in a district hospital in Sierra Leone. *Archives of Disease in Childhood*, 100(Suppl 3), A114–A114. doi:10.1136/archdischild-2015-308599.253
- Mubyazi, G. M., Bloch, P., Byskov, J., Magnussen, P., Bygbjerg, I. C., & Hansen, K. S. (2012). Supply related drivers of staff motivation for providing intermittent preventive treatment of malaria during pregnancy in Tanzania: Evidence from two rural districts. *Malaria Journal*, 11(1), 1–14. <https://doi.org/10.1186/1475-2875-11-48>
- Neal, D., Ding, Y., Bello, I., Han, R., Byamukama, M., Kebir, N., McCulloch, M., Rogers, D., Nyamongo, I., & Waweru, K. (2020). Demand Side Energy Management and Customer Behavioral Response in a Rural Islanded Microgrid. 2020 IEEE PES/IAS PowerAfrica, 1–5.
- Osman, A. K., Ibrahim, M., Elsheikh, M., Karrar, K., & Salih, H. (2021). Saving the fundamentals: Impact of a military coup on the Sudan health system. *Sudan Journal of Medical Sciences*, 16(4), 567–573. doi:10.18502/sjms.v16i4.9959
- Ouedraogo, I., Jiya, A. N., & Dianda, I. (2021). Access to electricity and health capital accumulation in Sub-Saharan Africa. Conference Paper: 2021 International Development Economics Conference (ICDE2021). <https://doi.org/10.13140/RG.2.2.28833.22882>
- Owili, P. O., Muga, M. A., Mendez, B. R., & Chen, B. (2019). Quality of care in six sub-Saharan Africa countries: A provider-based study on adherence to WHO's antenatal care guideline. *International Journal for Quality in Health Care*, 31(1), 43–48. <https://doi.org/10.1093/intqhc/mzy105>
- Poore, P. (1988). Vaccination strategies in developing countries. *Vaccine*, 6(5), 393–398. [https://doi.org/10.1016/0264-410x\(88\)90136-3](https://doi.org/10.1016/0264-410x(88)90136-3)
- Ramírez, N. A., Ruiz, J. P., Romero, R. V., & Labonté, R. (2011). Comprehensive primary health care in South America: Contexts, achievements and policy implications. *Cadernos de Saúde Pública*, 27(10), 1875–1890. <https://doi.org/10.1590/S0102-311X2011001000002>

- Remson, J. (2015). Rural energy development: Are mini-grids the solution to East Africa's energy crisis. CUNY Academic Works. https://academicworks.cuny.edu/cc_etds_theses/359
- Rodríguez-Pose, A., & Hardy, D. (2015). Addressing poverty and inequality in the rural economy from a global perspective. *Applied Geography*, 61(Spatial Inequality), 11–23. <https://doi.org/10.1016/j.apgeog.2015.02.005>
- Spiegel, D. A., Choo, S., Cherian, M., Orgoi, S., Kehrer, B., Price, R. R., & Govind, S. (2011). Quantifying surgical and anesthetic availability at primary health facilities in Mongolia. *World Journal of Surgery*, 35(2), 272–279. <https://doi.org/10.1007/s00268-010-0904-7>
- Stang, A. (2010). Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *European Journal of Epidemiology*, 25(9), 603–605. <https://doi.org/10.1007/s10654-010-9491-z>
- Swanson, D., Lokangaka, A., Bauserman, M., Swanson, J., Nathan, R. O., Tshetu, A., McClure, E. M., Bose, C. L., Garces, A., & Saleem, S. (2017). Challenges of implementing antenatal ultrasound screening in a rural study site: A case study from the Democratic Republic of the Congo. *Global Health: Science and Practice*, 5(2), 315–324. <https://doi.org/10.9745/GHSP-D-16-00191>
- Troeger, C., Forouzanfar, M., Rao, P. C., Khalil, I., Brown, A., Swartz, S., Fullman, N., Mosser, J., Thompson, R. L., Reiner, R. C., Abajobir, A., Alam, N., Alemayohu, M. A., Amare, A. T., Antonio, C. A., Asayesh, H., Avokpaho, E., Barac, A., Beshir, M. A., . . . Mokdad, A. H., & GBD 2015 LRI Collaborators. (2017). Estimates of the global, regional, and national morbidity, mortality, and aetiologies of lower respiratory tract infections in 195 countries: A systematic analysis for the global burden of disease study 2015. *The Lancet. Infectious Diseases*, 17 (11), 1133–1161. [https://doi.org/10.1016/S1473-3099\(17\)30396-1](https://doi.org/10.1016/S1473-3099(17)30396-1)
- Turnbull, H., Conroy, A., Opoka, R. O., Namasopo, S., Kain, K. C., & Hawkes, M. (2016). Solar-powered oxygen delivery: Proof of concept. *The International Journal of Tuberculosis and Lung Disease*, 20(5), 696–703. <https://doi.org/10.5588/ijtld.15.0796>
- United Nations. 2005. *Statement of H.E. Mr. Jean Ping, President of the 59th Session of the General Assembly, on the Occasion of World Health Day*. <https://www.un.org/en/ga/president/59/pdf/statements/20050407-health.pdf> [Accessed 12 May 2022]
- United Nations Foundation. (2019). *Lasting impact sustainable off-grid solar delivery models to power health and education*. United Nation Foundation and SE4ALL Report.
- WHO. (2018). *Energy access and resilience*. <https://www.who.int/teams/environment-climatechangeand-health/air-quality-and-health/sectoral-interventions/health-care-activities/health-risks>
- WHO. (2019). *Global action plan on physical activity 2018-2030: More active people for a healthier world*. World Health Organization. <https://apps.who.int/iris/bitstream/handle/10665/272722/9789241514187-eng.pdf>
- WHO. (2021). *Harmonized health facility assessment (HHFA) [Organization]*. World Health Organization (WHO). <https://www.who.int/data/data-collection-tools/harmonized-healthfacilityassessment/introduction>
- WHO. (2022). *Children: Improving survival and well-being*. <https://www.who.int/newsroom/factsheets/detail/children-reducing-mortality>
- WHO, & The World Bank. (2014). *Access to modern energy services for health facilities in resource-constrained settings: A review of status, significance, challenges and measurement*. World Health Organization. <https://apps.who.int/iris/handle/10665/156847>
- The World Bank. (2022). *World Bank country and lending groups – World Bank data help desk*. <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-countryandlending-groups>