Access to
Modern Energy Services for Health Facilities in Resource-Constrained Settings

A Review of Status, Significance, Challenges and Measurement

World Health Organization

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Photos

- *Cover:* Dr. Sidiki Toe with a new solar panel capable of powering a fridge and electric lights at the Kaara health centre, Mali (Photo: Abbie Trayler-Smith, Panos).
- *Chapter 1 cover:* Masougbo Chiefdom Primary Health Unit, Bombali District, Sierra Leone: During the rainy season and at night, the work of midwife Zainab Manserray is facilitated through the use of solar lighting (Photo: Abbie Trayler-Smith/H4+/Panos).
- *Chapter 2 cover:* An Ugandan nurse vaccinates a woman shortly after giving birth in a room illuminated by a solar-powered electric light affixed to the ceiling (Photo: Sam Wamani/Innovation Africa).
- *Chapter 3 cover, top:* Health worker performs a check-up at a newly-electrified health clinic in Ban Nongbuakham, Thakek District, Khammouane Province, Lao PDR (Photo: Bart Verweij / World Bank).
- *Chapter 3 cover, middle:* In Port-au-Prince, Haiti, technicians prepare to analyze stained sputum smears for TB diagnosis using new, low-energy LED microscope technology (Photo ©FIND/M-C Gutierrez).
- *Chapter 3 cover, bottom:* A portable generator is readied to power equipment at the Fond Parisien Field Hospital, Haiti, established after the 2010 earthquake. Such generators are often the only power source off-grid or in emergency response (Photo: Marshall Segal).
- *Chapter 4 cover, top:* Transformers at a grid transmission station (Photo: Sozaijiten).
- *Chapter 4 cover, middle:* Construction workers adjust equipment for the photovoltaic solar power system on the roof of University Hospital of Mirebalais, Haiti (Photo: Jon Chew / Partners In Health).
- *Chapter 4 cover, bottom:* In Aloha, Nepal, nurses and a midwife test the LED light powered by their new modular PV solar system, dubbed the "solar suitcase" (Photo: Dr. Bradley Wong/We Care Solar).
- *Chapter 5 cover:* Industrial electrical control panel (Photo: iStock).
- *Chapter 6 cover, top*: Midwife student Sahr Philip Sheku examines a patient with the help of a small solar-powered light in Bombali District, Sierra Leone (Photo: Abbie Trayler-Smith /Panos).
- *Chapter 6 cover, middle:* Natural ventilation design of a new South African health facility aims to curb cross-infection of patients with drug-resistant TB (Photo: Geoff Abbott, Council for Scientific and Industrial Research [CSIR] in South Africa).
- *Chapter 6 cover, bottom:* At Rikshospitalet in Norway, skylights provide daylighting in the recovery room for post-operative patients, reducing electricity requirements (Photo: Joel Loveland, University of Washington Integrated Design Lab).
- *Chapter 7 cover:* Women wait to vaccinate their babies at a health clinic in Mali (Photo: Dominic Chavez/ WB/Flickr).

List of abbreviations and acronyms

AFREA	Africa Renewable Energy Access programme
AC	Alternating current
BCG	Bacillus Calmette-Guérin
CD4	Cluster of differentiation 4
CFL	Compact florescent light
CHP	Co-generation of heat and power
DC	Direct current
D&C	Dilation (or dilatation) and curettage
DECRG	Development Economics Research Group
DOTS	Directly Observed Treatment, Short-course (for tuberculosis)
DHS	Demographic and health surveys
EC	European Commission
ELISA	Enzyme-linked immunosorbent assay
GHO	Global Health Observatory
GTF	Global Tracking Framework for Sustainable Energy for All initiative
IEA	International Energy Agency
kWp	Kilowatt-peak
LED	Light-emitting diode
LSMS	Living Standards Measurement Study
MDG	Millennium Development Goal
NRHM	National Rural Health Mission
PM	Particulate matter
PV	Photovoltaic
SARA	Service Availability and Readiness Assessment
SE4All	Sustainable Energy for All
SPA	Service provision assessment
TB	Tuberculosis
TERI	The Energy and Resources Institute
UHFWC	Union Health and Family Welfare Centre
USAID	United States of America Agency for International Development

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Executive summary

1. Introduction

Universal health coverage and universal access to efficient modern energy services are both global development goals. Rarely, however, have they been explored in tandem. This document sets out key issues, opportunities and synergies for further exploration. The report is intended to inform the *Sustainable Energy for All (SE4All)* initiative, which aims to achieve universal access to energy by 2030 as well as double the rate of improvement in energy efficiencies and the share of renewable energy in the global energy mix. This report is particularly relevant to SE4ALL's new *High-Impact Opportunity (HIO) on Energy for Women's and Children's Health*, which aspires to improve availability and quality of essential maternal and child health care through the scale-up of energy access in health facilities. This report lays the groundwork for further work and consultations leading to: the development of tools for better assessment of the state of energy access in resource-constrained health facilities; design of interventions; and measurement and monitoring of progress. Although household energy access has been a focus of increasing attention, access to energy for health facilities has received much less emphasis. Health facilities are community institutions where access to adequate, reliable and sustainable energy is particularly important. Energy access is a critical enabler of access to medical technologies, and thus an important determinant of the effective delivery of essential health services. Without energy, many life-saving interventions simply cannot be undertaken. This poses barriers to the attainment of universal health coverage as well as to key health-related Millennium Development Goals (MDGs).

Reliable data on energy access in health facilities is currently very sparse. WHO and other international and bilateral agencies support limited monitoring and measurement of energy access in health facilities in the context of facility infrastructure surveys. Some studies by the World Bank and other agencies have looked at indicators of health-sector energy access in community development contexts. But a better understanding of the multidimensional linkages between energy and health service delivery is needed. This report examines the energy needs of health facilities in resource-constrained settings most commonly found in low-income countries or emerging economies. The report considers available evidence about inadequate energy supplies' impacts on health services as well as trends in the use of energy technologies. These are used to develop a rationale and approach for tracking and monitoring energy access in health facilities.

This report's findings are most relevant to clinics and health centres at the primary and secondary tiers of health systems, many of which struggle to access sufficient energy to power lighting, refrigeration and a few basic medical devices. Access to reliable electricity, however, is also a severe problem at higher levels of the health services chain, including large urban hospitals. While the energy needs of larger facilities are inevitably more complex, many of the messages and findings presented here are relevant for hospitals. The broader aim of this report is to support better measurement, monitoring and design of energy interventions that optimizes delivery of health services at all levels.

2. Energy as an enabler of universal access to health care

Why energy is important for delivery of health services

Good health is integral to attainment of the Millennium Development Goals (MDGs). The health-related MDGs have focused the world's attention on the need for expanded access to skilled care, essential medicines and medical technologies for priority diseases and health conditions. Comparatively less attention, however, has been given to energy's vital role as an enabler of health care delivery, and particularly the lack of electricity access in many resource-constrained health facilities. Yet available data and anecdotal examples indicate that even the most basic modern energy services are often unavailable in thousands of facilities across the developing world, including lighting for child delivery and emergency night-time care, refrigeration for blood and vaccines, sterilization facilities, and electricity for simple medical devices.

The growing need to fight noncommunicable diseases that require complex interventions will drive additional energy requirements (for example, imaging equipment for cancer detection). Besides playing a key role in delivery of health services, facilities that have access to electricity may be better positioned to attract and retain skilled health workers, especially in rural areas. Electricity also enables mobile- and tele-health applications, and facilitates public health education and information. Modern energy provision is therefore a critical enabler of universal access to health care and universal health coverage.

Current status of electricity access in health facilities: measurement and available data

Reliable data is sparse. A WHO-led review found nationally representative data for only 14 developing countries globally, 11 of them in sub-Saharan Africa. Even this data set, however, yields striking results. On average, one in four sub-Saharan health facilities had no access to electricity (Adair-Rohani et al, 2013). Only 28% of health facilities and 34% of hospitals had what could be called "reliable" access to electricity (without prolonged interruptions in the past week). WHO's new Service Availability and Readiness Assessment (SARA) provides a consistent methodology for country-led monitoring of health service delivery, and has supported over a dozen surveys in Africa. Other health partners, such as the GAVI Alliance and the Global Fund to Fight AIDS, Tuberculosis and Malaria, have recently joined WHO to expand the survey base further in Africa and South-East Asia. These surveys have refined data collection on electricity access, reliability, and major sources of supply (e.g. grid, generators, solar). However, further improvements in energy survey tools would support more refined analyses of energy issues.

Research into links between energy access and health services provision

The very few studies that have been conducted indicate that electricity access may have a significant impact on some key health service indicators, such as: prolonging night-time service provision; attracting and retaining skilled health workers to a facility; and providing faster emergency response, including for childbirth emergencies. This report analyses the available evidence.

Few studies, however, have systematically examined the impacts of energy access at health facilities on health services provision – and fewer still have looked at treatment outcomes. Impacts on health outcomes are particularly difficult to measure due to the many confounding factors, including staff skills and knowledge, availability of medicines, proximity to treatment and time lag before measureable improvements. Better data collection can help facilitate research into the linkages between reliable electricity access and major health-care priorities such as improving maternal and child health and reducing mortality.

A kerosene lamp *illuminates a community pharmacy in Nigeria. Despite the impacts of kerosene smoke on both health and climate, such lamps remain the only lighting option for countless health clinics as well as homes in the developing world. (Photo: World Bank)*

3. Energy requirements in health facilities: a closer look

Electricity needs for health services and medical equipment

Health facilities may provide a wide range of health services, such as obstetric care, immunizations, basic emergency treatment and surgical services. Each of these may require specific equipment, trained staff and medicines. Defining essential energy needs in relation to all aspects of health service delivery has yet to be undertaken systematically. WHO's SARA and similar infrastructure survey tools are used by national health ministries, as well as multilateral and bilateral agencies, to conduct detailed monitoring of equipment available in health facilities in relation to their provision of specific services. Better definition of device electricity requirements is needed to help drive appropriate design of energy supply-side solutions. The recent emergence of more energy-efficient medical devices that can operate from low-power battery and solar panel sources creates exciting new opportunities to improve energy access using demand-side measures. Examples range from obstetrics devices such as fetal heart monitors to LED microscopes for TB smear microscopy and a new generation of WHO-pre-qualified solar-powered "direct-drive" vaccine refrigerators. Direct-drive refrigerators use solar electricity to power a cooling system that freezes ice or some other phase-change material rather than storing energy in a battery. This keeps the refrigerator at a stable temperature when solar power is not available while eliminating the expense of battery replacement. More systematic review and continuous updating of the energy performance requirements for essential technologies is thus important.

Thermal energy needs of health facilities

In addition to electricity for medical devices, appliances and facility support functions (such as lighting and water pumping), health facilities have thermal energy needs for cooking and water heating, sterilization, space heating and incineration of medical waste. Such needs are more significant in larger health facilities delivering more complex health services or offering inpatient services. Among high-income and grid-connected health facilities, thermal energy needs may be met using electricity and increasingly by high-efficiency co-generation of heat and power (CHP) systems. More commonly, thermal energy needs are supplied through direct combustion of fossil fuels (diesel, gas, coal and biomass) using on-site boilers; inexpensive thermal solar panels also can provide hot water for hygiene and space heating. Improving the energy efficiency of buildings can greatly reduce thermal energy needs as well as electricity requirements.

4. Electricity supply in health facilities: trends and opportunities

Grid-based electricity supply and on-site electricity production

Hospitals and clinics located near an electricity grid connection have traditionally relied on grid power as a primary energy source. Yet power failures or outages during periods of peak demand are a problem even in grid-connected cities and regions. This forces clinics to rely on expensive backup generators – or to remain without power.

In off-grid settings, stand-alone diesel-powered generators have been the most common solution, backed up mostly by kerosene lamps, candles or flashlights. Generators, however, are expensive to operate due to the increasingly high cost of fuel and its transport and storage. As equipment maintenance also may not be locally available, the unreliability of generators is thus a major issue. In a recent WHO survey of data from six large sub-Saharan African countries, less than 30% of stand-alone diesel generators were functional with fuel available on the day of the survey.

Generators also produce significant waste heat, which is essentially wasted energy. Small on-site diesel generators tend to be particularly inefficient. They produce high proportions of health-harmful particulate matter (PM) and CO_2 emissions per kWh of power generation, contributing to air pollution exposures as well as to climate change. Conventional thermal grid power generation is also an energy-inefficient process, generating significant waste heat during power production and thermal losses during transformation and long-distance transmission. More than two-thirds of input energy may thus be wasted in a conventional coal- or oil-fired power plant. Finally, grid power access does not alleviate the need for on-site generators, because all health facilities that offer emergency care, childbirth management or surgical procedures also require backup power. Regulatory or accreditation requirements typically make on-site power mandatory for such facilities.

Overall, energy and fuel costs in many developing countries are high compared to per-capita income levels. While few reviews of health-sector energy costs have been undertaken, these costs appear to consume a significantly larger proportion of operating budgets than in comparable developed-country settings. Such stresses have been exacerbated by fossil fuel price increases over the past decade.

Increasing role of solar power in health facilities

As the costs of renewable energy technologies fall, they are more affordable for health facilities, both as a primary or backup energy sources. This is particularly true in the case of photovoltaic (PV) solar power. The recent WHO-led review of sub-Saharan African health facilities found a trend towards increasing use of on-site PV solar either as a primary or backup electricity source. In Uganda, some 15% of hospitals used PV solar to complement grid electricity access, and in Sierra Leone, 36% of all health facilities and 43% of hospitals used solar systems in combination with other electricity sources (Adair-Rohani et al, 2013). In Liberia, a country with little grid coverage beyond the capital city, the pace of solar electrification has outstripped that of other power sources; in 2012, more first-line public health clinics used PV solar than generators as their primary energy source. While PV systems are limited in capacity, they appeared to offer somewhat greater reliability: more solar-equipped clinics reported having electricity available on the survey day compared with those using diesel generators as their primary source.

The interest in solar has been stimulated by the increasing range of direct-current (DC) medical devices and appliances that can be charged from PV solar panels. Major donors, such as UNICEF are making solar refrigerators a major procurement item for vaccine refrigeration. Solar systems are also being purchased in bulk by the Global Fund to Fight AIDS, Tuberculosis and Malaria, often to power TB diagnostics. A number of NGOs have developed inexpensive portable solar systems designed for off-grid health clinics' basic lighting and communications needs, particularly to support childbirth and emergency services.

Emerging solutions: Hybrid systems to limit fuel costs, climate-changing emissions and pollution

Hybrid energy applications are of increasing interest among energy experts. For small and mid-size health clinics, well-managed hybrid solar-diesel systems can achieve lifetime fuel savings on an order of 75–80% while ensuring reliable electricity supply. Small-scale energy management systems can shift efficiently between different energy sources so clinics harness sunlight during most operating hours, but benefit from automatic generator backup in peak periods or when solar storage has been depleted. Insofar as diesel fuel use is reduced, such systems reduce CO_2 as well as particulate emissions that are harmful to health. Diesel particulate emissions also contain considerable amounts of black carbon, a short-lived climate pollutant whose mitigation can reduce near-term climate change impacts.

High capital cost barriers to initial solar energy investments

Despite their potential long-term appeal, renewable or hybrid energy systems still require greater capital investments by health facilities than conventional generators. This poses a significant barrier to change.

Other barriers to effective uptake of PV solar include security issues, inadequate budgets in small clinics for replacement of solar system batteries and spare parts, and lack of technical capacity to troubleshoot and perform equipment maintenance. More advanced and robust battery technologies also are needed; the lead-acid batteries most commonly available have short lifespans in hot climates and present waste disposal issues. Health-care facilities have not traditionally viewed energy services as a "core function" – although increased recognition of its role in modern health care can open up new opportunities for innovation. Finally, innovative financial solutions are needed to overcome capital cost barriers to the deployment of clean, energy-efficient systems in health facilities that harness renewable energy capacities.

Health facilities as energy providers

With better access to new technologies and financial models to ensure system sustainability, health facilities can become "anchors" for distributed energy generation in their communities, stimulating even wider development co-benefits.

While small and mid-size clinics are the major focus of this report, hospitals, which have a very large and constant need for energy, can also benefit from investments in efficient on-site energy systems. Combined heat and power systems (CHP), increasingly common in the hospital sectors of the United States of America and Europe, also are attracting interest in emerging economies such as India and Brazil. When these are fuelled by natural gas, CO_2 and PM emissions are very low, and use of energy inputs is extremely efficient since waste heat is captured for building use. On-site hydroelectric power systems have also been developed by some African hospitals. When such systems produce electricity at a lower lifetime cost and higher rate of reliability, resource use and service delivery are both improved.

However, business models suitable for health facilities in resource-constrained settings need to be devised for making and maintaining investments in energy-efficient hospitals and in reliable and efficient energy systems.

In grid-connected areas, "feed-in" tariffs can facilitate the sale of surplus electricity produced on-site by a health facility to the grid; other forms of incentives can make energy efficiency investments more attractive. To finance new investments, more and more hospitals in North America and Europe have become partners in "power purchase agreements" (PPAs) whereby energy utilities or other investors pay to construct and operate a CHP, wind or solar installation on the hospital premises. The health facility receives a guaranteed supply of power at a fixed rate in a long-term lease arrangement – and any surplus (e.g. from off-peak periods) is sold by the utility. In off-grid settings, some NGOs have supported health clinics to create micro-enterprises that mimic such arrangements on a very small scale. In this approach, the clinic is equipped with a solar system and a small proportion of the power generated is used to charge community cell phones. Fees collected are used to finance system maintenance, including replacement of critical spare parts such as light bulbs and batteries – ensuring long-term operational sustainability.

Stimulating investments in power solutions

Decisions about which on-site energy solutions are needed are based on a wide range of factors. These include: electricity and other energy requirements; reliability and quality of grid supply (if available); local availability of other energy technologies or fuels; and the capital and operating costs of grid versus on-site supply options.

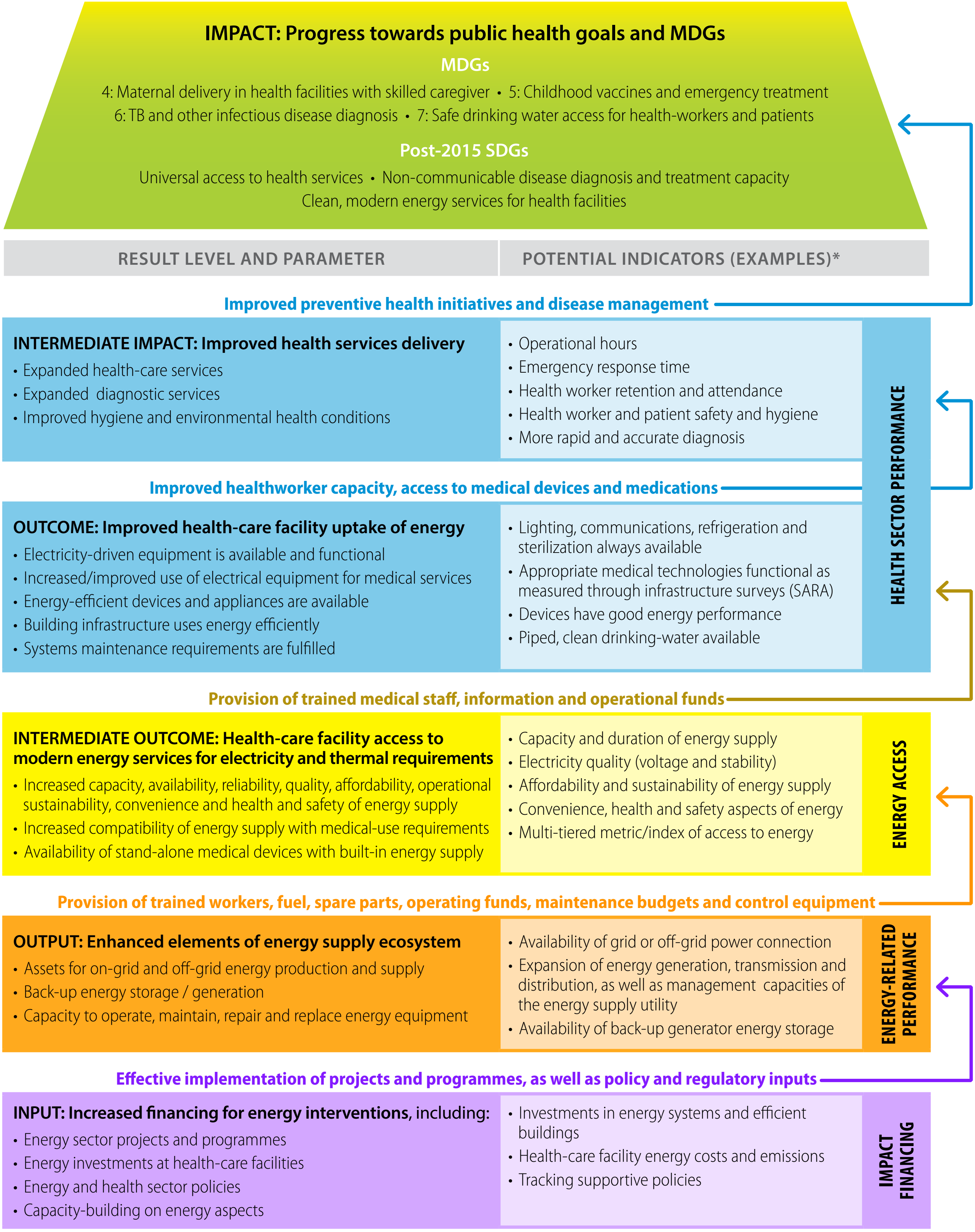
Partnerships between the health and energy sectors are mutually beneficial in overcoming barriers to new modes of energy provision. Partnership models that are becoming increasingly common in developed countries need to be considered and adapted for resource-constrained settings. Health services may thus gain more reliable and less expensive energy sources, and investors can secure from health facilities an institutional commitment to long-term repayment of capital investments. These arrangements can be supported by public policies such as grants and soft financing to mitigate high cost barriers, as well as by structured products that securitize budgetary allocations for diesel fuel procurement towards repayment of capital investment loans on energy-efficient alternatives.

A proposed energy results chain for appropriate energy delivery

Energy initiatives in health facilities may range from stand-alone off-grid and micro-grid solutions using a mix of renewable and/or fossil fuel-based technologies to large-scale grid expansion around centralized power plants. In all cases, the principles of effective energy delivery remain similar. Fuel distribution systems (for fossil fuel-based power generation), availability of spare parts and skilled staff to maintain all energy systems are critical for sustained operation. Effective delivery of energy also requires a strong energy supply ecosystem encompassing laws, policies, regulations, markets and institutions to support equitable access to energy, its efficient use and a transparent payment system. Finally, within the facility itself, an appropriate suite of medical devices and appliances, as well as skilled staff to maintain and operate equipment, are required.

An *energy results chain framework for health services* (see figure below) illustrates the pathways by which modern energy investments enable improved health services delivery. Of course, improved electricity supply and use is not a panacea. Effective health services delivery and ultimately health outcomes depend on many variables, including: an appropriate mix of preventive and curative services; availability of trained health-care personnel; access to medicines; and medical equipment and support systems. In a world of increasingly complex medical technologies, access to modern energy services, particularly electricity, can certainly enhance the range and quality of health services provided.

Energy results chain framework for health services



IMPACT: Progress towards public health goals and MDGs

MDGs

4: Maternal delivery in health facilities with skilled caregiver • 5: Childhood vaccines and emergency treatment
6: TB and other infectious disease diagnosis • 7: Safe drinking water access for health-workers and patients

Post-2015 SDGs

Universal access to health services • Non-communicable disease diagnosis and treatment capacity
Clean, modern energy services for health facilities

RESULT LEVEL AND PARAMETER | POTENTIAL INDICATORS (EXAMPLES)*

Improved preventive health initiatives and disease management

HEALTH SECTOR PERFORMANCE

INTERMEDIATE IMPACT: Improved health services delivery

- Expanded health-care services
- Expanded diagnostic services
- Improved hygiene and environmental health conditions

- Operational hours
- Emergency response time
- Health worker retention and attendance
- Health worker and patient safety and hygiene
- More rapid and accurate diagnosis

Improved healthworker capacity, access to medical devices and medications

OUTCOME: Improved health-care facility uptake of energy

- Electricity-driven equipment is available and functional
- Increased/improved use of electrical equipment for medical services
- Energy-efficient devices and appliances are available
- Building infrastructure uses energy efficiently
- Systems maintenance requirements are fulfilled

- Lighting, communications, refrigeration and sterilization always available
- Appropriate medical technologies functional as measured through infrastructure surveys (SARA)
- Devices have good energy performance
- Piped, clean drinking-water available

Provision of trained medical staff, information and operational funds

ENERGY ACCESS

INTERMEDIATE OUTCOME: Health-care facility access to modern energy services for electricity and thermal requirements

- Increased capacity, availability, reliability, quality, affordability, operational sustainability, convenience and health and safety of energy supply
- Increased compatibility of energy supply with medical-use requirements
- Availability of stand-alone medical devices with built-in energy supply

- Capacity and duration of energy supply
- Electricity quality (voltage and stability)
- Affordability and sustainability of energy supply
- Convenience, health and safety aspects of energy
- Multi-tiered metric/index of access to energy

Provision of trained workers, fuel, spare parts, operating funds, maintenance budgets and control equipment

ENERGY-RELATED PERFORMANCE

OUTPUT: Enhanced elements of energy supply ecosystem

- Assets for on-grid and off-grid energy production and supply
- Back-up energy storage / generation
- Capacity to operate, maintain, repair and replace energy equipment

- Availability of grid or off-grid power connection
- Expansion of energy generation, transmission and distribution, as well as management capacities of the energy supply utility
- Availability of back-up generator energy storage

Effective implementation of projects and programmes, as well as policy and regulatory inputs

IMPACT FINANCING

INPUT: Increased financing for energy interventions, including:

- Energy sector projects and programmes
- Energy investments at health-care facilities
- Energy and health sector policies
- Capacity-building on energy aspects

- Investments in energy systems and efficient buildings
- Health-care facility energy costs and emissions
- Tracking supportive policies

* Note: Further research is needed to define the health outcome indicators most closely related to sustainable energy provision.

5. Improving measurement of electricity access in health facilities

The need for improved measurement and monitoring of electricity access

Traditionally, electricity access in health facilities was measured using only a few basic indicators, such as: a) availability of a grid connection and b) availability of a backup generator with fuel. Although convenient, such indicators fail to clarify important dimensions of energy supply issues, as illustrated in this report and summarized in Fig. 1, *Energy Results Framework.* As a next step forward, Chapter 5 considers a more refined measurement framework to systematically capture the key characteristics of a cost-effective and sustainable electricity supply for health facilities. Such measurement and monitoring should capture a wide range of valuable indicators and information useful for assessing energy needs and gaps, effectiveness of different energy interventions, and progress in improving access against defined baselines.

Defining the main attributes of electricity supply

Improved measurement and monitoring of energy supplies should yield data on whether facilities have sufficient power capacity to run all critical support functions (e.g. lights, water pumping) and available appliances during all working hours while maintaining stable voltage and without significant power outages (reliability). In addition, the system needs to have sufficient funding and personnel for operation and maintenance. The key attributes of electricity supply might be summarized as: (i) power capacity (including peak power capacity and daily energy capacity), (ii) duration (including daily duration of supply and evening supply), (iii) power quality (minimal fluctuations in voltage, current and frequency), (iv) reliability of supply, (v) affordability, and (vi) sustainability (operational and environmental).

Enhanced health clinic surveys and data collection tools

Measuring electricity access based on these attributes of supply requires improved data collection parameters in health facility surveys. One way to accomplish this is by integrating more energy indicators into routine annual health facility infrastructure surveys performed by ministries and donors. The World Health Organization's recent SARA surveys have already been undergoing refinement in this direction, capturing a wider range of electricity sources (e.g. solar) and some basic indicators of power capacity and reliability. In addition, a comprehensive stand-alone "energy survey module" is proposed here as a means of baseline energy measurement and regular tracking of energy issues (Annex 1). This approach can help to advance more refined measurement of the electricity supply performance in relation to the energy requirements of the health facility.

6. A 'multi-tier metric' to track electricity access in health facilities

This chapter describes a method for aggregating the data on different attributes of electricity supply, as gathered from improved survey tools, into a standardized *electricity access tier* for the health facility, which is then comparable across groups of facilities or countries. Such a rating would represent the cumulative impact of deficiencies in different attributes on the usability of such supply for various needs. The approach is based on a *multi-tier framework* (Tiers 0–5) that specifies the minimum levels of attributes at each tier, with higher tiers representing progressively greater access to a larger, more reliable and more sustainable power capacity. The system permits systematic assessment of the proportion of health facilities with differing degrees of access to energy supplies and comparisons among groups of health facilities within and across countries. A weighted aggregation of the proportion of health facilities falling into each of the tiers can yield an *index of access to electricity in health facilities*. Such an index collapses the tier ratings across multiple health facilities into a single indicator, allowing easier comparisons of electricity access status across countries and of progress in improving electricity access over time.

Limitations of the multi-tiered approach

Monitoring access to energy in terms of attributes of electricity supply has limitations. The system does not consider thermal energy demands. Nor does it define at what threshold levels health facilities of various sizes have "adequate" access to electricity or adequate access for night-time or 24-hour services. Issues related to electricity access in high-end facilities are not as well reflected in the tier system. While certain health and sustainability factors are captured in terms of PM and CO_2 emissions from the power systems, building-related energy efficiencies are not comprehensively reflected.

Tracking demand-side factors in relation to supply

Ideally, electricity supply should be tracked in relation to electricity requirements (for both essential building functions and medical appliances/devices). This is challenging due to the wide diversity in health services between countries as well as differences in access to medical technologies. Health systems have varying national priorities and funding for procurement of medical equipment. Demand-side energy efficiencies, ranging from higher-performing energy systems to more energy-efficient buildings, as well as improved user behaviors (e.g. turning off lights, computers on standby), can significantly reduce building energy demands and improve overall access to energy. As a result, no universal prescriptive standard exists for the minimum capacity of electricity or thermal energy systems that should be available to health services at different levels of the health system. Future work should lead to a more comprehensive analysis of demand-side energy factors that defines thresholds for such minimum energy provision.

7. Next steps and conclusions

Going forward, two parallel tracks can be envisaged for further improving health facilities' access to energy.

I. Improved monitoring of energy access

- Effective tracking of energy access requires piloting, validation and broader application of a measurement framework, such as the multi-tiered metric described here. Harmonization of approaches, indictors and data collection efforts is another important aspect. Better monitoring data also is important to research and scale-up of energy access.

II. Scaling up energy access

- **Research:** Additional research is needed to refine tracking tools and better define the optimal energy technologies suitable for health facilities in resource-constrained settings. More research is also needed to better establish the benefits of energy access to improved health services delivery. This would support prioritization of energy investments towards facilities and services most in need.
- **Policy and finance innovation:** Health and energy sectors need to design new policies, standards and regulations to support procurement, installation, and sustainable operation of energy technologies, as well as innovative financing structures to catalyse investment in modern energy systems. Policies should also foster research and development (R&D) into efficient medical technologies.
- **Capacity-building:** Health systems need to strengthen capacity of health facility managers to procure, implement and operate energy systems.

An overarching theme of this report is the need for closer cooperation between health and energy sectors. Greater awareness of the serious gaps in energy access that currently exist should stimulate policymakers to action. SE4All initiatives, especially the *High Impact Opportunity on Energy for Women's and Children's Health* can help catalyse collaborations between energy actors and mainstream health sector programmes on maternal and child health, as well as in other critical areas of disease prevention and control. This joint WHO and World Bank report aims to sow the seeds for such fruitful cooperation in this long-neglected domain.

1

Introduction

Access to adequate, reliable, sustainable and affordable modern energy services is crucial for socioeconomic development. Such energy access facilitates basic household comforts, reduces drudgery and promotes poverty reduction, and contributes to rural development, health and well-being, education, food security and gender empowerment, among other benefits. The *Sustainable Energy for All (SE4All)* initiative aims to achieve by 2030: universal access to modern energy services for households, productive uses and community applications; doubling the global rate of improvement in energy efficiency; and doubling the share of renewable energy in the global energy mix. Although household access to modern energy has received increasing attention over the past decade, access to energy for community and productive uses has not been highlighted as prominently nor tracked as closely.

This study focuses on health facilities as an important subset of community institutions where access to adequate, reliable and sustainable energy requires particular attention. Energy in health facilities is a critical enabler of universal access to health services. Without energy, many life-saving interventions cannot be undertaken – creating a barrier to the attainment of universal health coverage as well as key health-related Millennium Development Goals (MDGs). Many rural health facilities suffer from acute shortages of energy to power basic services such as lighting, communications, refrigeration, diagnostics and medical devices required for safe childbirth and treatment of illness or injury. District health facilities often lack reliable power for essential laboratory and medical equipment. Many hospitals also operate with only intermittent grid electricity provision or suffer from chronic electricity failures that interrupt support systems such as lights, water and temperature control in laboratories and critical care and surgery units. Such electricity outages also can damage medical and diagnostic devices.

At the same time, power production and energy consumption in homes, workplaces and community service sites, including health facilities, cause multiple environmental health risks (Wilkinson & Markandya, 2007; Wilkinson et al., 2007). WHO estimates that household air pollution from biomass and coal cookstoves causes millions of deaths each year (World Health Organization, 2008a). Such pollution is a contributing factor in nearly half of the pneumonia deaths among children under the age of 5, and among adults it is a leading cause of chronic lung disease, cardiovascular disease and some cancers (World Health Organization, 2009a; Lim et al., 2012). Cookstove pollution is also a risk in the institutional kitchens of schools and health facilities where coal or biomass stoves are used. Meanwhile, poorly designed electrical installations, common in countries with weak building regulation codes, increase risk of fire, electrocution and other safety issues.

The widespread use of kerosene for lighting in health facilities poses health risks in terms of high indoor air pollution emissions as well as safety issues similar to those in households (Mills, 2012). Well-documented kerosene hazards include poisonings, fires and explosions. Studies of kerosene used for cooking or lighting provide evidence that kerosene particulate emissions may impair lung function and increase risks of tuberculosis, asthma and cancer (Lam et al., 2012a). Chronic exposure to pollution from kerosene lamps is thus a concern for health workers as well as households (Mills, 2012; Lam et al., 2012a).

In terms of power generation, stand-alone diesel generators, a common backup and off-grid source of light and power, emit higher concentrations of CO_2 and particulates per unit of power generation than conventional grid power sources (Natural Resources Canada, 2008; Ani & Emetu, 2013; Edenhofer et al., 2011; Gilmore et al., 2010).[i] Globally, both stand-alone generators and kerosene lamps are significant sources of particles of black carbon, a short-lived climate pollutant whose contribution to total carbon emissions is particularly significant in developing countries. This is a growing concern to climate scientists in light of the widespread use of such generators for electrification in off-grid areas (Lam et al., 2012b; Scientific Advisory Panel, 2013).[ii]

Conventional large-scale coal- and oil-powered electricity generation is, however, also extremely energy-inefficient, due to the large loss of heat energy in electricity production and transmission (Sims, et al., 2007). Systems for more efficient co-generation of heat and power, which harness heat that otherwise would be wasted for building thermal needs, are becoming increasingly popular in developed countries, including in health facilities that can afford the capital investment (World Health Organization, 2011; Carbon Trust, 2013).

More energy-efficient design and construction of health facilities can generate further energy cost-savings as well as health co-benefits. For instance, improved use of natural ventilation in health facilities can help reduce transmission of airborne infectious diseases such as tuberculosis (Atkinson, et al., 2009). More generally, climate-adapted and energy-efficient building design helps reduce risks to vulnerable patients and health workers from heat stress, cold exposure, allergies and asthma (World Health Organization, 2011).

Energy is frequently required for pumping water, and thus for safe drinking-water access. Health care facilities are high-risk settings where basic water, sanitation and hygiene (WASH) services are prerequisites to effectively treat and prevent disease. Standard minimum water requirements in health facilities are 5 litres per patient consultation and 40–60 litres per inpatient per day, with 100 litres required for a basic surgical operation (World Health Organization, 2008).

In low and middle-income countries, WASH services in many health facilities are often extremely limited. Of the 66,101 facilities sampled from 54 countries in a recent analysis, 38% did not have access to an improved water source.[iii] Facilities in sub-Saharan Africa had the least access among all regions. In addition, 35% of facilities did not have water and soap for handwashing (World Health Organization, In Press). Inadequate WASH facilities compromises the ability to safely provide basic, routine health services, such as child delivery. It also can increase the risk of infection transmission among health workers, patients and

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[i] Gilmore et al. reported that municipal back-up diesel generators used to supplement power in urban areas during peak demand periods emitted 1.4 grams/kWh of $PM_{2.5}$, causing measurable health impacts on ambient air quality. Filtering generator exhaust or shifting to cleaner fuels can reduce emissions by 85–99%.

[ii] The Scientific Advisory Panel report of the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants notes: "The kerosene lamps commonly used in households in South Asia, Africa, and parts of Latin America have been confirmed to be a major source of indoor black carbon air pollution in these regions. Controlling this source would not only reduce air pollution, but also bring regional and global climate benefits. …. New information [also] shows that diesel generators are an important source of black carbon emissions in countries where public power supply lags behind electricity demand (e.g. India, Nepal and Nigeria). New evidence confirms that reducing black carbon emissions from diesel engines (both generators and vehicles) and some types of cook stoves provides clear climate benefits."

[iii] An improved drinking-water source is defined by WHO as a water source protected from outside contamination onsite or within 500 meters of the facility, and including: pipe water, public taps, standpipes, boreholes, protected springs and rainwater collection.

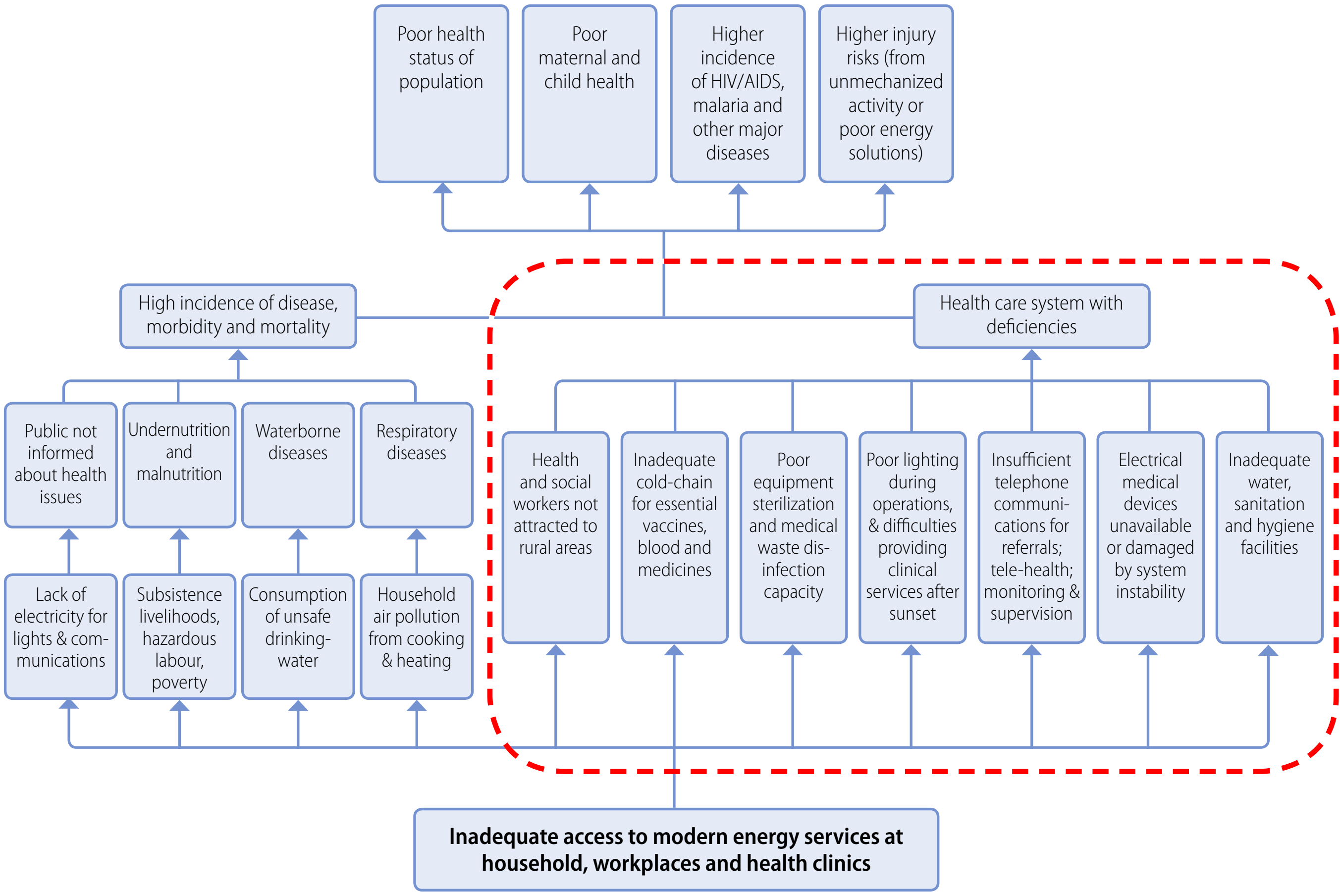
visitors. And lack of safe drinking-water access is the leading risk factor for diarrhoeal disease, one of the biggest killers of children under 5 years old (World Health Organization, 2008a).

Fig. 1 notes some of the broader linkages between access to clean, sustainable energy and public health generally, as well as in relation to health care facilities.

This report examines the energy needs of health facilities, available evidence of effects of inadequate energy supply on delivery of health services, and approaches for strengthening data availability on access to energy in health facilities.

The discussion is organized as follows. **Chapter 2** examines how adequate access to energy in health facilities is an enabler of universal access to health care, and presents available data on the status of energy access in health facilities in the developing country context. **Chapter 3** examines the diverse energy needs of health facilities based on infrastructure requirements and the health services they deliver. **Chapter 4** looks at trends in electricity supply options among on-grid and off-grid health facilities in energy-constrained countries, including renewable and energy-efficient solutions. **Chapter 5** highlights the need for improved measurement of electricity access in health facilities based on key characteristics (attributes) of electricity demand and supply. **Chapter 6** considers an improved metric for measuring electricity access to capture the key attributes of electricity supply. **Chapter 7** suggests next steps for improving the measurement and monitoring of electricity access in health facilities. Further analytic work is needed to explore how and where electricity access can best enhance delivery of health services and deliver improved health outcomes. These efforts ultimately aim to draw greater attention to the need to catalyze increased investment for improving electricity supply in health facilities.

Fig. 1. Impact of energy access on public health

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2

Energy as an enabler of universal access to health care

Health is both a prerequisite for and an outcome of sustainable development (United Nations, 2012). Good health is integral to attainment of all of the Millennium Development Goals (MDGs) (World Health Organization, 2013a). Three of the eight MDGs specifically address priority health issues, while other MDGs address health indirectly (Box 1).

Box 1. Health and the MDGs

Three MDGs relate specifically to critical health issues:

MDG 4: Reduce child mortality

MDG 5: Improve maternal health

MDG 6: Combat HIV/AIDS, malaria and other diseases

In addition, MDG 1 (Eradicate extreme poverty and hunger) has a clear health component linked to nutrition. Nutritional adequacy for children, pregnant women and lactating mothers is particularly important.

Also, Target 7C under MDG 7 (Ensuring environmental sustainability) aims to halve the proportion of people without sustainable access to safe drinking water and improved sanitation. This is the main risk factor for diarrhoeal diseases, one of the leading killers of children under the age of 5.

Health facilities are on the frontlines of disease control and response for:

- ***Infectious diseases of poverty and maternal/child health*:** Many primary care interventions have been developed and implemented, such as: HIV anti-retroviral treatment; DOTS, the 5-point package for "directly observed treatment" that is the central component of the Stop TB Strategy for tuberculosis; community-based distribution of antimalarial medication; oral rehydration for diarrhoea; scale-up of vaccines against polio, measles and other vaccine-preventable diseases; and training of/access to skilled midwives.
- ***Noncommunicable diseases:*** Addressing this growing burden in poor countries is a critical health concern: nearly 80% of deaths from cardiovascular diseases and diabetes and 90% of deaths from chronic obstructive pulmonary disease are now occurring in low- and middle-income countries (Alwan et al., 2011). In response, WHO and its Member States have significantly increased attention to and investment in prevention, diagnosis and treatment for conditions such as heart disease, cancer, diabetes, high blood pressure and chronic respiratory diseases like chronic obstructive pulmonary disease (World Health Organization, 2013).

Lack of electricity, however, remains a neglected barrier to effective provision of health services in many developing countries. Often-cited anecdotal examples include lack of lighting for child delivery, refrigeration for blood and vaccines, and of power for equipment sterilization, basic medical devices and provision of emergency and other services at night (Voluntary Service Overseas, 2012). Scale-up of noncommunicable disease prevention and control will require more energy than is available in many health facilities, particularly since NCD detection and treatment require additional equipment (e.g. imaging equipment for cancer detection).

Meanwhile, new medical technologies are creating opportunities to make more efficient use of available energy for improved health services. Examples include low-energy devices that can run on batteries or directly from solar panels; these range from small medical devices such as fetal heart monitors and blood glucose monitors to larger appliances such as solar-powered refrigerators. Optimal use of these emerging medical technologies requires access to cost-efficient and reliable energy sources.

Additionally, communication is a critical enabler of access to public health education and information in an era of rapid global and regional disease transmission, pandemic alerts and extreme weather. Mobile phone-based "tele-health" applications have been extremely effective in supporting activities such as remote health worker consultations, ongoing training and education, and home treatment for the elderly, disabled and chronically ill (Barlow et al., 2007; Wootton et al., 2009).

Improving public health requires universal health coverage as well as adequate access to health services. Strong and effective health facilities that offer a range of primary preventive and treatment services are crucial. A comprehensive framework for *Strengthening of health systems to improve health outcomes* was set forth by WHO (World Health Organization, 2007), and incorporated into a 2009 Member States resolution aimed at advancing primary health care, including health systems strengthening (World Health Organization, 2009b). It identified six key building blocks of health systems as:

- Service delivery
- Health workforce
- Information
- Medical products, vaccines and technologies
- Financing
- Leadership and governance

The provision of energy plays a key role in strengthening health systems across all of these areas. It is a critical enabler of health services delivery (e.g. lighting, powering medical equipment) and helps attract and retain skilled health workers, especially in rural areas (Practical Action, 2013). A European Commission (2006) study on renewable energy in the health sector summarizes how energy access can positively impact health and health service provision (Table 1).

Current status of electricity access in health facilities: available data

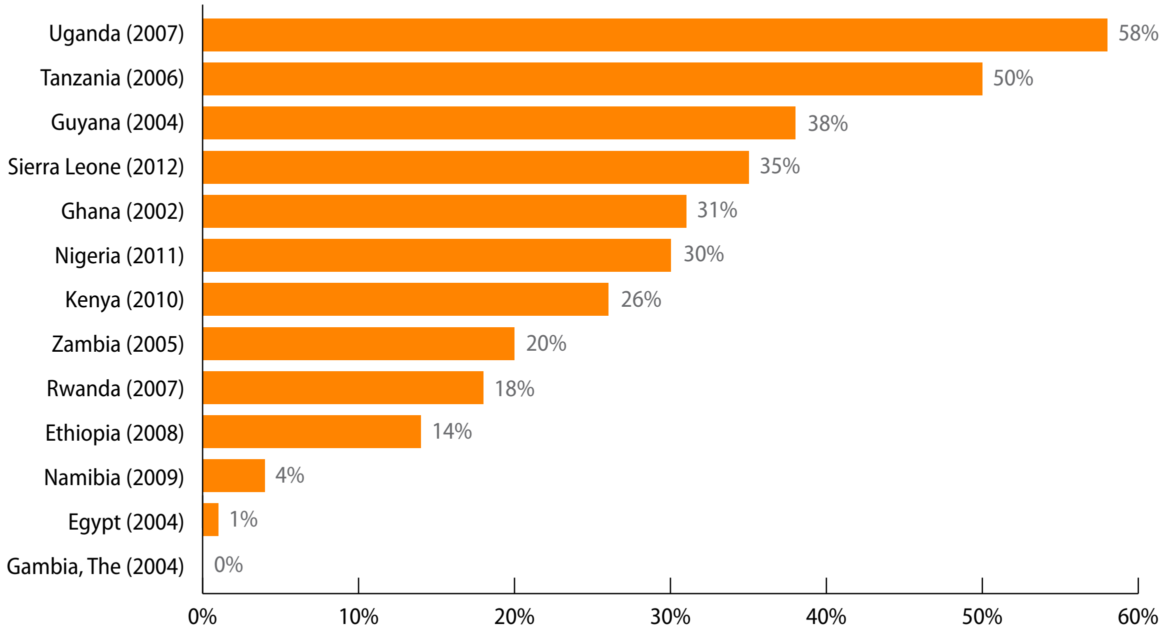
Reliable data on energy access among health facilities in developing countries is sparse. An initial WHO-led review (Adair-Rohani et al., 2013) found nationally representative data for only 14 developing countries globally; 11 of these were in sub-Saharan Africa (Fig. 2). However, even this slim set of data yields striking findings regarding the widespread lack of electricity access. Among the 11 African countries assessed an average of 26% of health facilities did not have any access to electricity. Only 34% of hospitals on average had "reliable" electricity (defined as no outages of more than two hours in the past week) across the eight countries for which such data was available. Little additional data was available on the capacity and quality of electricity supplies.

Table 1. Potential impacts of stable energy provision on health services performance

Medical services	• Prolonged opening hours with general lighting and security lights provided • Wider range of services implemented, because more qualified staff are attracted to stay • Improved emergency surgical services • Better obstetric emergency care (many maternal deaths are due to birthing complications) • Improved management of childhood illnesses • Better management of chronic conditions • Improved referral system (radio communication system between peripheral and referral units) • Better sterilization procedures leading to fewer complications • Improved planning and quality assurance
Health and safety	• General cleanliness improves with adequate lighting and water available • Inpatients feel more comfortable and secure • Staff feel more secure • Security lights provided during evening open hours
Disease prevention and treatment	• Improved cold chain and vaccine storage conditions will yield lower immunization failure rates and better immunization coverage • Improved testing for HIV and TB • Evening awareness sessions are possible with general lighting and TV/VCR
Staff recruitment and retention	• Better job satisfaction for staff because of better living and working conditions • Staff will want to stay longer in a place where there are better living and working conditions • Electricity in staff houses means continued medical education is possible • Easier recruitment of staff to locations with electricity and water • Easier to train staff because of improved lighting, equipment and TV/VCR
Administration and logistics	• Better administration, since it can be done in the evening • Better communication between health facilities and better planning of transport logistics

Source: *(European Commission, 2006).*

Fig. 2. Health-care facilities with no electricity access



Source: *Compiled from* (Adair-Rohani et al., 2013) *for sub-Saharan Africa; data for Guyana and Egypt is from the Service Provision Assessment (SPA) of USAID's Measure Health initiative* (United States Agency for International Development, 2013).

In countries with data from multiple years, progress in electrification was apparent. In Rwanda, for instance, the overall proportion of facilities with electricity access increased from 58% to 82% between 2001 and 2007, and in Kenya the proportion of facilities with electricity access increased from 65% to 74% between 2004 and 2010. More timely and detailed analysis can clarify current trends and highlight what works and what does not in terms of health sector energy provision.

Health facility infrastructure surveys typically cover a limited set of energy use indicators. These typically include whether a facility has grid access, a portable generator or a solar power source, and frequency of power interruptions. Such surveys are usually undertaken at national level by ministries of health, and at international level by WHO and other multilateral and bilateral health and development agencies (International Health Facility Assessment Network, 2013).

Among the early survey tools were the Service Provision Assessments (SPA) implemented under the MEASURE Demographic and Health Survey programme, supported by the U.S. Agency for International Development (2013) and WHO's Service Availability Mapping (SAM) (World Health Organization, 2009). A more recent tool, the Service Availability and Readiness Assessment (SARA), developed jointly by WHO and USAID, aims to harmonize diverse approaches to facility assessment in a freely available tool supported by WHO-led training (World Health Organization, 2013b). SARA measures infrastructure and equipment available in health facilities in relation to provision of specific services, based on minimum service standards. "Tracer indicators" are used to reflect the presence or absence of key infrastructure and thus readiness for service provision (see Annex 2). SARA provides a consistent methodology for annual country-led monitoring of health service delivery, providing statistically representative national data that can be compared between countries. This survey tool is receiving considerable uptake, with over a dozen surveys completed in 2011–2013. The GAVI Alliance and the Global Fund to Fight AIDS, Tuberculosis and Malaria began collaborating with WHO to expand use of the tool to more African and South-East Asian countries in 2014.

Research into links between energy access and health services provision

While it is clear many modern interventions cannot be delivered without electricity, few studies provide empirical evidence of the links between energy access rates of health facilities and actual health outcomes of treatment. A systematic global literature review identified only about a dozen articles out of 417 titles considered that included information on the impact of electricity access, or lack thereof, on health outcomes or health worker performance (Aranda et al., 2014; UBS, 2011). The search did not identify a single study in which linking energy access and health outcomes was the primary objective.

The impacts are difficult to measure due to the many contributing and confounding factors that need to be controlled, including staff skills and knowledge, availability of medicines, proximity to treatment and time-lag before measureable improvements. Most currently available evidence about health impacts of inadequate energy access in health facilities is thus derived from case studies and anecdotal evidence. However, such impacts may be assessed indirectly using proxy indicators, such as:

(i) **Facility performance indicators: operating hours and clinic visits.** Night-time health service provision or total hours of service provision per day have been used to evaluate the intermediate impact of energy access on health outcomes. The World Bank (2008) analysed health facility survey data from Kenya and Bangladesh and found that electrified clinics are open on average four more hours per day in Kenya, and one more hour per day in Bangladesh.

(ii) **Analysis of health services indicators in relation to the availability of electricity and/or electrical equipment.** Data on availability of specific types of electrical equipment in health facilities is captured by existing WHO/SARA and USAID/Measure Health surveys, as well as by some national government infrastructure surveys (Adair-Rohani et al., 2013). Some of this data can be compared with data on provision of specific services, such as immunization coverage. For instance, the World Bank (2008) reviewed vaccine refrigeration capacity in health facilities in selected countries, finding refrigerators more widely available in clinics with electricity (Table 2). However, clinics lacking electricity did not have lower immunization rates, possibly due to use of strategies such as mobile immunization teams and immunization campaigns in areas where refrigeration was unavailable. This points to the diverse set of factors that influence health-care delivery and actual health outcomes.[v]

(iii) **Analyses of health workers' attitudes and performance**. Health workers' attitudes and motivation can be affected by energy access in health facilities as well as in the surrounding community. A study (World Health Organization, 2010) on rural health worker retention noted that community electricity access was a key factor in attracting and retaining qualified health workers. The WHO study cited a World Bank study (Chaudhury N, 2003) that found Bangladeshi health workers preferred living in electrified communities, and this in turn reduced absenteeism in health facilities. Conversely, a civil society report about job satisfaction among Ugandan health workers describes the dissatisfactions expressed by both health workers and patients when electricity is unreliable or unavailable in clinics or hospitals. The report refers to health worker complaints about "non-functioning operating theatres, erratic or non-existent electric power," as well as other energy-related problems such as unreliable access to clean water and lack of communication technologies. Midwives and maternity nurses emphasized risks to women giving birth at night, when "assisting deliveries by the light of a mobile phone or candle begged from a patient, they were forced to delay episiotomies until daylight" (Voluntary Service Overseas, 2012).

Table 2. Cold chain vaccine storage features in association with rural health clinic electrification

	Ghana (2003)		**Egypt (2002)**		**Kenya (2004)**	
	Clinics with electricity	**Clinics with no electricity**	**Clinics with electricity**	**Clinics with no electricity**	**Clinics with electricity**	**Clinics with no electricity**
Clinic vaccine facilities	72.8%	27.2%	98.6%	1.4%	77.5%	22.5%
	Among clinics with electricity	**Among clinics with no electricity**	**Among clinics with electricity**	**Among clinics with no electricity**	**Among clinics with electricity**	**Among clinics with no electricity**
A. % with refrigeration for vaccine storage	64.2	40.7	51.3	0.0	71.9	67.3
B. % with ice used for vaccine storage	2.6	6.2	0.6	0.0	0.6	0.0
C. % with no vaccine storage	21.9	37.2	11.6	0.0	3.3	7.1
% Total clinics with immunization services (A+B+C)	**88.7**	**84.1**	**63.4**	**0.0**	**75.7**	**74.5**

Source: *Welfare impact of rural electrification* (The World Bank, 2008) based upon DHS data from USAID/Measure Health Facility Survey.

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[v] The fact that access to refrigeration did not necessarily correlate with immunization rates reflects the ways in which workaround solutions are found to overcome access barriers, as when health districts whose clinics lack refrigeration stage vaccine campaign days.

3

Energy requirements in health facilities: a closer look

Classification of health facilities

Types of facilities vary with countries' health systems, socioeconomic development orientation and policies. Classification of health facilities for inventory and analysis purposes has been attempted by various international development agencies (Annex 3). For example, a global survey of medical device availability by country (World Health Organization, 2010a) refers to three to five basic levels of health facility services, most commonly including:

- ***Health clinics/health posts*** cater to primary health needs of communities nearby, offering treatment for the most prevalent diseases (e.g. malaria, TB, HIV/AIDS) as well as maternal and child health services and first response to emergencies. Depending on the country, this level of care may also include special clinics for mother/child care, HIV/AIDS counseling and treatment, or dispensaries to provide anti-retroviral therapy, blood pressure medicine, anti-malarials and TB treatment.
- ***District health centres*** typically offer a wider range of health services to larger populations, as well as some patient beds and more advanced services such as complex obstetric procedures, injury response and diagnosis and treatment of serious infections and fevers.
- ***District, provincial and regional hospitals*** serve larger populations with a more diverse range of services, including more specialized services, surgical centres, intensive care and noncommunicable disease treatment.

Energy needs vary not only in relation to the health facility type, but also in terms of actual services provided, hours of operation, facility size, target population and available equipment. In addition, the range of services offered by primary health facilities, second-tier services, and so on are deeply influenced by external factors such as country-specific needs and priorities, national standards and health budgets.

Electrical equipment required for health services: devices, appliances and infrastructure

Because facilities can offer a wide range of health services, defining energy needs in terms of equipment required has yet to be undertaken systematically. This area requires greater attention by health and energy agencies at global, regional and national levels. However, infrastructure surveys such as SARA do make detailed inventories of equipment available in health facilities, and these surveys can be used as a basis for assessing existing energy needs.

Based on the SARA classification of health services, essential electric equipment and its indicative power requirements can be grouped as: (i) infrastructure, including lighting, communication, water supply and waste management; (ii) medical devices[vi]; and (iii) support appliances for specific health services such as vaccination, infectious and noncommunicable disease treatment, emergency care such as blood transfusions, and surgical services.

Table 3 provides a listing of most of the devices inventoried in the SARA and similar infrastructure surveys. Although energy performance data is not currently a part of the inventory, an indicative estimate of device electricity requirements is presented to illustrate the range and order of magnitude of energy requirements for even basic health facility equipment.

It should be noted that the SARA survey for health clinics and health centres inventories only x-ray devices and a few basic surgical tools, but not more advanced diagnostic and surgical devices. A specialized SARA survey focusing on hospitals, which would include more detailed equipment inventories, is also under development. The *WHO baseline survey on medical devices* also maps current availability by country of seven types of more advanced equipment required for diagnosis and treatment of major noncommunicable diseases such as cancer, as these devices are not widely available in many low-income countries (World Health Organization, 2010a).

The energy requirements denoted in Table 3 provide an indication of the peak demand for power in a facility when many or most devices and appliances are used at one time. However, some devices that consume a lot of electricity may be used intermittently while others may remain on standby power mode for most of the day. Considering all of these factors is important when estimating average daily energy use, particularly if a facility has battery-powered storage capacity so it can store energy from a generator, the grid or a solar power source, and then use that energy at another time.

It is also important to calculate evening and overnight electricity demand, particularly for facilities that rely upon an on-site power source. As previously noted, clinics that are open in the evening may face power shortages when grid power sources fail or are turned off altogether in peri-urban areas so as to channel more electricity to nearby cities.

[vi] A medical device is defined by WHO as an "instrument, apparatus or machine used to diagnose, treat, monitor or alleviate disease or injury. It is also used to prevent disease and compensate for injury." Medical devices thus cover a wide range of products, including syringes, stethoscopes, hip implants, ECG recorders, X-ray equipment, spectacles, dental equipment and virtually any product used specifically for health care purposes that is neither a medicine nor a biological product (*Health Topics: Medical Devices*. 2013. Geneva: World Health Organization, 2013. http://www.who.int/topics/medical_devices/en/).

Table 3. Indicative power requirements of electrical devices for health services[vii]

	Health services	Electrical devices (features and characteristics)	Indicative power rating [W] operation mode	AC power supply	DC power supply or battery port
INFRASTRUCTURE	**Basic amenities**	**Basic lighting**[1] requirements for **health clinics** are estimated at: ~l62 lux (lumens/m²), which may be achieved by various types of lamps:			
		✹ Incandescent lamp (~10–15 lm/W)	40–100 W	110/220 V AC	–
		✹ Halogen lamp (~15–20 lm/W)	20–50 W	110/220 V AC	12 V DC
		✹ CFL[viii] (~45–65 lm/W)	10–20 W	110/220 V AC	12 V DC
		✹ LED lamp (~70–90 lm/W)	5–13 W	110/220 V AC	10–30 V DC[3]
		Security lighting, outdoors (LED)	10–100 W[4]	110/220 V AC	10–30 V DC
		Mobile phone battery (charging)	5–20 W[5]	110/220 V AC	5–16.5 V DC
		Desktop computer[ix]	15[6]–200 W[7,8]	110/220 V AC	8–20 V DC[9]
		Laptop computer	20–60 W	110/220 V AC	12–20 V DC[10]
		Internet (V-Sat connection)	85–500 W[11]	110/220 V AC	15–24 V DC[12]
		Printer, ink jet	65[13]–100 W[14]	110/220 V AC	12–20 V DC[15]
		Printer, laser	150–1100 W[16]	110/220 V AC	
		VHF radio receiver: Stand-by Transmitting	2 W[17] 30 W[18]	110/220 V AC	12 V DC
		Ceiling fan (AC)	30–100 W[19,19a]	110/220 V AC	–
		Ceiling fan (DC)	28 W[20,21,22]		12 V DC
		Refrigerator, 165 L (for food & water) (AC)	150–200 W[23,x]	110/220 V AC	–
		(DC)	40–80 W[24,xi]	–	12 V DC
		Portable electric space heater	1392–1500 W[25]	110/220 V AC	48 V DC
		Portable air conditioner (AC & DC variants)	1000–1500 W	110/220 V AC[26]	48 V DC[27]
	Processing of equipment for reuse	Countertop autoclave (steam sterilizer) (19–45 L)	1200–2850 W[28,29]	110/220 V AC	–
		Dry heat sterilizer	500 W[30]–1.56 kW[31]	110/220 V AC	–
	Health-care waste management	Small waste autoclave (35–178 L)	2–6 kW[32]	220 V AC[xii]	–
		Autoclave grinder	1400 W	–	–
		Small water pump – clinic	50–200 W[33]	–	15–30 V DC
		Water pump – district health centre	400–1000 W[34]	110/220 V AC	–
		UV water purifier	10–40 W[35,36]	–	12 V DC
		Reverse osmosis/other water purifier	264 W[37]–570 W[38]	110/220 V AC	–
SPECIFIC SERVICES	**General outpatient services**	Micro-nebulizer	2.5[39]– 36 W[40]	100–240 V AC	9–12 V DC
		Nebulizer	80–90 W[41]	110/220 V AC	–
		Oxygen concentrator[42]	270–310 W 70 W	110/220 V AC	12–18 V DC
		Pulse oximeter Pulse oximeter (AA battery-operated)	50 W[43] 2–3 W[44]	110/220 V AC	1.5–3 V DC

Continues…

[vii] Note: This table does not consider electricity demands for dentistry services, which also are important to primary health-care, and deserve further consideration in the energy context. All values are calculated for use in the "active" mode unless otherwise stated. Total daily power consumption (Wh/day) would normally be a function of watt hours of active use plus any standby power requirement. Wherever possible, indicative power requirements have been compiled from data contained in reports and supply catalogues offered by recognized UN or national health and energy research agencies, including: (UNICEF, 2014; World Health Organization, 2013c; United States Agency for International Development, 2012; African Renewable Energy Access Program, 2010; National Renewable Energy Laboratory, 1998). References to other indicative values are noted individually in Annex 4. Reference to performance specifications of specific products or manufacturers does not imply any endorsement or recommendation by the World Bank or WHO, or that they are preferred to others of a similar nature not mentioned.

[viii] Note: Regarding lighting options: Incandescent bulbs are very inefficient and generate a lot of heat. Such lamps are progressively being banned in some countries. CFLs contain volatile mercury and should be avoided when a strong recycling service is not in place. In addition, CFLs produce electromagnetic and UV emissions. Thus whenever possible, LED is preferred. Linear fluorescent tubes, common in developed-country health facilities, have an additional problem insofar as they break easily in settings with electrical perturbations that occur frequently in the unstable grids of developing countries. As an alternative to fluorescent tubes, LED tubelights (9–18 W) with dimming option and running with both AC and DC power are now available in the market.

[ix] Note: Power varies widely for desktop computers, from 15 W for very efficient, new models, plus another 15 W for the monitor display, and up to 200 W for older ones.

[x] Daily electricity requirement for AC refrigerator: 600 Wh–1.44 kWh at ambient temperature of 21.1–32.2° C

[xi] Daily electricity requirement for DC refrigerator: 77–168 Wh at ambient temperature of 21.1–32.2 C°

[xii] Larger models or models with faster cycles often require 440 VAC.

	Health services	Electrical devices (features and characteristics]	Indicative power rating [W] operation mode	AC power supply	DC power supply or battery port
SPECIFIC SERVICES	**Antenatal, child and adolescent health**	**Vaccine refrigerator** (polio, measles, DPT-Hib+HepB, BCG & tetanus toxoid)[xiii] designed to perform at 43° C:			
		Vestfrost VLS200 AC (electric mains) refrigerator, 100 litres (WHO/PQS: E003/031)	115 W[45, xiv]	110/220 V AC	N/A
		Dometic TCW 3000 DC (solar-charged, battery-driven) vaccine refrigerator, 110 litres (WHO/PQS-E003/008)	250 W solar array[46, xv]	N/A	12/24 V DC
		Sure Chill BLF100 DC (solar direct-drive) vaccine refrigerator, 99 litres (WHO/PQS: E003/019)[47]	370 W +/- solar array[xv]	N/A	12/24 V DC
	Obstetric and newborn	LED light for phototherapy treatment of neo-natal jaundice[48]	440 W	110/220 V AC	–
		Suction apparatus[49]	90–200 W 33 W	110/220 V AC	 ± 12 V DC
		Vacuum aspirator or D&C kit[50]	36–96 W	110/220 V AC	± 3–6 V DC
		Neo-natal incubator	800–1035 W[51,52]	110/220 V AC	–
		Neo-natal infant warmer[53]	125/550 W[54]	110/230 V AC	–
		Fetal heart monitor (Doppler)	1.5–3 W (AA battery)[55,56]	–	1.5–3 V DC
		Ultrasound	800–1000 W[57]	110/220 V AC	–
		Portable ultrasound	6 W (idle) – 22–28 W (active-charging)[58,59,60]	100–240 V AC[61]	11–15 V DC[62]
	General diagnostics, blood analysis and laboratory equipment	Laboratory refrigerator	60–160 W[63,64] 40–80 W (165 L)[65]	110/220 V AC	 12/24 V DC
		Centrifuge	250 – 400 W (low-medium speeds)[66]	110/220 V AC	–
		Mini-centrifuge	25 W[67]	–	12 V DC
		Haematology analyser	230–400 W[68,69]	–	–
		Blood chemistry analyser	45–88 W[70,71]	–	–
		Blood chemistry analyser (hand-held)[72]	–	–	18 V DC battery[73]
		CD4 counter	200 W[74, 75]	110/220 V AC	12 V DC
		Brightfield white light microscope (with LED light)	20–30 W[76]	110/220 V AC	3–6 V DC
		LED microscope (for fluorescence smear microscopy (halogen or LED light)[77,78]	70 W [79,80]	110/220 V AC	12 V DC
		Mercury/xenon fluorescence microscope[81,82]	75–200 W	220–240 V AC	–
		X-ray machine[83, xvi]	15–20 kW	120 V AC	–
			30–40 kW	1Φ/108–230 V AC	–
			50–80 kW	3Φ/400–480 V AC	–
		Portable X-ray machine	3–4 kW[84,85]	90–264 V AC	
		Laboratory incubator	200 W[86]	110/220 V AC	12 V DC
		Vortex mixer	18 W[87]	90/220 V AC	6 V DC
			70–90 W[88]	120/230 VAC	–
	TB diagnosis	Sputum-smear microscopy (LED microscope w/fluorescent smear)[89]	30 W (+ 6 W LED bulb)[90] 20–30 W[91,] (+6 W LED bulbs)	110/230 V AC –	– 6 V DC
		GeneXpert MTB/RIF diagnostic	190 W[92,93]	110/220 V AC	12/24 V DC
	HIV diagnosis	ELISA test reader	500–650 W[94]	110/220 V AC	48 V DC
	Cardiovascular diagnosis/ treatment	Portable electrocardiograph (ECG)	1.2 W[95]–45/70 W[96]	100/240 V AC	3–12 V DC
		Defibrillator with ECG	130–200 W[97,98]	110/220 V AC	14–15 V DC
			100–130 W[99]	–	11.1 V DC
	Diabetes	Blood glucose monitor	<1 W	–	3.3–5 V DC[100]
	Basic surgical services[xvii]	Suction apparatus (AC)	90–200 W	110/220 V AC	–
		Suction apparatus (DC)	33 W	–	± 12 V DC
		Anaesthesia machine	1440 W[101]	110/220 V AC	
		Low-energy anaesthesia machine with DC monitor backup[102]	480 W – oxygen concentrator 20 W – monitor[103]	220 V	12 V DC backup (for monitor)

[xiii] Note: Vaccine refrigerators are designed to keep vaccines in a stable +2° C – +8° C range; vaccine cold packs require freezers.

[xiv] Note: In a well-designed refrigerator, the cooling compressor only operates intermittently so total daily demand would be estimated at about 710 Wh/day

[xv] At solar radiation reference period average = 3.5 kWh/m^2/day – (approximating average solar radiation in less-than-optimal sunlight, e.g. cloudy, rainy and cool-weather days).

[xvi] These values refer to the power supply for the x-ray generator; 150 kVp is the maximum voltage across the x-ray tube itself.

[xvii] Including basic procedures such as: tracheotomy, tubal ligation, vasectomy, dilatation and curettage, obstetric fistula repair, episiotomy, appendectomy, neonatal surgery, skin grafting, open treatment of fracture, amputation, cataract surgery. Note: Dental surgery procedures can impose significant load requirements including: dental compressor (~750 W-2.2 KW); dental sterilizer (~850 W); and dental chair & exam light (200 W); as well as x-ray and other specialized devices.

Table 4 illustrates a simplified example of how average daily demand for power can be calculated in more detail. It has been excerpted from real-life experience in planning the power needs for an off-grid health research facility in Liberia (Kuesel, 2013). Simple spreadsheet tools permitting even more sensitive hour-by-hour load calculations also are available online and described further in Annex 4 (United States Agency for International Development, 2012). These can more precisely assess energy needs during peak load times, as well as energy use at all hours.

Table 4: Example of an average load calculation using selected medical equipment*

Application	Qty.	Unit power consumption [W]	Total power consumption [W]	Hours of use daily	Days used in a week	Mean energy [Wh/day]	Share of total daily consumption	Day	Night	Daytime Wh	Night Wh
Laptop computer, Dell 630 1	1	160	160	8	7	**1280**	3.29%	80%	20%	1024	256
Photocopier/scanner	1	1200	1200	1	7	**1200**	3.09%	80%	20%	960	240
Mobile phone charger for ~15 phones (15 pieces counted as 1)	1	5	5	24	7	**120**	0.31%	80%	20%	96	24
DC electrocardiograph (ECG) 1	1	25	25	4	5	**71**	0.18%	80%	20%	57	14
Freezer, Kirsch Frostex (96 L) #2	1	160	160	6	7	**960**	2.47%	50%	50%	480	480
Refrigerator, Kirsch Labo (100 L) #1	1	150	150	3	7	**450**	1.16%	50%	50%	225	225
Peak power consumption (W)			**1700**								
Mean daily power consumption (Wh/Day)						**4081**					
Mean daytime power consumption										**2842**	
Mean night-time power consumption											**1239**

* This analysis presumed a single 230 Volt AC (VAC) power supply for all appliances (and including use of AC converters for connecting DC devices). A more complete assessment would also consider energy efficiency strategies to reduce demand and optimize power system design.

Improving energy efficiency of medical devices and appliances

Whereas traditionally, energy efficiency was not a primary objective in the design of medical devices, today the trend is towards higher efficiency and greater portability. For example, mercury-lit microscopes that consumed large amounts of energy were, until recently, the state-of-the-art equipment for certain procedures such as TB fluorescence smear microscopy, which is important for TB diagnosis in low-income countries. Mercury-lit microscopes are being rapidly replaced by ultra-efficient LED-lit microscopes that are more robust and reliable and can be operated using batteries or PV solar sources (Hanscheid, 2008; World Health Organization, 2010b). Similarly, conventional diagnostics using enzyme immunoassays (e.g. ELISA) require a reliable electricity source for test incubators as well as intermittent electricity access for analysis (World Health Organization and UNAIDS, 2009). Yet rapid tests that require little or no energy have become increasingly robust and available at primary health care level for malaria, HIV/AIDS, congenital syphilis and some vector-borne diseases.

The constant emergence of new technologies also means power requirements of different designs may vary widely, including across AC and DC variants of the same device. AC is the traditional current provided by the grid or generators for which most heavy electric appliances were originally developed. There is, however, an increasing array of portable and digital devices designed to use low-voltage DC power supplied by batteries and PV solar systems. Such devices include vaccine refrigerators, many of which have been WHO-reviewed and "prequalified" (World Health Organization, 2013d), battery-operated blood glucose monitors, LED-lit microscopes for TB diagnosis, digital pulse oximeters to measure blood oxygen levels, and sphygmomanometers which are blood pressure measurement devices (Parati et al., 2010; World Health Organization, 2010b). There are also low-power fetal heart monitors, ultrasound and medical suction devices to monitor and assist women in childbirth.

Many electronic devices (phone chargers, computers, etc.) are inherently DC-designed devices. Digital and semiconductor technologies that originated with information technologies and telecommunications stimulate medical device innovation, including more low-energy devices that can run on batteries and solar panels (Aronson, 2012). Frequent review of available technologies and devices is needed to determine energy requirements for health service delivery and inform a demand-driven approach to energy access. Table 3 provides indicative examples of devices that are powered by AC and DC technologies, along with their respective energy requirements.

Thermal energy needs of health facilities

In addition to electricity, health facilities may use thermal energy for cooking, water heating, space heating, sterilization and medical waste incineration, as well as for cooling in applications such as absorption refrigeration (using LPG or kerosene). Thermal energy may be produced through direct combustion of fuel (e.g. stove or boiler use of biomass, gas, kerosene or diesel). In settings where electricity is abundant, some or all thermal energy needs may be met with electric-powered stoves, water heaters, etc.

Health facilities use steam for purposes such as air humidification, equipment sterilization and hazardous health care waste disinfection (autoclaving). A recent landscape analysis covering 21 developing countries found that only 56% of facilities had access to adequate sterilization equipment; analysis across 16 countries found that only 59% of health facilities had adequate disposal systems for hazardous waste (World Health Organization, 2014).

Hot water can also be useful for hygiene (e.g. bathing), kitchen sanitation, laundry and other cleaning, supporting reduced nosocomial infection transmission between patients or patients and staff. Hot water, or steam, can also be used for space heating.

Large hospitals may produce hot water and steam from central boilers, municipal district heating systems or on-site CHP sources, although electric boilers and electric autoclaves are also common for point-of-use steam generation, particularly in smaller facilities (Emmanuel, 2012). This can make steam production costly as well as polluting. Solar thermal or solar photothermal-powered autoclaves that generate steam have been tested and validated in field and laboratory settings by Rice University (Neumann et al., 2013) and MIT's Innovations in International Health platform (Kaseman et al., 2012). These use forms of concentrated solar power or broadband light-harvesting nanoparticle technologies to achieve temperatures sufficient for small-scale medical equipment sterilization and reuse, although not for larger-scale waste management. More conventional passive solar thermal water heating systems are becoming more common in both developed and developing countries, and can usually heat water to a temperature suitable for basic hygiene and sanitation.

Space heating is important in health facilities in temperate climates, and during the cold season of higher-altitude zones of Central Asia, Latin America and Africa, as well as the Mediterranean. Exposures to cold or dampness increase the likelihood of asthma, allergies and acute respiratory diseases (Wu et al., 2004; World Health Organization, 2011; World Health Organization, 2012a). Space heating in developing-country facilities may be provided by district heating, electricity or on-site fuel-based solutions. Thermal solar "combi-systems" that heat both water and space are increasingly being used in Europe, China and the Middle East (World Health Organization, 2011).

Avoiding excessive overheating – particularly in sensitive wards, operating theatres and laboratories – is likewise a particular concern in mild, arid and tropical climates. Improving building thermal performance with significant passive cooling can help accomplish this using careful building orientation, shading, and natural or mechanically supported natural ventilation.

As both space heating and air conditioning are often energy-intensive applications resulting in high expenses, improving buildings' energy efficiency through use of window placement, day lighting and passive solar strategies can reduce heating and air conditioning requirements. Use of natural ventilation can also help reduce transmission of airborne infectious diseases, particularly tuberculosis (Atkinson et al., 2009).

Together with the use of climate-adapted materials for roofing, walls and insulation, passive cooling strategies can reduce reliance on energy-intensive air conditioning systems while saving significant long-term energy costs. In modern buildings, the energy savings can amount to 30–50% or even more (Levine & Urge-Vorsatz, 2007; Kapoor & Kumar, 2011; Bonnema, 2010). Recently, some large modern facilities have been designed in Africa and Asia using indigenous building materials (e.g. local brick and stone) that are more climate-adapted than mass-produced concrete blocks (Partners in Health, 2011). While there are many contextual factors to consider, such as structural safety and resilience, use of energy-efficient building materials can significantly improve thermal conditions and save energy and expense compared with conventional materials. Along with cost savings, reducing mechanical space cooling and heating requirements allows available heat and power supplies to be allocated to medical interventions. Such energy efficiencies are receiving increasing interest and uptake among health facilities worldwide (Box 2).

Thermal energy is frequently used for medical waste incineration. Poor management and unsafe disposal of medical waste can threaten patients, communities and medical staff. Developing countries have limited options for safe health care waste disposal. Dumping untreated infectious waste in landfills can create health risks for scavengers and cause local environmental damage. Contaminated sharps,[xvii] in particular, are a source of injury and infection risks. At the same time, waste incineration in open pits or single-chamber combustion incinerators – the methods most common today in many low-income countries – creates other serious health risks through the airborne emission of dioxins and furans as well as the creation of hazardous solid waste residues (Chartier Y et al. 2014).

As a result, WHO recommends that infectious and noninfectious waste be separated at the source to reduce the hazardous waste stream as much as possible. This also facilitates recycling of certain kinds of non-infectious waste, e.g. cartons, and composting of kitchen waste where feasible.[xviii]

For infectious medical waste, WHO also recommends that wherever possible, infectious waste undergo microwave or autoclave disinfection or sterilization, rather than incineration. This may be followed by grinding to reduce the volume of waste that needs landfill disposal. WHO and the United Nations Development Programme also are testing new ways to safely reprocess sterilized plastic, glass and metal in a project supported by the Global Environment Fund (Global Environment Fund, 2013). Non-incineration management of medical waste, however, requires considerable electricity. As such methods become more widespread,

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[xvii] "Sharps" is a health sector term referring to sharp objects such as needles, blades, scalpels and other items that can break the skin; sharps can also include broken glass items such as Pasteur pipettes and blood vials. Used syringes and tubes connected to sharps are also typically regarded as infectious waste.

[xviii] Biodegradable waste (e.g. paper and food scraps) and solid-waste sewage also can be processed using anaerobic digestion to generate biogas energy.

Jimma, Ethiopia: *Hospital staff cook over a wood fire. Cleaner stoves and fuels can reduce exposures to indoor air pollution. (Photo: WHO)*

their power needs will also have to be considered in health facilities' electricity budgeting.

Particularly in energy-constrained settings, successful development of reliable energy systems thus requires careful assessment of all aspects of health facility energy needs. Electricity needs, which are the focus of this report, are typically calculated in terms of average daily (kWh) and daily peak (kWp) loads, as well as day-time and night-time variants.

Certain building energy needs vary seasonally, especially for heating and cooling. The presence or absence of energy-efficient building design features such as day lighting, ventilation, insulation and passive solar design also profoundly affect energy loads required for lighting, cooling and heating. Foreseeable load increases to serve additional energy needs in the near future also need to be considered in the facility's load profile. Procurement of more or less energy-efficient medical equipment will influence the future load profile, as will energy-saving retrofits to the building itself.

On the supply side, key considerations include the power capacity that can be provided by various sources as well as their reliability and all capital and running costs – whether the primary supply source is the grid, off-grid or hybrid. Daily, as well as seasonal, peaks and gaps in energy demand and supply also are critical factors. For instance, there may be interruptions in grid electricity supply especially during the evening peak, or seasonal variations in solar or wind power production, or interruptions in fuel deliveries when roads become impassable. These variables are considered further in the next chapter.

Box 2. Energy efficiency in building design and management

India's energy-efficient Bhopal Sambhavna Clinic is designed with double external walls, including a perforated shell called *jaali*, to deflect the sun's rays while allowing daylight to penetrate. This green facility provides medical care to survivors of the 1984 Union Carbide chemical leak, one of the world's worst incidents of industrial chemical poisoning (Stephens, 2006; Guenther & Vittori, 2007). A similar double-wall approach is used in Susques Hospital, Argentina (Hernández et al., 2010). Space between outer and inner walls enhances building cooling, while large windows as well as ceiling fans and vents provide more air exchanges than in comparable air-conditioned buildings.

Rooftop pools (Jain, 2006), evaporative cooling systems (Hindoliya & Jain, 2010) and cooling courtyards (Safarzadeh & Bahadori, 2005) are other common passive solar techniques receiving serious attention among building researchers and designers. Energy required for lighting can also be reduced significantly with effective use of daylight (Levine, 2007). In Nguru, Nigeria, a nursery for newborns was redesigned to reduce energy by lowering floors 120 cm below ground, raising roof heights, creating double walls, placing new windows for cross-ventilation and adding window blinds. Air conditioners that had frequently ceased operation due to power cuts were replaced with a solar-operated roof extractor fan and a flowing water heat exchanger. Between January and July 2013 these measures kept indoor ambient temperatures stable below 33.5° C, while in a "control" nursery temperatures rose as high as 39.5° C on peak-heat days of 45–46° C outdoors. These interventions reduced risk of neonatal hyperthermia, referred to as evening fever syndrome, which is a common but rarely studied condition affecting morbidity and mortality of newborns in hot climates (Amadi et al., 2014).

Modeling of alternative strategies can allow engineers to determine which work best in different thermal conditions. For instance, a study on passive cooling of cement-based roofs in tropical climates found that fitting a corrugated aluminum sheet, specially angled to dissipate heat, and overlaying another sheet of insulation to minimize heat transfer could reduce thermal heat load by 70% as well as regulate thermal fluctuations (Alvarado, 2008). In China, porous wall tiles have been studied regarding their cooling effects on buildings (Luo et al., 2009). Similarly, a concrete roof insulated with a layer of vermiculite and covered by tiles was part of a model Indian facility's energy-efficiency plan. Hareda, a community health centre, used vegetation and window orientation as well as layers of roof and wall insulation to shield the clinic from radiant heat. Evaporative cooling systems also helped reduce indoor temperatures from an average of 40° C to 30° C (Shukla, 2009).

Energy management strategies are equally important and can range from complex computer-controlled systems to very simple sensor-powered lighting, water taps with automatic shut-off valves, and user training to turn off appliances such as computers when not in use. Energy efficiency should receive higher priority in facility design, planning and management to allow health services in energy-poor countries to "move up" the energy ladder most inexpensively and efficiently.

Butaro District Hospital, Rwanda: Airy, open-air waiting areas reduce infection risks as well as facilitating community interaction in an energy-efficient hospital developed by the Rwanda Ministry of Health along with Partners In Health.

Butaro District Hospital, Rwanda: Patient beds face a window, so healing mothers have a view of nature, while ceiling fans affixed to the high ceilings support cooling and fresh air circulation. (Photos: MASS Design Group)

4

Electricity supply in health facilities: trends and opportunities

Grid-based electricity supply and on-site electricity production

The traditional paradigm of energy supply for health facilities worldwide involved access to grid power backed up by on-site fuel-based generator power (or a two-way battery storage generator)[xix] whose capacity and sophistication depended on the size of the facility. In off-grid settings, portable diesel generators[xx] have been the primary source of power. In larger clinics or hospitals, these are backed by a second fuel-powered generator; small clinics use flashlights and kerosene lamps.

Although grid power remains a dominant mode of energy supply, many health facilities in developed and developing countries are investing more thought and money in on-site power generators using an expanding array of energy technologies. These range from advanced fossil fuel-based technologies producing combined heat and power (CHP) to large- and small-scale PV solar systems.

Driving this trend is the need of hospitals and health clinics that provide first-line emergency and obstetrics services for on-site power sources to ensure essential service provision in the event of grid failure. A backup power source is essential for any hospital or for any outpatient clinic handling childbirths, emergencies, day surgeries, vaccine storage or laboratories – including those connected to usually reliable grid power supplies in advanced economies. Yet on-site power sources are more critical for health facilities operating in developing regions where grid supply may be interrupted daily.

Diesel generators, which have long been the default on-site power option, have become increasingly expensive to fuel and maintain. As a proportion of total health service costs, fuel costs can be particularly high, especially in the most resource-constrained settings. One study in Bangladesh found that the amount spent on diesel in a year to power a backup generator could fund a skilled nurse for six months (Practical Action, 2013). Securing fuel in the rainy season, when rural roads are often impassable, is another challenge.

A WHO-led review of health clinics and hospitals in nine sub-Saharan African countries found that only 7% relied solely on a generator for power, and 26% of facilities had no power at all. In six countries where

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[xix] This converts AC power to DC, stores the power for use when the grid is down, and then reconverts the power back to AC.

[xx] Gasoline or LPG-powered generators are used in some settings where these fuels are more available.

generator functionality was assessed, only 10–29% of facilities reported having functional generators with fuel available at the time of the assessment (Adair-Rohani et al., 2013).

While fuel costs have increased, the costs of some key renewable energy technologies – especially solar – have sharply declined, making such systems more affordable for small facilities and remote locations (African Renewable Energy Access Program, 2010). The next section focuses on how photovoltaic solar power is becoming increasingly important as an on-site solution for health facilities in energy-poor settings to assure reliable daily electricity access for basic functions such as lighting.

The trend towards on-site PV systems and development of other on-site power solutions is not confined to small health clinics or energy-poor settings. In African countries where hydropower is abundant, some larger hospital projects have involved hydroelectric power development (Box 3). Large-scale investments in more efficient on-site energy technologies are being made by many health facilities in high- and middle-income countries, as well as by larger urban hospitals in emerging economies. These systems often involve highly efficient co-generation of heat and power. In higher-income settings, the potential for saving energy costs is a key driver of investments in CHP systems for facilities that use 25 kW of power or more. Improving resilience in the face of extreme weather events may be a co-benefit (Carbon Trust, 2013). Carbon credits and environmental incentives are helping to stimulate this change in the health sector (Carbon Trust, 2010).

The increasing role of solar power in health facilities

A recent review of energy supply patterns in 11 sub-Saharan African countries using countrywide surveys and representative samples of over 4000 public and private health facilities found that hundreds of clinics and hospitals are using on-site solar photovoltaic (PV) power sources either as a primary or backup source. In Uganda, some 15% of hospitals used PV solar to complement grid electricity access, and in Sierra Leone, 36% of all health facilities and 43% of hospitals used solar systems in combination with other electricity sources (Adair-Rohani et al., 2013).

In Liberia, a country where the central electricity grid covers little more than the capital city (Foster & Pushak, 2011), the pace of solar electrification has outstripped that of any other power source. A 2012 survey covering all first-line public health clinics found 146 clinics using PV solar as their primary energy source as compared to 116 using generators. Only 3 clinics were hooked up to the grid or mini-grid, and 53 clinics had no electricity source. The PV systems offered somewhat greater reliability: 81% of solar-equipped clinics reported that they had electricity available on the survey day, compared with only 52% of clinics using fossil fuel generators as their primary source. While problems with battery and light bulb replacement and other maintenance tasks often hamper PV solar availability, the results reflect the even greater challenges faced by small clinics in maintaining and fueling generators. The types of solar systems available are becoming more robust and diversified, ranging from small solar kits serving minimal electricity needs to very large solar systems supporting virtually all aspects of hospitals' electricity needs, from lights and refrigeration to water pumping, equipment sterilization and laboratory operations.

Mini-systems such as the "solar suitcase" have filled a niche for low-cost solutions with a capacity of 100–200 W that target the most immediate energy needs of front-line health clinics currently lacking any energy at all. One or two small rooftop solar panels power an array of high-efficiency LED area lights that can be affixed to a ceiling. These are supplemented by portable headlamps or lanterns suitable for more

Parabolic solar collectors *power the air conditioning system at Muni Seva Ashram Hospital in Goraj, India. (Photo: Urvish Dave's Blog & Muni Seva Ashram – Goraj)*

detailed task work or for moving outdoors or in poorly illuminated areas. A charger – activated when sufficient power has been stored in the battery – provides supplementary power for mobile phones and small medical devices such as fetal heart monitors. Such modular "plug and play" systems are used to facilitate night-time obstetrics services or emergency surgery in very small clinics and remote locations (WE CARE Solar, 2013).

Solar-powered refrigerators are increasingly popular for vaccine and blood storage. First-generation solar-powered refrigerators presented problems with expensive battery maintenance and replacement. Second-generation "direct-drive" solar-powered appliances can store solar power in ice or other types of cold packs, sidestepping batteries altogether. A joint WHO and PATH landscape assessment described solar refrigeration as essential to meet soaring vaccine cold chain demands (PATH and World Health Organization, 2008). Investments by PATH and WHO in the Project Optimize initiative led to wider testing and piloting of solar direct-drive models, introducing these to the wider donor market. About a dozen types of solar refrigerators are now approved by WHO for sale at reduced prices to developing countries through "pre-qualified" procurement lists. Some models can maintain the cold chain for a week or more without any solar electricity (Robertson & McCarney, 2012). Because these refrigerators require over-sized solar arrays to insure the cold-chain, surplus electricity is often generated and can be tapped for other health facility loads. Rational systems for doing this are of increasing interest to key health agency actors and NGOs as a low-cost incremental energy solution.

Investments by health-focused intergovernmental agencies in solar-powered vaccine refrigeration are growing rapidly. As of December 2014, UNICEF had purchased close to 10,000 solar refrigerators for over 24 countries, with numbers more than doubling in the past three years. Solar direct-drive (SDD) refrigeration procurement represented 13% of all refrigerators and freezers procured by UNICEF in 2013 with this market share projected to increase further as the agency pressed industry to step up production (UNICEF, 2013).

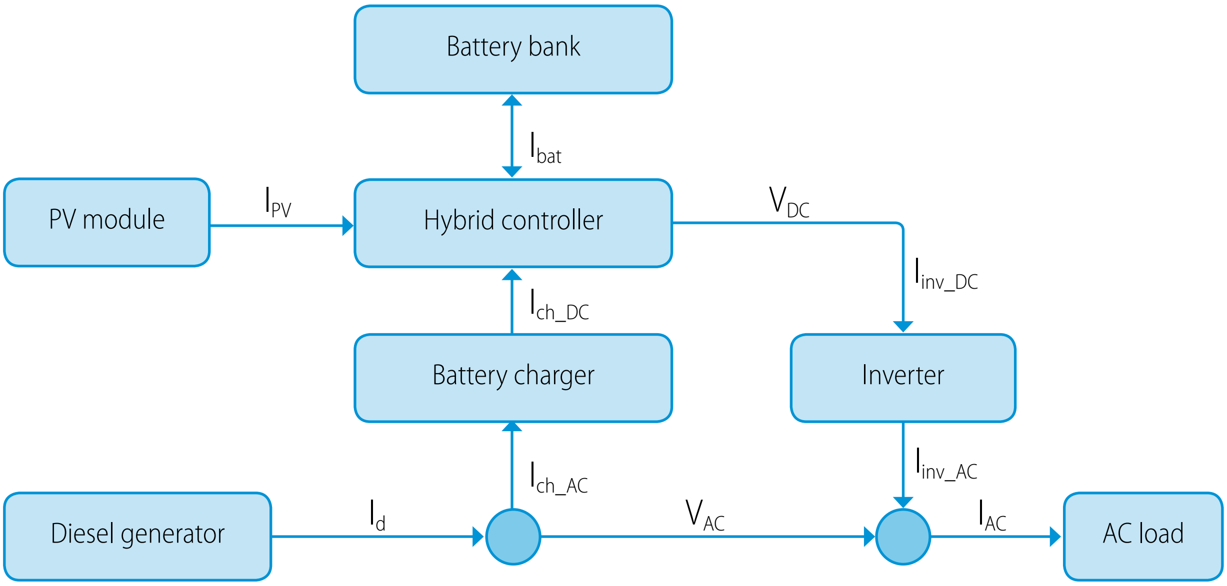
Since 2007, the Global Fund to Fight AIDS, Tuberculosis and Malaria has invested millions of dollars in the procurement of solar panels to power small-scale diagnostic tools and laboratories in Asian and African health clinics (The Global Fund, 2014). Large-scale investments in solar systems for developing country health clinics are also being made by bilateral and multilateral institutions in Europe (UBS Optimus Foundation, 2011) and USAID's Powering Health initiative (United States Agency for International Development, 2013a). The increased use of solar PV, which generates a DC power current, has reinforced interest in research on and development of energy-efficient DC medical devices, as described in Chapter 3 and Table 3. For very small clinics with limited electricity and equipment access, DC-designed medical devices are a particularly attractive proposition, as the use of traditional AC devices with a solar panel system requires converting DC power into AC through an inverter. Adding an inverter to a solar system adds to its cost, and inverters may be difficult to repair or replace, particularly in remote areas.

Even so, only very small solar systems can sidestep inverters altogether and provide all-DC "suites" that supply power for the applications needed by health clinics (WE CARE Solar, 2013).

The creation of a single DC power supply platform capable of directly powering all equipment needs in a mid-size or larger clinic without conversion to AC remains a challenge. DC power from a solar panel or battery is typically produced at only one voltage level (e.g. 24 V), while voltage requirements for DC-powered devices tend to vary anywhere between 3 and 34 volts, requiring voltage conversion.

Even so, hybrid AC/DC building energy systems that permit hookups to both AC sources such as a grid or generators as well as "direct-DC" connection to PV solar-charged batteries are being explored in the energy sector of developed countries for residential and small commercial buildings due to their energy savings potential (Lawrence Berkeley National Laboratory, 2011). In such systems, smaller DC devices can feasibly be connected directly to dedicated DC plugs powered from the battery bank power source, while AC appliances requiring more power could be connected to an AC outlet directly powered by a generator. An inverter would remain available for backup conversion of DC to AC current, and the battery charger would be available to convert AC power from a generator to DC (Fig. 3).

Fig. 3. Diagram of a hybrid system with dual AC-DC connectivity potential



Source: (Ani & Emetu, 2013).

Photovoltaic solar power systems can also be supplemented by passive solar thermal energy systems. These are generally robust and relatively inexpensive, and can meet certain heat energy needs. For instance, a passive solar hot water heater can bring water to temperatures of 50° C or more, suitable for storage and use for kitchen sanitation, laundry and (when diluted with cooler water) for hand-washing and bathing. Some passive solar hot water systems generate sufficient thermal energy for space heating, which can be significant in a thermally efficient building.

Solar power offers multiple benefits to health facilities of all sizes, especially those with no access to the grid. In many tropical countries, solar arrays with a battery storage source can provide reliable power on most days of the year, with the advantage of low operating costs as no fuel is required. Solar power is healthier for patients and health workers insofar as it creates no local air pollution and reduces the burn risks associated with kerosene lamps (Mills, 2012). Exposure to diesel or kerosene emissions is associated with development of cardiovascular and respiratory diseases (WHO, 2009); diesel engine emissions are further classified as carcinogenic (International Agency for Research on Cancer, 2012).

The climate gains of shifting from kerosene lighting and diesel generators to solar systems are significant on a per-kilowatt hour basis. Solar-powered lanterns can save up to 25 kg CO_2/kWh if they replace a kerosene lamp, or up to 250 kg of CO_2 per year from a single 60 watt light bulb equivalent (Mills, 2003).

As health facilities increase their use of solar energy, these gains will become even more important. PV solar systems on average generate less than 250 grams of CO_2/kWh of power produced, including lifecycle emissions (Edenhofer, et al., editors [2011]). In comparison, stand-alone diesel-powered generators produce upwards of 1 kg CO_2/kWh, with emissions proportionately higher for smaller systems that may operate only part-time and even more inefficiently (Natural Resources Canada, 2008; Ani & Emetu, 2013). Particulate emissions are also reduced proportionately, and insofar as PM contains black carbon, a short-lived climate pollutant, this represents another net gain for climate as well as health (Scientific Advisory Panel, 2013).

Hybrid solar-diesel systems can capture most of those same climate and health savings while buffering against the hazards posed by intermittent power interruptions. In sub-Saharan African settings such as Nigeria, efficiently managed hybrid solar-generator or solar/generator/wind power systems could reduce diesel fuel consumption, costs and associated emissions by up to 75–90%, depending on climate zone and energy requirements (Ani & Emetu, 2013; Ani, 2014).

Comparisons of emissions from and costs of renewable, fuel-based and hybrid systems can be made for any setting using common industry tools such as the HOMER (Hybrid Optimization Model for Electric Renewables) management software developed by the US Department of Energy's National Renewable Energy Laboratory (National Renewable Energy Laboratory, 2014). HOMER assesses and models optimal energy systems based on climate conditions and energy requirements. It plots a pattern for the most efficient use of generators, solar arrays and battery storage in light of the energy cycle as well as peak and overall energy needs (HOMER Energy, 2014).

Yet PV solar systems and hybrid solar-generator systems have some inherent drawbacks. Although solar panels are comparatively low-maintenance, battery management and replacement are critical to ensure system longevity. Local access to suitable replacement batteries and other spare parts is not always available, and health clinics that receive solar systems from donors may not have funding to maintain the systems they receive. Local workers' skills for maintaining solar power systems may be less well developed than knowledge about generator maintenance. Battery disposal is also a problem insofar as lead acid batteries remain the most widely available battery type. Under tropical, equatorial or arid desert conditions, lead acid batteries have a lifespan of only two to five years, and then they must be safely disposed. Exposure to lead as a result of improper battery disposal can cause severe poisoning as well as cognitive and developmental damage in exposed children. Alternatively, lithium batteries of the size required for larger applications could pose fire risks. Lithium battery designs suitable for solar charging, as well as business models for recycling lead-acid batteries, are critical for safe and sustainable scale-up of solar technologies.

Trade and tariff barriers still hamper imports of solar panels into many developing countries, which may have little solar manufacturing capacity of their own. Insofar as solar panels are usually affixed to a rooftop outdoors, security is also essential to avoid theft (Jitta et al., 2008).

High capital cost barriers to solar energy solutions

The biggest barrier to rapid expansion of solar solutions is the higher initial cost of PV solar systems compared to small, stand-alone generators – despite the sharp decline in the cost of solar components over the past decade. While the lifetime cost of an on-site solar system will generally be lower than that of a small generator requiring constant fuel inputs, the capital cost of a generator is likely to be lower.

To illustrate the trade-offs, a hypothetical case study based on a validated assessment tool is presented here. The study makes use of online software for health clinic power design developed by USAID's *Powering Health* (United States Agency for International Development, 2012), and based on the USA National Renewable Energy Laboratory (NREL) HOMER® power optimization model. The model estimates costs, pollution and climate emissions for alternative energy solutions based on simple inputs of data on clinic equipment, operating hours, local costs and locational data (United States Agency for International Development, 2013a). The case study developed here was based on the presumed needs of a small, off-grid health facility in rural Kenya with a limited array of equipment, requiring 8.61 kWh/day to operate reliably.[xxi] A complete description of the simulation is provided in Annex 4, while Table 5 presents a summary of costs for different energy solutions.

As per the results, a diesel generator without batteries has the lowest capital cost (US$ 2000), but also the highest lifetime cost (US$ 62 862) due to its large and continuous fuel requirements. Adding batteries to the diesel system increases the capital cost but reduces fuel requirements and electricity costs, insofar as storage of excess power generated in off-peak times clearly optimizes fuel efficiency. The capital cost

Table 5. Comparative costs of stand-alone power supply options

Configuration	PV capacity (kW)	Generator capacity (kW)	Number of batteries	Converter capacity (kW)	Initial capital (US$)	Annual generator usage (hours)	Annual quantity of diesel (L)	Total net present cost (US$) for 25 years	Cost of energy (US$/kWh)	Renewable fraction
Generator only	-	2.0	-	-	2 000	6 570	2 258	62 862	1.981	-
PV + generator	4.0	2.0	-	2.0	10 640	3 714	1 157	43 139	1.359	0.74
Generator + battery	-	2.0	18	2.0	7 014	2 327	1 395	39 917	1.258	-
PV + battery	3.5	-	16	2.0	11 528	-	-	13 992	0.441	1.00
PV + generator + battery	3.0	2.0	8	2.0	10 584	253	91	13 778	0.434	0.96

Notes: Simulation assumptions are based on local prices and data, as well as locational data and equipment needs, as detailed and referenced in Annex 4. Cost assumptions include: Generator (US$ 1000/kW); Fuel (US$ 1.2/liter); PV system (US$ 2 000/kWp or US$ 2/Wp); Inverter (US$ 0.320/Wp) and Trojan-105 battery (US$ 180/kWh), all including installation. Interest rate (7.5%). A daily "noise" potential of electricity load variation of 10% and potential of hourly variations of 15% also are assumed.

[xxi] The presumed location is latitude 1°2´South, longitude 39°30´East. Applications served include lighting, refrigeration, radio, computer, laboratory centrifuge, microscope, blood chemical analyzer, hematology analyzer and CD4 machine.

of a PV configuration with batteries is nearly two times higher than that of a generator and battery combination (US$ 11 528), but the net present cost, representing cost over the lifetime of the system, is only US$ 13 992, or less than a fourth of the generator-only option (US$ 62 862).

Finally, a PV-diesel hybrid solution supported by battery storage is the most cost-efficient over time (US$ 13 778). The net present cost (NPC) of the PV + diesel + battery hybrid is slightly lower than that of the PV + battery combination because fewer storage batteries are needed – and replacing batteries is a significant factor in system maintenance costs. If fuel is available, the hybrid system may also be more reliable in regions with prolonged periods of cloudy weather. Conversely, if fuel is less available and solar radiation more stable, then the PV + battery system with a larger battery array may be more reliable, and the cost difference is not significant.

The hybrid array may also allow for smoother energy management of the facility. The facility may rely on fuel-based generators, if needed, for peak-time requirements and cloudy days, while using PV solar energy directly or stored in batteries during periods of ample sunlight and lower, more constant needs. This is in contrast to a generator-only system that has to be run at all times, including periods of low power demand, leading to potentially poor fuel efficiency.

The simulation also illustrates how optimal combinations of photovoltaic and diesel generation with appropriate energy storage can yield win-win benefits for health, climate and development. Harnessing renewable energy sources reduces pollution and climate emissions. At the same time, health facility energy costs are reduced and reliability is improved. The relationship between costs, pollution and climate emissions are summarized in Table 5a.

Table 5a: Costs, pollution and climate emissions in alternative stand-alone energy arrays

Configuration	Pollutant emissions (kg/yr)				Capital cost (US$)	Net present cost (US$) for 25 years
	PM*	CO_2	NOx	CO		
Generator only	1.110	5 947	131.00	14.70	2 000	62 862
PV + generator	0.567	3 046	67.10	7.52	10 640	43 139
Generator + battery	0.684	3 673	80.90	9.07	7 014	39 917
PV + battery	-	-	-	-	11 528	13 992
PV + generator + battery	0.045	239	5.27	0.59	10 584	13 778

* measured in terms of total particulate matter

Optimizing energy demand and supply to limit costs, pollution and emissions

The case study above illustrates how system optimization is a key aspect of reliable and cost-efficient off-grid energy use. Such optimization must consider variations in climate and days of sunshine, as well as component and fuel costs. A third factor critical to performance is appropriate sizing of the energy system. This section covers demand-driven and supply size measures used to ensure appropriate sizing, and optimization of the energy system.

In larger on-grid health facilities, where unlimited energy is available, systems may be sized with reference to a standard factor for power required, in association with total square meters of service space, number of patients, and the number and types of outpatient and inpatient services provided.

For smaller facilities, and particularly those facing power shortages, ensuring that demand and supply are very well aligned is more critical. A careful inventory of available medical equipment and appliances, and associated energy requirements, is the basis for ensuring that supply can meet demands. In addition, building infrastructure energy requirements need to be precisely assessed wherever electricity is used for heating, cooling or water pumping. In assuring such alignment, demand side energy efficiency measures are important, but often overlooked. These include investments in more energy-efficient medical devices, such as LED lights and energy efficient refrigerators, as well as more energy-efficient building systems.

An indication of the energy and cost savings that may be obtained from demand-side investments is provided in a second scenario developed for the hypothetical case study in Kenya (Table 6). A complete description is found in Annex 4. Notably, investments in more energy-efficient medical devices reduce the capital cost for the hybrid system to US$ 7702 – almost equal to the cost of the generator + battery option in the scenario using conventional medical devices (US$ 7014). This illustrates how greater attention to demand-side energy efficiencies can help make renewable energy more affordable.

On the supply-side, it remains important to ensure that systems are large enough to operate reliably to meet present (and if possible anticipated future) demands, but not inefficiently. This is particularly a concern with generators that produce large bursts of power, which must be stored in costly batteries if not used immediately.

Another case study of a real-life health clinic in Nigeria, illustrates the supply-side dynamics (Ani & Emetu, 2013). The study modelled the costs of the clinic's existing generator + battery system and compared those with a potential hybrid option. The existing generator was oversized and inefficient, particularly due to the large fluctuations between day and night-time energy requirements, and using a large battery array for surplus energy storage. A correctly-sized hybrid PV + generator + battery system was less expensive both to purchase as well as to operate (Table 7). The study found that if the hybrid system was introduced, both PM pollution and CO_2 emissions would decline by more than 75% due to reduced fuel use. These simulations, using validated assessment tools, illustrate how optimized energy systems can offer significant advantages in terms of health service quality and cost, as well

Table 6: Comparative costs of power supply configurations for clinic with conventional versus energy efficient medical devices

Configuration	PV capacity (kW)		Genset capacity (kW)		No. batteries 6V/225Ah		Initial capital (US$)		Total NPC (US$) 25 years	
	Conventional	Energy-efficient	Conventional	Energy-efficient	Conventional	Energy-efficient	Conventional	Energy-efficient	Conventional	Energy-efficient
Generator only	-	-	2.0	1.7	-	-	2 000	1 700	62 862	53 285
PV + generator	4.0	3.0	2.0	1.7	-	-	10 640	8 244	43 139	34 034
Generator + battery	-	-	2.0	1.7	18	12	7 014	5 160	39 917	29 799
PV + battery	3.5	2.5	-	-	16	12	11 528	8 460	13 992	10 305
PV + generator + battery	3.0	2.0	2.0	1.7	8	6	10 584	7 702	13 778	10 233

Table 7. Summary of initial system costs, operating costs and net present costs (NPC) in Nigerian case study

	Existing system diesel only		Proposed hybrid diesel-solar PV system	
Parameter	Dollars ($)	Naira (₦)	Dollars ($)	Naira (₦)
Initial cost	63 760	10 329 120	46 280	7 497 369
Operating cost	30 254	4 901 148	7 012	1 135 944
Total NPC	410 769	66 544 578	126 712	20 527 344

Source: (Ani & Emetu, 2013).

as sustainability. Further development of such assessment models can help make the case for innovative financial solutions that overcome capital cost barriers to deployment of renewable energy in facilities lacking reliable grid services. Such solutions may range from grants and soft financing to new energy or health finance policies that permit budgetary allocations for diesel fuel purchases to be used to secure and repay loans for capital investments in more efficient renewable or hybrid systems.

CHP and other on-site energy systems for larger hospitals

Large grid-connected hospitals in urban areas of both developing and developed countries are increasingly investing in on-site energy systems to generate their own power supply, thereby reducing long-term costs, improving system reliability, and reducing climate and pollution emissions.

Heat and power co-generation, also known as combined heat and power (CHP), is one increasingly popular option. Such systems capture the waste heat produced by electricity generation for building heating needs, as well as for cooling driven by absorption refrigeration.[xxiii] CHP is therefore more energy efficient; systems also may be more resilient in emergencies (Sims et al., 2007; Natural Resources Canada, 2008).

As CHP systems can deliver large quantities of heat and power, they are a good match for modern hospitals with energy requirements of 25 kW or more. A 2004 study on CHP's potential for the Brazilian hospital sector estimated 50 kW as the minimum commercially viable capacity (Szklo et al., 2004). However, projects beginning at 25–30 kW of power have since been developed in the USA and Europe (Carbon Trust, 2013; Natural Resources Canada, 2012; Midwest CHP Application Center & US DOE, 2007). CHP systems can be powered by a range of renewable and fossil fuels including oil and natural gas, biogas, biomass and other biofuels such as wood chips or waste palm oil.

CHP can operate alongside grid power, or other fossil fuel or renewable energy sources, in a complementary array. Shifts between different electricity sources occur automatically based on currently available power, stored power capacities and costs of power at different times.[xxiv] The system is thus capable of a seamless transfer from one power source to another.[xxv] Insofar as CHP systems have sophisticated on-site management systems to shift between different energy sources, they also integrate well with renewable energy sources such as solar, wind or hydroelectric power.

CHP is an increasingly common energy solution in the hospital sector in North America[xxvi] and Europe as well as in the general commercial and industrial sector (United States Department of Energy, 2011a; Natural Resources Canada, 2012).

In emerging economies such as India, China and Brazil, hospitals and commercial building developers are exploring and investing in CHP systems as a primary or backup energy source (Szklo et al., 2004; Agarwal, 2009; Shukla, 2009). Already in 2005, CHP systems in India generated an estimated 5% of total electricity supply (International Energy Agency, 2010). Given the high cost and soaring demand for electricity, CHP may represent an attractive alternative for other emerging economies, if financial and regulatory barriers can be addressed.

[xxiii] When waste or solar heat is harnessed, the heat source can also provide the energy needed to directly drive a cooling system through absorption refrigeration, but compression refrigeration requires electricity.

[xxiv] Costs of grid power vary at different times, so a management system might draw power from the grid during cheaper off-peak times and shift to CHP during peak times. CHP systems may even feed power back to the grid during peak periods for added savings.

[xxv] Hospitals must ensure that the systems have automatic transfer capability and that output can be matched with demand.

[xxvi] Several hundred US hospitals operate on CHP systems (United States Department of Energy, 2011a).

Box 3. Case studies of onsite power generation: climate resilience, financial and health systems benefits

More than two-thirds of energy produced by a conventional thermal power plant is lost as heat, while energy is also lost in the process of grid transmission. CHP uses much of the energy otherwise wasted during generation, and being on-site also avoids transmission losses. It is thus more energy-efficient than electricity drawn from a traditional thermal power plant. It is also more energy-efficient than only heat or only electricity produced by conventional boilers or power generators onsite (Sims et al., 2007), where that same heat would otherwise be wasted.

The UK's Carbon Trust estimates that hospitals adopting CHP systems can save 20–30% in energy costs (Carbon Trust, 2010). In an Indian case study, a grid-connected hospital in Ghaziabad with more than 400 beds estimated that shifting to a CHP system for most electricity needs would reduce its electricity costs by about 30% compared to the grid supply and by half in comparison to diesel backup. It would also ensure more reliable provision of electricity, since the grid source often failed (Agarwal, 2009).

In the United States of America, the Mississippi Baptist Medical Center, a 624-bed facility in Jackson, Mississippi, lost grid power for 52 hours in 2005 in the wake of Hurricane Katrina. The CHP system allowed the hospital to continue full operations and to extend emergency aid to patients from other hospitals that lost power, as well as providing shelter and food to displaced community residents (Midwest CHP Application Center & US DOE, 2007). During Superstorm Sandy that hit the northeastern United States of America in 2012, a number of major New York City institutions were able to maintain power during the storm thanks to CHP systems, including Long Island's South Oaks 300 000-square-foot Hospital Campus, which operated for five days on its CHP system when grid power was unavailable. It then operated for another 10 days after power was restored to the surrounding area at the request of the crisis-besieged Long Island Power Authority (United States Department of Energy, Northeast Clean Energy Application Center, 2013).

CHP is not the only kind of onsite power solution being adopted by large health facilities. This report also identified hospitals in Rwanda (Partners in Health, 2011), Zambia (North West Zambia Development Trust, 2013), Uganda (Jitta et al., 2008) and the Democratic Republic of Congo (DRC) that use or had developed hydropower facilities on their own or in tandem with nearby communities (Jane Goodall Institute, 2013). One leading example in DRC is the Catholic University of Graben-Butembo, which has been investing heavily in solar and hydroelectric projects with support from USAID (Hale, 2009). DRC, through which the Congo River flows, is among the countries with the continent's greatest untapped hydropower potential.

In a number of USA hospitals, CHP systems performed well during extreme weather that shut down grid power, making the hospitals more resilient in emergencies (Box 3).

Due to their reliability and efficiency, CHP systems may thus offer diverse financial advantages to facilities that can make the investment. However, the costs and benefits must be assessed individually in a feasibility study considering power and heat load profiles, current energy costs, capital costs of a new system, and so-on.

CHP is not the only kind of large-scale, on-site energy system being adopted by health facilities. Hydropower, along with solar, has the largest renewable energy potential on the African continent, and this is also being harnessed by hospitals (Box 3). An analysis of the national renewable energy potential of hydropower in sub-Saharan Africa ranges from 1.3 times current consumption in South Africa to 100 times current consumption in Namibia, with a median of 10–12 times current national consumption among 42 countries reviewed[xxvii] (United Nations Development Programme, 2013; Murray et al., 2010).

On-site power generation in health facilities can be designed as part of larger community systems. This is congruent with new approaches for "distributed energy

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[xxvii] The analyses referred to renewable energy potential from solar, hydropower, wind and geothermal sources and biofuels.

generation," or mini-grids, intended to provide power in dispersed locales that are not efficiently reached by large and centralized power plants. The barriers to such an approach, however, may also be significant. On-site systems may represent a significant investment that many hospitals cannot afford without external financial support. As energy supply is not traditionally a core activity of health systems, decision-makers may lack information about new technologies and their benefits. These issues are addressed in the next section.

Health facilities as energy providers

The International Energy Agency estimates that to achieve universal access to electricity by 2030, 70% of unconnected rural areas would have to be connected with either mini-grids or small stand-alone off-grid systems (International Energy Agency, 2011). Among public and institutional buildings, health facilities – particularly hospitals – have a comparatively high and constant need for energy. This means they could potentially play a role as electricity suppliers or anchor loads in mini-grid systems, given appropriate policy and financial incentives.

Along with their high inherent energy requirements, hospitals universally require backup sources of energy on-site for peak periods and emergencies. When such backup sources are not being used by the facility, available energy can be shifted to other community users, generating resource efficiencies and revenues. In developed countries, this trend is closely associated with the development of hospital cogeneration (CHP). As one US Department of Energy report noted, "CHP can create an additional revenue stream by allowing hospitals to sell surplus electricity back to their utilities" (United States Department of Energy, 2011a). However, as illustrated in Box 3, facilities in developing countries have also partnered with local communities to develop mini-grids based on PV solar or hydroelectric power.

In expanding such approaches, however, multiple policy and institutional barriers must be overcome. There may be insufficient interaction between medical, building and engineering staff, and utilities. The potential of new energy technologies may not be fully appreciated by hospital directors who control budgets and planning. Maintenance even of existing systems is often a challenge for health faciltiies, creating risks for personnel as well as equipment. In smaller clinics, health-care workers often manage building infrastructure alongside their health-care tasks, and lack funding for even fuel and spare parts. Ensuring sustainability of even simple solar systems or generators can be very difficult. Thus, attempts to leverage the power generation potential of health facilities for broader community needs must be carefully planned, and supported by capacity-building and budgets for system maintenance.

Financial barriers posed by the high capital costs of new energy technologies also must be overcome. Business models suitable for health facilities in resource-constrained settings need to be devised for investments in clean, reliable and efficient systems. Two models that have been successfully used in developed countries to finance investments include the following:

a) An energy utility or other third party invests in a health facility energy system; the utility/third party owns the energy asset while the facility benefits from a long-term energy contract or power purchase agreement at a favourable rate. The health facility serves as an anchor customer; excess supply is sold by the utility/investor to local businesses and households, generating more revenues. Public environmental credits or carbon incentives may augment financial viability (Reed, 2008; United States Department of Energy, 2011b).

b) A health facility invests in its own energy system, leveraged by carbon credits, public grants or commercial loans. These, in turn, may be repaid through energy cost savings as well as revenues from supplying clean electricity back to the grid or the local community.

Innovative adaptation of such models to conditions in low-income countries requires careful assessment of policy incentives and barriers. In grid-connected areas supportive policies can include more favourable rate structures and feed-in tariffs that incentivize health facilities to become energy generators for their own needs as well as those of the community.

While detailed discussion is beyond the scope of this document, two examples show how such models have been applied or adapted for health facilities in resource-constrained settings:

- **Health clinic-based micro-enterprise approach:** One NGO working in Africa created a system whereby health clinics that receive a PV solar system donation simultaneously set up a micro-business at their facility to power mobile phones for the community using a portion of the solar power generated. Earnings from the phone-charging service are banked to pay for replacement of light bulbs, batteries and other parts. A country manager remotely monitors energy use and accounts to ensure appropriate use of the core energy resources and transparent sale of the surplus power (Innovation Africa, 2013).
- **Power purchase agreement (PPA):** A private hospital in Haiti contracted with an international investor to cover the cost of a new PV solar system, signing a 20-year purchase agreement for a fixed quantity of energy at a fixed rate. The hospital saves money because that price is lower than the cost of electricity from diesel generation, and the investor has a secure payback for the capital investment. The solar system provides 10% of hospital electricity needs, yielding climate and environment benefits.

While many technical, political and financial hurdles must be overcome to replicate such models, partnerships between health and energy sectors can provide an impetus. In a supportive policy environment, health facilities could not only become generators of clean energy from sources such as solar, wind and hydroelectric power, (and in the case of hospitals, CHP), but also “anchor loads” for systems of improved community energy provision to households, schools, and other essential services.

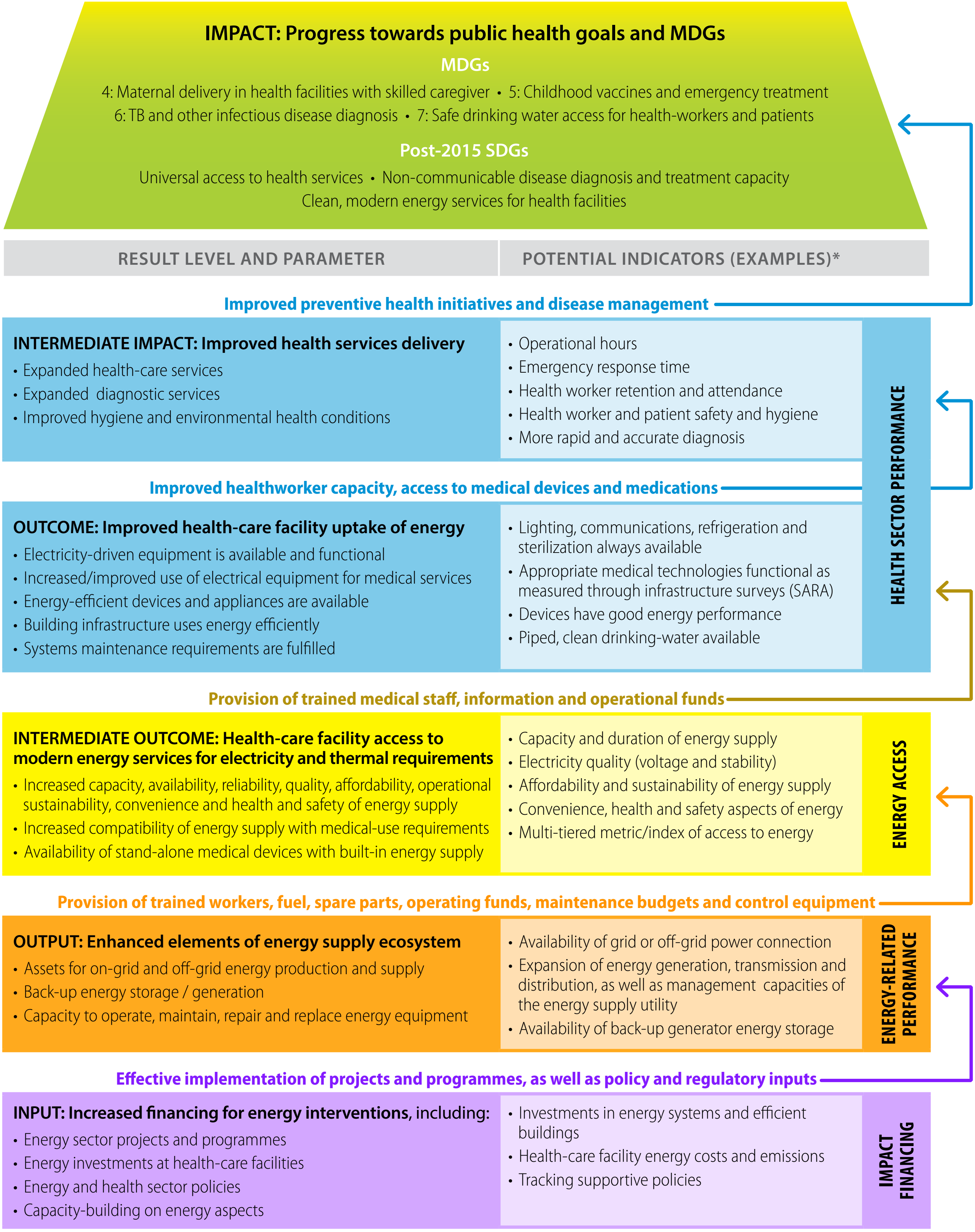
A proposed framework for energy and health service linkages

Energy sector initiatives relevant to health facilities encompass a wide range of interventions. These range from stand-alone off-grid and micro-grid solutions using a mix of renewable and/or fossil fuel-based technologies to grid expansion around centralized power plants. Fuel delivery systems (in the case of fossil fuel-based power generation) and availability of parts and skilled staff to maintain both fuel-based and renewable energy systems are critical for sustained operation. Effective delivery of energy requires a strong energy supply ecosystem encompassing laws, policies, regulations, markets and institutions to support equitable access to energy, its efficient use and a transparent payment system.

The *energy results chain* framework (Fig. 4) illustrates pathways discussed in this report, through which energy investments may improve health services and benefit socioeconomic development.

The chain illustrates the attributes of capacity, duration, quality, reliability and operational sustainability required for effective energy systems. At the same time, it highlights the fact that energy supply is only one among a number of elements (such as trained personnel and access to essential medicines) required for effective health services delivery. A model to systematically measure and monitor these attributes or dimensions of energy demand and supply is discussed in the next chapter.

Fig. 4: Energy results chain framework for health services



IMPACT: Progress towards public health goals and MDGs

MDGs

4: Maternal delivery in health facilities with skilled caregiver • 5: Childhood vaccines and emergency treatment
6: TB and other infectious disease diagnosis • 7: Safe drinking water access for health-workers and patients

Post-2015 SDGs

Universal access to health services • Non-communicable disease diagnosis and treatment capacity
Clean, modern energy services for health facilities

RESULT LEVEL AND PARAMETER	POTENTIAL INDICATORS (EXAMPLES)*	
Improved preventive health initiatives and disease management		
INTERMEDIATE IMPACT: Improved health services delivery • Expanded health-care services • Expanded diagnostic services • Improved hygiene and environmental health conditions	• Operational hours • Emergency response time • Health worker retention and attendance • Health worker and patient safety and hygiene • More rapid and accurate diagnosis	**HEALTH SECTOR PERFORMANCE**
Improved healthworker capacity, access to medical devices and medications		
OUTCOME: Improved health-care facility uptake of energy • Electricity-driven equipment is available and functional • Increased/improved use of electrical equipment for medical services • Energy-efficient devices and appliances are available • Building infrastructure uses energy efficiently • Systems maintenance requirements are fulfilled	• Lighting, communications, refrigeration and sterilization always available • Appropriate medical technologies functional as measured through infrastructure surveys (SARA) • Devices have good energy performance • Piped, clean drinking-water available	
Provision of trained medical staff, information and operational funds		
INTERMEDIATE OUTCOME: Health-care facility access to modern energy services for electricity and thermal requirements • Increased capacity, availability, reliability, quality, affordability, operational sustainability, convenience and health and safety of energy supply • Increased compatibility of energy supply with medical-use requirements • Availability of stand-alone medical devices with built-in energy supply	• Capacity and duration of energy supply • Electricity quality (voltage and stability) • Affordability and sustainability of energy supply • Convenience, health and safety aspects of energy • Multi-tiered metric/index of access to energy	**ENERGY ACCESS**
Provision of trained workers, fuel, spare parts, operating funds, maintenance budgets and control equipment		
OUTPUT: Enhanced elements of energy supply ecosystem • Assets for on-grid and off-grid energy production and supply • Back-up energy storage / generation • Capacity to operate, maintain, repair and replace energy equipment	• Availability of grid or off-grid power connection • Expansion of energy generation, transmission and distribution, as well as management capacities of the energy supply utility • Availability of back-up generator energy storage	**ENERGY-RELATED PERFORMANCE**
Effective implementation of projects and programmes, as well as policy and regulatory inputs		
INPUT: Increased financing for energy interventions, including: • Energy sector projects and programmes • Energy investments at health-care facilities • Energy and health sector policies • Capacity-building on energy aspects	• Investments in energy systems and efficient buildings • Health-care facility energy costs and emissions • Tracking supportive policies	**IMPACT FINANCING**

* Note: Further research is needed to define the health outcome indicators most closely related to sustainable energy provision.

5

Improving measurement of electricity access in health facilities

Needs and benefits of a monitoring metric

There is currently little measurement of electricity access in health facilities; it has been assessed through some health infrastructure surveys by a few basic indicators such as whether the health facility has a grid connection and/or a generator, and whether the electricity supply was functional on the survey day or over the previous week. These indicators, while simple and convenient, fail to capture many important aspects of electricity supply and functionality, including:

(i) The diversity of electricity sources, including grid, mini-grid and on-site stand-alone devices being used for primary as well as backup solutions encompassing fossil fuel or renewable energy-based technologies, alone or in combination.
(ii) The adequacy of electricity supply in meeting the requirements of medical devices and support equipment to deliver targeted health services.
(iii) Key characteristics of electricity supply (also called attributes) that define the degree to which the supply is functional and available for delivery to health services.

This chapter presents a framework for more detailed measurement of electricity access in health facilities, encompassing all possible sources of electricity supply and reflecting various attributes of electricity supply in relation to health facility needs. Such data can inform policies and investments, with the aim of attaining *SE4All* goals for clean, sustainable energy access in community health facilities in support of universal access to health services. The key features of the measurement approach introduced here are:

Health services delivery at the heart of energy access metrics

Electricity in health facilities is only useful if it allows the desired health services to run adequately. Health services provision should be the essential consideration in measuring access to electricity; this can be achieved by tracking use of medical equipment and other electric devices required to meet facility needs. Existing surveys such as the SARA undertake detailed inventory of equipment by health service category. Beyond the availability of medical equipment, it is important to evaluate whether available electricity is able to support equipment use, based on key attributes of energy supply.

An all-inclusive and technology-neutral approach

All possible supply technologies – grid, mini-grid, and off-grid solutions – are considered. Performance is measured through nine common "attributes" of electricity supply. Those include: peak power capacity, daily power capacity and nighttime power capacity; power duration; quality; reliability; affordability; and operational and environmental sustainability of the power supply. Such a methodology is technology-neutral, and can thus support more robust evaluation of the performance of both grid and off-grid systems at health facility and aggregate level.

Energy access measured as a continuum of improvement

Energy access follows a continuum of improvement based on electricity supply characteristics required for health services provision. Multi-tier indicators (presented in Chapter 6) can overcome some of the limitations of a binary metric (whether or not a grid-connection is available) and reflect different levels of attributes of robust electricity performance that shall be considered here.

Attributes of electricity supply

Health facilities may access electricity from a variety of sources, but effective use of electrical equipment depends ultimately on the system's performance. The electricity supply should be sufficient to run all required appliances based on their power requirements (peak power capacity, measured in watts), as well as the total electric energy needed to meet the establishment's daily needs (daily energy capacity, measured in watt hours). Electricity should be available during all of the health facility's working hours (duration), including evening and night hours (as required), while having stable voltage (quality) and being reliable (reliability) and cost-effective (affordability). For example, in some cases off-grid solutions may not provide enough power to run all medical appliances, while health facilities in many developing countries may not have constant electricity supply during all working hours even when they are connected to the grid. Repeated outages as well as voltage instability interrupt health services and can damage vital medical equipment.

Health facilities need to have sufficient funds to be able to operate and maintain electricity systems in terms of timely payment of utility bills, purchase of fuel and maintenance of electrical equipment (operational sustainability). Finally, as illustrated by the modeling of optimized hybrid power systems in Chapter 4, more cost-efficient modes of electricity supply very often can, and should whenever possible, minimize harmful climate and pollution emissions (environmental sustainability).

These attributes of electricity supply are described in greater detail as follows:

1. Peak power capacity (in watts)

The capacity of the electricity supply is measured in watts and refers to the peak capacity that the system can deliver.[xxviii] Diverse electricity applications consume different quantities of electricity. These range from a few watts, as for LED lighting, to several kilowatts, as for space heating or x-ray machines. Similarly, power generating technologies of various capacities supply different quantities of electricity: a few watts from a small solar panel, megawatts from a national grid connection. The capacity should be sufficient to support the electrical devices available. Conversely, use of more energy- efficient lights and medical devices is critical to optimizing available peak power supply.

As health facilities vary in terms of size and health services delivered, devising a one-size-fits-all benchmark to capture whether or not electricity supply is adequate poses difficulties. Small health facilities delivering basic health services may only need to operate low-power equipment and therefore require minimal capacity

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[xxviii] The peak capacity is the maximum amount of power that can be drawn at any single point in time.

while larger facilities that offer inpatient services need higher power capacities.

2. Daily energy capacity (in watt hours)

Supply must meet daily energy needs of the health clinic in terms of the total required based on use of different equipment. Such usage may be continuous (refrigerators, space heating, etc.), intermittent (laboratory equipment), periodic (evening lighting) or just once or twice daily, such as the operation of autoclaves for instrument sterilization. The daily energy capacity needed for a health facility can be estimated based on a simple spreadsheet, as illustrated in Table 4 of Chapter 3. While grid-based electricity can typically supply any amount of energy and is not constrained in terms of daily energy capacity, off-grid solutions are typically constrained by the system's generation and storage capacity.

3. Evening peak hours supply

During the evening, the demand for grid electricity across all consumer segments – including households, commercial establishments and street lighting – is typically high. As a result, the central electric grid in many developing countries often is constrained to cut supply to rural and sometimes even peri-urban or urban load centres, including health facilities. Evening and night hours are a time when many patients, including expectant mothers, may arrive for treatment if they do not want to lose time from their daytime jobs or if they lack child care until other household members return from work. Yet especially in rural areas, health clinics may not extend service hours into the evening, in part due to lack of electricity supply.

Many health contingencies also have to be addressed in real-time. For example, childbirth and accidents requiring trauma care can take place at any time. Availability of electricity supply in health clinics in the evening – and during the night where no referral clinic is available nearby – is critically important. Evening electricity supply also is important insofar as it enables health workers to feel a greater sense of security when working nighttime hours, as well as helping them to deliver services safely (being able to see adequately to stitch a wound or draw blood).

4. Duration of supply

Electricity supply should be available to support all infrastructure required and medical services provided during the opening hours of the health facility, as well as for maternal health and childbirth services or other emergency services offered outside of regular business hours. Some equipment may be used intermittently, as for laboratory testing of samples collected throughout the day and then analyzed in a batch. However, other electricity services such as refrigeration may require a 24-hour supply of electricity regardless of facility opening hours; although an increasing range of refrigeration technologies operate on intermittent power supplies.

Similar to capacity, health facility needs in terms of duration of energy supply depend on size and health services delivered. A small health facility in a rural area may only require electricity routinely for a few hours per day, although that supply also needs to support maternal delivery and emergency services unless there is a referral facility nearby. A larger facility with inpatient services needs constant electricity day and night. The duration of electricity supply can be compared against the service hours of the health facility to determine any duration gap.

5. Power quality

Poor power quality can interrupt or harm the functioning of medical devices and services that rely on them. Many AC-powered devices do not work properly when voltage is inadequate or frequency fluctuates. Power quality disturbances such as surges can damage or destroy devices, or cause severe injuries or fires if adequate protections are not implemented.

The Institute of Electrical and Electronics Engineers has developed a standard for power quality that includes definitions of various power disturbances. These include transient disturbances, power interruptions, under-voltage, over-voltage, waveform distortion, voltage fluctuations and frequency variations (IEEE, 1995). Understanding and measuring these disturbances is of prime importance for making purchase decisions for power correction devices such as surge protectors and power factor correctors. Identifying and addressing common electrical disturbances is further discussed in *The Seven Types of Power Problems* (Seymore & Terry, 2005).

Low voltage and voltage fluctuations are the most common quality problems, usually resulting from overloaded electricity systems or long-distance, low-tension cables connecting remote areas. Most AC appliances are intended to operate on a constant voltage supply (such as 120 or 240 volts) provided by the central grid; below this, they may not operate properly. For example, compact fluorescent lights do not light up and fans do not provide enough airflow if voltage is low. In addition, power transformers[xxix] draw higher current when voltage drops, subjecting the entire electricity system to greater thermal losses and risk of transformer burnout.

In easily observable terms, quality may be considered adequate when voltage drops or voltage fluctuations are rare and minor, with little or no impact on facility operations.

6. Reliability

Reliability is part of power quality, but in the health facility context it is important enough to merit separate consideration. Reliability here refers to the incidence and duration of unexpected outages. Unexpected interruptions are usually due to failure of the grid or stand-alone system. To maintain essential health services during power disruptions, most health facilities have backup power generators, even in developed countries. Backup generators may not provide sufficient electricity for all uses; they may only support priority applications such as lighting, refrigerators and critical equipment. Frequent unscheduled power interruptions of long duration can have severe impacts on health services. For example, reliable supply is crucial for anaesthesia machines and oxygen concentrators, and outages may harm patients as well as damage equipment, vaccines, blood and medicines. Reliability is inadequate when unscheduled supply interruptions are frequent and long despite backup generators, and therefore significantly affect facility operations.

7. Affordability (cost-competitiveness)

Electricity costs vary by source, and when average power costs are high, this imposes a considerable burden on health facility budgets. Power from stand-alone diesel generators is typically much more expensive than that from grid sources supplied by thermal or hydroelectric power. The cost competitiveness of electricity must compare across capital as well as operating costs. In case of stand-alone renewable sources of electricity, typically the operating costs are low, but capital costs are very high. With fuel-based stand-alone generation, it is usually the reverse.

Affordability is generally defined with reference to the prevailing electricity tariff for grid-connected commercial consumers as the benchmark. Supply of electricity at an average life-cycle price more than 50% higher than this benchmark is widely considered unaffordable.

8. Operational sustainability

Operational sustainability refers to the availability of funds for operating and maintaining electricity systems (including backup systems). Three types of expenses require secure budget allocations to avoid electricity supply disruptions: (i) running expenses for fuel and electricity bills, (ii) maintenance expenses, including spare parts and technical support, and (iii) replacement expenses such as batteries. Increasing fossil fuel costs are often a barrier to adequate electricity provision for financially vulnerable health facilities, while maintenance plays a key role in securing undisrupted supply for diesel generators and renewable energy systems. Operational sustainability is inadequate when there is insufficient and/or delayed availability of funds for covering such expenses.

9. Environmental health and sustainability

Supply of energy should not lead to environmental damage in the health clinic or adjoining areas. Such environmental damage includes pollution of air, water and soil, as well as noise pollution in such quantities that any of these may damage the health of patients, medical staff or people living near the health facility – or

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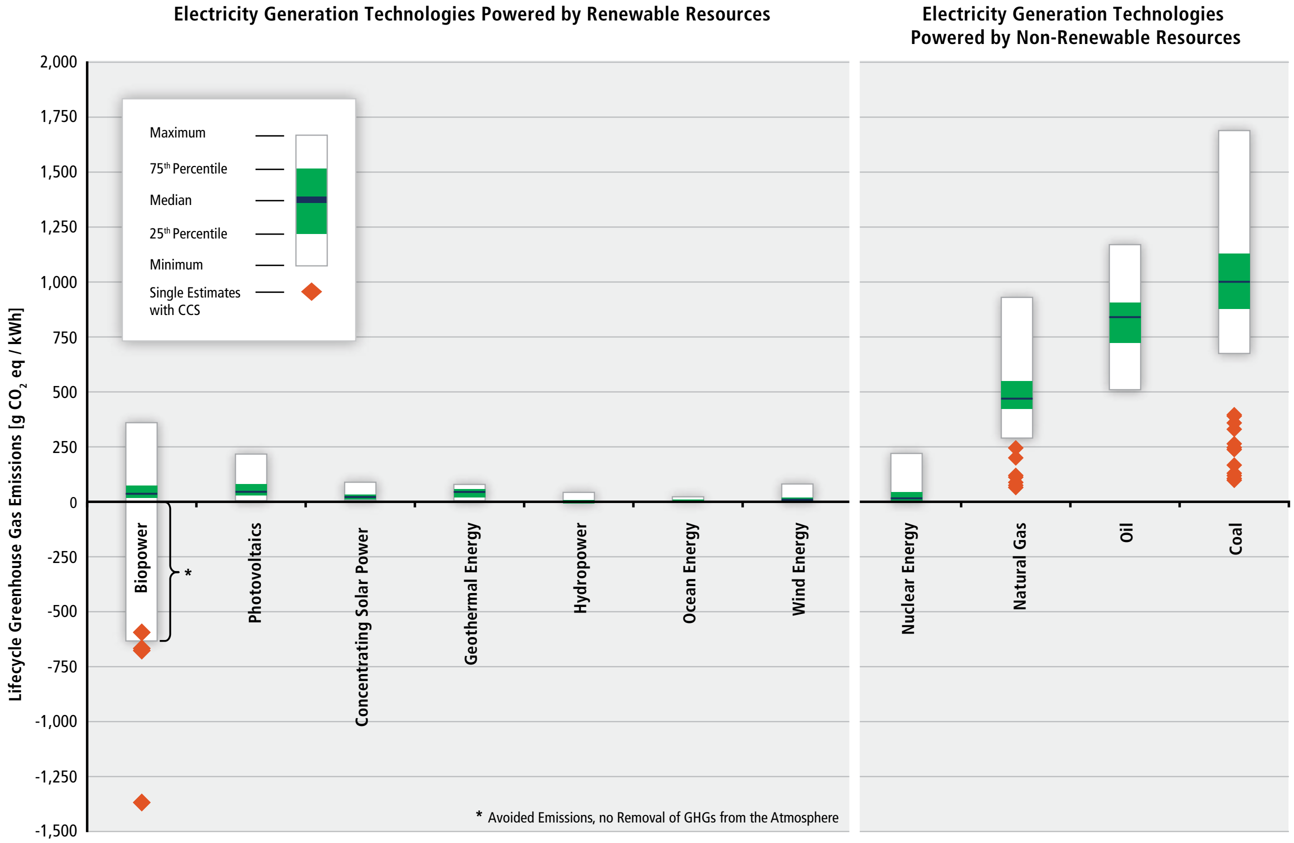
[xxix] Transformers are typically used to change AC voltages from one voltage level to another within power networks.

near a dedicated power plant producing energy for a health facility.

Emissions of PM_{10} per kWh of power generation is a well-accepted indicator of health impacts of energy system emissions. Insofar as a significant proportion of diesel's PM emissions are black carbon, this is also an indicator of near-term climate impacts. Estimates of PM emissions/kWh of power generation can be derived from the power cycle and emissions factors of each technology employed.

Emissions of CO_2 per kWh of power generation are another marker of environmental sustainability. As with PM, such emissions tend to be higher for the most polluting light and power production technologies (such as kerosene lamps and small diesel generators operating without batteries) and progressively lower for less polluting and more efficient technologies, as well as for renewable systems, as illustrated by Fig. 5 (Sims et al., 2007; Edenhofer et al., 2011).

Fig. 5. Estimates of life-cycle greenhouse gas emissions



Count of Estimates	222(+4)	124	42	8	28	10	126	125	83(+7)	24	169(+12)
Count of References	52(+0)	26	13	6	11	5	49	32	36(+4)	10	50(+10)

Source: Reprinted with permission from: Sathaye JO et al. (2011). Renewable Energy in the Context of Sustainable Energy. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* (Edenhofer O et al., editors), Cambridge University Press.

Note: As an oil-derived fuel, diesel is covered by the oil range portrayed in the figure. CO_2 emissions for small stand-alone diesel generators are generally in the higher end of the range, e.g. 1.15 kg CO_2 /kWh (Ani & Emetu, 2013). Natural Resources Canada (2008) estimates emissions from generators of <15 kW as 1.2–2.4 g CO_2-eq/kWh, depending on the size and running cycle. CO_2-eq refers to the climate forcing potential of any particles and gasses measured in terms of the equivalent quantity of CO_2.

Because air pollution and climate change are increasing concerns worldwide, PM and CO_2 emissions are also being used as markers by analysts in developing countries for assessing alternative models of energy delivery, including for the health sector (Ani & Emetu, 2013; Ani, 2014). In cases where environmental health and economic benefits coincide, such as for hybrid diesel-renewable systems that yield significant fuel cost savings, identifying such synergies can stimulate interest in investment in clean energy systems.

Enhanced health clinic surveys and data collection tools

A measurement of electricity access based on the nine key supply attributes requires new data, most readily collected through infrastructure surveys of health facilities. One of the most widely used tools for collecting national-level data on health clinics has been the USAID-supported Service Provision Assessment (SPA), a component of the larger Demographic and Health Surveys (DHS) initiative. However, SPA surveys are costly to implement and have been done in a relatively limited number of countries. In parallel, WHO developed a Service Availability Mapping (SAM) survey that shared many features with SPA and was made freely available to ministries of health of several developing countries. Agencies such as the Global Fund to Fight AIDS, Tuberculosis and Malaria have developed their own infrastructure surveys, often modeled on the WHO or USAID tools, to assess service provision in supported facilities.

More recently, WHO and USAID have collaborated to harmonize indicators from SAM and SPA for a more comprehensive and cross-cutting health facility assessment: the Service Availability and Readiness Assessment (SARA) (World Health Organization, 2013b). This measures the availability of health services in conjunction with key infrastructure and equipment required for these services, based on minimum service standards (Annexes 1 & 2). It is important to note that such minimum service standards are based on implicit consensus assumptions among health sector practitioners, not upon a universally agreed norm.

SARA provides a consistent methodology for annual country-led monitoring of health service delivery, supported by WHO-led training. This survey tool is receiving considerable uptake, with a dozen surveys completed as of late 2013. In 2014, the GAVI Alliance and the Global Fund to Fight AIDS, Tuberculosis and Malaria will fund new rounds of the SARA in more African and South-East Asian countries to monitor service provision in supported facilities.

SARA makes a very detailed inventory of equipment available in a health facility, including a wide range of basic medical devices and appliances, such as vaccine refrigerators, as well as general equipment for water sterilization, heating, cooling and ventilation. Recent additions to the SARA questions (expanding the energy section of the survey from two questions to nine) provide somewhat more details about the sources of electricity available and their reliability. Power "capacity" available to operate appliances and devices, however, is not fully captured by the current survey tool. Table 8 illustrates how characterization of device demand and systematic classification of energy requirements in terms of "lighting only," "low power load" or "high power load" could assist in plotting a facility's current energy needs, even in the absence of more comprehensive data and assessment.

An improved version of the SARA tool recently launched by WHO includes a larger range of questions about energy access. This version captures information about diverse modes of electricity supply along with simple indicators of electricity reliability and capacity, as follows:

- **Sources of power:** Primary and backup power sources (such as grid/community system, on-site PV solar, stand-alone generator or other);

- **Reliability:** Defined by whether electricity has been interrupted in the past week, and whether both primary and secondary electricity sources are functional and (in the case of a generator) have fuel available;
- **Power capacity:** Whether power is available for "lights only," "lights plus some medical devices" or "lighting, communication and all medical devices."

Enhancing the SARA toolkit to include a stand-alone energy survey module could capture all key attributes of energy supply and support a standardized metric for energy access measurement in health facilities within and across countries. Such a tool could be used on its own for benchmarking and periodically tracking energy performance. Key questions could be further integrated into an enriched energy section of core annual facility infrastructure surveys. Such data would provide useful insights into aspects of health services constrained due to electricity supply issues, such as lack of a reliable backup electricity source. A draft framework for a stand-alone SARA "energy module" is considered in Annex 1.

As for the financial and operational sustainability of the energy system, the World Bank has recently initiated a Service Delivery Indicator (SDI) survey tool that captures health facility expenditures for facility operational functions, including electricity provision. The survey tool also documents funding sources (user fees, donors, public funds, etc.). This tool has so far been tested in three countries; seven more surveys are due for completion in 2014 (The World Bank, 2013). This tracking of electricity cost data could be used synergistically with data on: electricity access, sources of electricity supply, and performance/reliability to develop a profile of what energy modes can deliver electricity to health facilities most cost-efficiently and reliably.

Table 8. Health equipment by power load level

	Lighting load[xxx]	Low-power-load devices (<500 W)		High-power-load appliances (>500 W)
GENERAL EQUIPMENT	Basic lighting General lighting	Phone charging VHF radio Air circulation Computer Modem Printer Basic refrigeration		Projectors Water pumping Space heating Air conditioning
MEDICAL EQUIPMENT		UV water purifiers Light for neo-natal jaundice Blood chemistry analyzer Sputum test equipment LED or bright field (white light) microscope Vacuum aspirator or D&C kit Portable ultrasound (DC model) Fluorescence microscope Micro-nebulizer Suction apparatus	ECG machine Vortex mixer CD4 counter Incubator Hematology mixer Centrifuge Anaesthesia machine Oxygen concentrators Dry heat sterilizer Vaccine refrigeration Dental compressor check wattage	Hand dryers Obstetric incubator Boiler or steamer Autoclave Waste autoclave & grinder X-ray machine

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[xxx] Specific medical lighting devices, such as light for neo-natal jaundice, are considered under medical devices.

6

A 'multi-tier metric' for electricity access

Assessment of electricity demand and supply, as described in Chapters 3 and 4, can be done at facility level to support more informed local energy investment and management decisions. In order to derive a profile of electricity access nationally, regionally or globally, data aggregation into key indicators of health sector energy access is essential. As with other areas of health service delivery, tracking and monitoring of key energy access indicators can inform national and international decisions on energy policies and health sector investments. This can identify what works in terms of approaches, needs and gaps, as well as wise energy investments' impacts on health systems and health outcomes.

This chapter considers one potential formula for aggregating critical supply-side attributes (or deficits) of energy supply into an *electricity access tier* rating as part of a *multi-tier metric* measuring access to electricity in health clinics. Such a metric characterizes access to electricity in terms of the combined service attributes available in progressively higher tiers of electricity services. It thus represents the cumulative impact of assets or deficiencies in access to energy for various facility needs.

This approach is based on the Global Tracking Framework (GTF) report for the *Sustainable Energy for All* initiative (Sustainable Energy for All, 2013).[xxxi] The GTF report presents a multi-tiered framework for household energy access, and proposes to develop similar frameworks for access to energy for productive and community energy uses, including health facilities.

This framework recognizes that measuring electricity access in terms of a grid-electricity connection ignores off-grid solutions while also disregarding shortfalls in grid-based supply in many developing countries. It recognizes the multiplicity and capabilities of energy sources, from simple solar lanterns and small solar generation systems to larger mini-grids and centralized grid systems.

For a technologically neutral comparison of supply solutions in terms of applications they support, electricity supply may be assessed based on the recognized attributes of high-performing systems discussed in Chapter 4. These include capacity, duration, quality, reliability, operational sustainability, as well as environmental sustainability and health impacts when these can be measured. The metric involves a five-tiered framework in which each tier is defined by the

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[xxxi] The *SE4ALL* initiative was originally initiated by the United Nations Secretary-General, and is now co-chaired by the World Bank President.

combined quality of eight measurable electricity attributes. Progressively higher tiers represent greater access to power sources that can reliably and efficiently supply electricity to run more electric applications. Not every facility, however, will need to attain the highest tier of energy/electricity access – as facilities have very diverse needs. Rather than setting prescriptive goals, the intention is to suggest useful energy thresholds against which health systems and health facilities may begin to evaluate their level of energy access against needs as defined by national or local health systems.

Since this metric is consistent with the *SE4ALL* Global Tracking Framework approach, it can empower the health sector to formulate methods to track progress in electricity access in a way that is compatible with methods being used for other essential services and sectors, such as schools.

Electricity access tier ratings for health facilities

An electricity access tier at the health facility level may be obtained by compiling the assessment of each electricity supply attribute. In a multi-tier framework, progressive tiers represent improving levels of electricity supply across the nine attributes, thus implying enhanced ability to deliver medical services reliably, affordably and sustainably (Table 9). The combined power supplies from all primary and secondary sources of electricity are considered for capturing these attributes, providing that the systems are functional and (in the case of generators) have fuel available. The electricity access tier for a health facility corresponds to the lowest tier obtained across the nine attributes. Health facility operations that could be supported by progressively higher tiers of service are noted in Table 10.

Solar-powered *health centre in rural Uzbekistan. A recent government initiative aims to improve health services by harnessing solar energy as a source of reliable power and heating. (Photo: UNDP/Uzbekistan)*

Table 9. Proposed multi-tier measurement of electricity supply in primary and secondary health facilities

	Tier 0 No access	Tier 1 Minimal access	Tier 2 Basic access	Tier 3 Intermediate access	Tier 4 Advanced access	Tier 5 Full access
Peak power capacity Watts (W)	<5	5–69	70–199	200–1999	2000–9999	≥10 000
Daily energy capacity Watt hours [Wh] per day	–	20–279 Wh per day	280–1599 Wh per day	1600–31 999 Wh per day	32–220 KWh per day	>220 kWh per day
Duration of supply Hours per day	–	≥4	≥4	≥8	≥16	≥23
Evening peak hours supply Hours per day	–	–	≥2	≥2	4	4
Cost-effectiveness (affordability)* Lifetime costs per kilowatt hour	–	≤ 5 times benchmark	≤ 3 times benchmark	≤ 2 times benchmark	≤ 1.5 times benchmark	≤ 1 times benchmark
Quality No/poor/unstable voltage	–	–	–	Adequate	Adequate	Adequate
Reliability No outages of more than 2 hours in the past week	–	–	–	–	Adequate	Adequate
Operational sustainability Adequate operation and maintenance budget)#	–	–	–	Adequate	Adequate	Adequate
Environmental sustainability and health (g $CO_{2\text{-eq}}$ /kWh)[xxxii]	–	≤2400 g $CO_{2\text{-eq}}$/kWh	≤1400 g $CO_{2\text{-eq}}$/kWh	≤1000 g $CO_{2\text{-eq}}$/kWh	≤850 g $CO_{2\text{-eq}}$/kWh	≤500 g $CO_{2\text{-eq}}$/kWh

* The grid tariff applicable to health clinics located in the nearest electrified area is taken as a benchmark for affordability.

\# Electricity is not vulnerable to interruption as a result of: unpaid utility bills and/or lack of budget for fuel purchases; maintenance; lack of spare parts or (PV) battery replacement.

As in Table 9, the tiers of access to electricity supply, representing improving levels of supply performance, may be described as follows:

Tier 0 (no access): The health facility does not have access to any electricity supply (except dry-cell batteries with a peak power capacity of less than 5 W). As a result, the facility has to rely on kerosene lamps or candles for lighting and a dry-cell battery-powered radio.

Tier 1 (minimal access): The health facility can access at least 5 W of peak available capacity for at least four hours during the day, typically for electrical lighting. It is also possible that the facility faces issues of inadequate evening supply, quality, reliability and operational or environmental sustainability.

Tier 2 (basic access): The health facility can access at least 70 W of peak available capacity for at least four hours per day, including at least two hours after nightfall if required. The supply is capable of meeting additional applications beyond lighting such as blood analyzer, UV water purifier, jaundice light, VHF receiver, LED microscope, air circulation, printing, ultrasound and vacuum aspirator. The facility may experience reliability issues and/or voltage problems, as well as difficulties with operational and environmental sustainability.

[xxxii] g $CO_{2\text{-eq}}$ /kWh: The thresholds described here refer approximately to mean emissions factors of oil-based and renewable power generation technologies as described in Chapter 4 and by (Edenhofer, et al., editors [2011]) and (Natural Resources Canada, 2008). With reference to these sources, specific thresholds are defined as follows: Portable diesel generator of <15 kW with no battery storage (1.4–2.4 kg $CO_{2\text{-eq}}$ /kWh); portable generator of < 15 kW with battery storage (1.2 kg $CO_{2\text{-eq}}$ /kWh); coal-fired grid (1 kg $CO_{2\text{-eq}}$ /kWh); oil-fired grid (850g $CO_{2\text{-eq}}$ /kWh); natural gas-fired grid (<500g/kWh); and nuclear or renewables including photovoltaics, concentrating solar power, geothermal, wind and hydropower (≤250g/kWh). Where available, PM_{10} emissions factors may be a more sensitive indicator of local environmental health risks. However, the same electricity generation technologies that have progressively lower emissions of CO_2 also tend to emit progressively less PM, making $CO_{2\text{-eq}}$ emissions a reasonable proxy indicator for health as well as environment.

Table 10. Health facility electrical applications likely to be supported, by tier of service

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Likely feasible applications	-	Cell phone Basic lighting Blood analyzer 3 LED lights (3 W)	Cell phone Basic lighting Blood analyzer UV water purifier Jaundice light VHF receiver LED microscope Light microscope Air circulation Printing Ultrasound Vacuum aspirator	Cell phone Basic lighting Blood analyzer UV water purifier Jaundice light VHF receiver LED microscope Light microscope Air circulation Printing Ultrasound Vacuum aspirator Xenon microscopy Vacc. refrigerator Micro-nebulizer ECG machine ELISA test Suction apparatus Vortex mixer GeneXpert MTB/RIF External lighting CD4 counter Hematology mixer Centrifuge Anaesthesia mach. Oxy. concentrator V-Sat connection Dry heat sterilizer Basic water pumping	Cell phone Basic lighting Blood analyzer Refrigerator UV water purifier Jaundice light VHF receiver LED microscope Light microscope Air circulation Printing Ultrasound Vacuum aspirator Xenon microscopy Vacc. refrigerator Micro-nebulizer ECG machine ELISA test Suction apparatus Vortex mixer GeneXpert External lighting CD4 counter Hematology mixer Centrifuge Anaesthesia mach. Oxy. concentrator V-Sat connection Dry heat sterilizer Incubator Ultrasound Water pumping Portable air con. Boiler or steamer Hand dryer Waste autoclave Autoclave grinder Portable heater Desktop autoclave	Cell phone Basic lighting Blood analyzer Refrigerator UV water purifier Jaundice light VHF receiver LED microscope Light microscope Air circulation Printing Ultrasound Vacuum aspirator Xenon microscopy Vacc. refrigerator Micro-nebulizer ECG machine ELISA test Suction apparatus Vortex mixer GeneXpert External lighting CD4 counter Hematology mixer Centrifuge Anaesthesia mach. Oxy. concentrator V-Sat connection Dry heat sterilizer Incubator Ultrasound Water pumping Portable air con. Boiler or steamer Hand dryer Waste autoclave Autoclave grinder Portable heater Desktop autoclave X-ray machine
Possible electricity supply technologies based on peak power	Dry cell Solar lantern	Portable or small fixed solar panel array for devices with rechargeable batteries	– – Fixed solar panel array or on-site generator with or without battery	– – – On-site solar panel array diesel generator or solar/generator hybrid with battery charging/mini-grid/grid	– – – Large solar array and/or diesel generator w/ battery charger Small hydro-electric mini-grid/grid	– – – – Grid or mini-grid of diverse generation technologies, CHP, etc.

Note: The electricity source is typically used to run multiple applications simultaneously. Ideally, an assessment of capacity requirement should involve a combination of peak available capacity and average daily energy requirements, taking into account the daily usage patterns of different applications. However, in this simplified estimation, it is assumed that not all devices are used simultaneously and no more than one third of the peak available supply capacity source will be used for any single device.

Tier 3 (intermediate access): The health facility can access an electricity supply of least 200 W of peak available capacity for at least eight hours during the day, of which at least two hours are in the evening. In addition to applications mentioned in Tier 2, the health clinic is able to use most medium-capacity equipment, such as suction apparatus, vortex mixer, CD4 counter and centrifuge. While the facility does not face issues of supply quality or reliability, it may face environmental and operational sustainability problems.

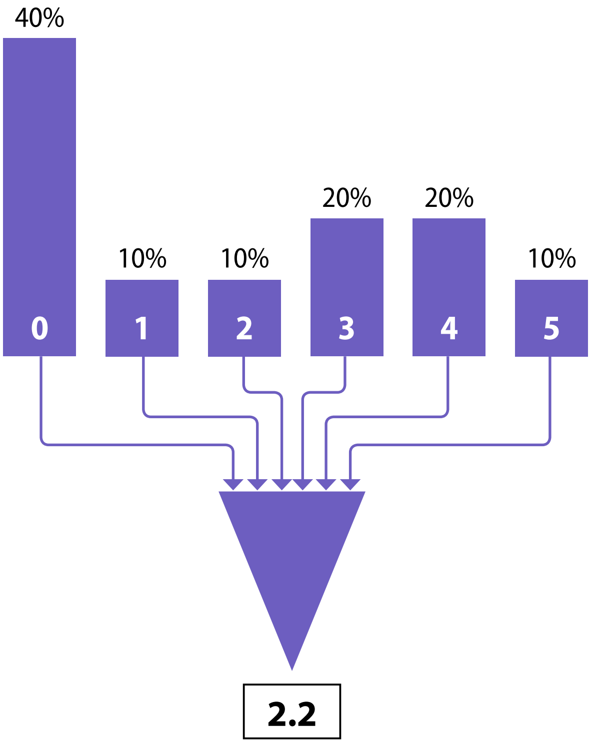
Tier 4 (advanced access): The health facility has access to an electric supply of at least 2000 W and can operate most applications, though it may be constrained to use a large number of these applications simultaneously (for example, in a large clinic with multiple high-capacity applications). Supply is available for at least 16 hours per day, including all of the evening hours. Voltage is adequate and interruptions are infrequent. The facility has sufficient funds to pay for fuel and electricity bills and to cover any maintenance costs. Also, the electricity source does not cause negative environmental or health impacts in the local area around the health clinic.

Tier 5 (full access): Health facilities can access virtually unlimited amounts of power, including at all hours of the day and night without any deficiencies in quality or reliability of supply. Additionally, the health facility has sufficient funds to pay for fuel and electricity bills and to cover any maintenance costs. The electricity source does not cause any negative environmental health impacts in the local area around the health clinic.

Electricity access index: aggregation of tiers into a single value

Policy dialogue at national and global levels often focuses on a single indicator such as GDP that can reflect a range of variables in a single value that is easily understood by policy-makers. In the case of energy, an *Index of Electricity Access in Health Clinics* may be proposed. This index may be calculated by aggregating the weighted proportion of health facilities in each of the electricity access tiers (Fig. 6). The index may be obtained for a geographical area or for a specific type of facility (hospitals, dispensaries, etc.). This index varies between 0 and 5 and represents the average electricity access level in health facilities in a country, province or project area. Such an index is sensitive to electricity supply conditions in health facilities; it also allows comparison across countries and regions and can be easily understood by policy-makers and the public. If the required data is collected periodically, progress in electricity access can be monitored by comparing an area's index over time. However, aggregating the electricity access tiers of health facilities makes detailed information on different attributes less visible. A disaggregated data analysis to clarify the underlying trends of different attributes, and other parameters can be used to complement the aggregate index.

Fig. 6. Index of access to electricity in health facilities



Index of electricity supply in health facilities = Σ(Rk x k)

where, R_k = proportion of health facilities at the kth tier

K = tier number [0,1,2,3,4,5]

Disaggregated data analysis

The data collected as inputs to the multi-tiered approach can also be used for a disaggregated analysis in the form of a "diagnostic of electricity access" for a facility or smaller facility clusters. This provides a better understanding of the electricity supply situation in health facilities relative to their service provision needs, and highlights areas for improvements (Box 4).

Additionally, analysis of the incidence of various aspects of electricity supply constraints (such as gaps in peak available capacity or power interruptions may be undertaken in relation to available supply technologies (e.g. grid, solar PV or diesel generator, hybrid system, etc.). This can identify which "packages" of energy technologies and in what combinations offer the highest overall levels of service in different settings. Operational sustainability, comparative cost of electricity, and environmental sustainability can also be assessed across technologies on an equal playing field. Disaggregated data analysis across various parameters mentioned above can be conducted in relation to factors such as: the geographical location of the health facility, facility size, public versus private sector ownership, and medical services provided. Such analysis can provide insights into where efforts to improve electricity services need to be concentrated.

Capacity and reliability of energy services may also be assessed not only in terms of improved health services and health systems energy savings, but also in relation to health outcomes such as reduced maternal and child mortality (MDGs 4 and 5). These health outcomes are likely to be associated with more reliable electricity provision. Confounding variables, such as differences in equipment levels and staff competencies in health facilities with similar levels of electricity access, must also be considered for a robust analysis of health outcomes.

Overall, such disaggregated analysis of indicators can provide invaluable inputs for policy formulation, project design, utility performance accountability, regulatory processes, and evaluation of project impact. It can also help identify settings and energy combinations that work well and offer opportunities for further qualitative assessment to fine-tune best-practice strategies and approaches to energy provision.

Box 4. A diagnostic of electricity access

Data collected on electricity supply through the use of improved survey tools can contribute to national, regional or global databases covering key indicators such as:

(i) the proportion of health facilities with no access, or very minimal access, to electricity;
(ii) the proportion of health facilities with both primary and backup electricity systems;
(iii) the proportion of facilities using different sources of stand-alone electricity supply (both fuel-based and renewable systems);
(iv) the proportion of health facilities with evening service hours, and whether electricity is available then;
(v) the proportion of health facilities with reliable and unreliable electricity supplies;
(vi) the proportion of health facilities reporting low-voltage problems;
(vii) the proportion of health facilities with a functional backup system by type of technology (including fuel availability);
(viii) the proportion of health facilities with sufficient budget allocations to pay operating and maintenance expenses;
(ix) the proportion of health facilities with affordable electricity; and
(x) the proportion of facilities with low-emissions energy systems.

Limitations of the proposed methodology

The proposed methodology requires further expert review and pilot testing for fine-tuning and validation. It is also subject to the following inherent limitations:

Energy access is one of many elements in the health system: Higher levels of electricity access will not, in and of itself, yield better health services or outcomes. Suitable medical equipment and devices, essential medicines and trained staff are required to deliver services reliably. While having unrestricted access to clean and reliable energy sources, as reflected in the highest energy tiers, is generally desirable as a long-term social goal, it is not a realistic option for many small, off-grid facilities. And not all facilities would need to reach the highest tier(s) of access to deliver quality services – e.g. "well-baby" clinics operating in close proximity to referral centres. Therefore the "tiers" proposed in the multi-tiered framework, should be seen as providing useful technology-based thresholds for evaluating levels of energy access.

High-end health facilities likely require a separate customized metric: The proposed metric adequately tracks the energy access level of most health facilities, but may not be appropriate for high-end hospitals and specialized clinics. It may not fully capture their large and diverse energy demands, nor account for energy efficiency attained through sophisticated building design and energy management systems that are increasingly common in large modern hospitals in some developing countries. In high-end facilities with an abundant power supply and extensive use of sophisticated medical equipment, the main focus is not on energy access but on energy cost savings through greater efficiencies, which are measurable in terms such as average kWh of power use per square meter of floor space or patient bed. At the same time, many large hospitals in developing cities face frequent energy outages and shortages. Further work may need to be undertaken to expand or supplement the multi-tiered metric proposed here with measures that are more sensitive to the large-hospital sector.

Thermal energy produced by non-electrical sources is not reflected: The proposed metric is limited to access to electricity supply and does not capture energy released through the direct combustion of fuels for heating, cooking, sterilization or other applications.[xxxiii]

Energy-efficient facility design as a parameter of sustainable energy supply: While the proposed multi-tiered system includes a sustainability indicator for energy supply, energy-efficient building design is a key determinant of sustainability of energy on the demand side. This is not fully reflected in the multi-tiered framework. As noted in Chapter 3, design elements such as the thermal envelope, effective natural ventilation, daylighting and passive solar heating or shading can drastically reduce building needs for lighting, heating and cooling by 30–50%, or even more. Particularly in energy-poor settings, those features might help close the "capacity gap" between available energy supply and demand, as discussed in the next section.

Assessing supply in relation to demand: the 'electricity access gap'

An even more fundamental limitation of the multi-tiered approach is that it focuses primarily on tracking energy access on the "supply side" and less on the "demand side" of the equation. It looks at the attributes of the energy being supplied, but ignores the energy requirements of the health services that need to be provided. Tracking this demand side can help ascertain at what thresholds health facilities in energy-constrained

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[xxxiii] In the case of direct fuel combustion, the joule and its multiples (e.g. kilojoule) are standard measures of energy released as heat.

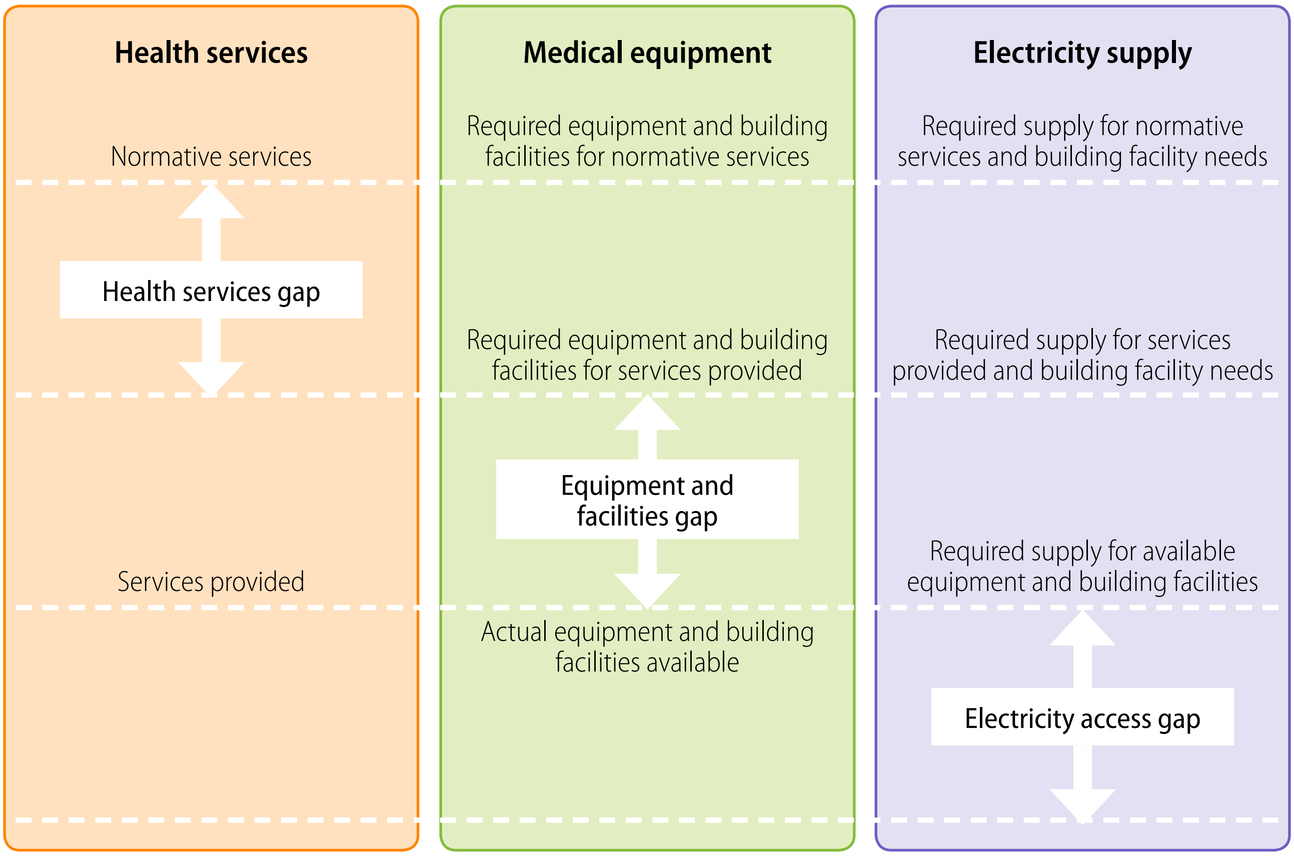
settings can access adequate energy for all of their functions and services.

Multi-country tracking of this demand side, however, remains problematic. Unlike for water, sanitation or essential medicines, where universal norms have been defined, there are no internationally validated health sector norms for the minimum amount of electricity that should be available at any level of the health system. Nor are there minimum standards for essential electrical medical devices and appliances. Finally, no universal norms exist for health facility design and related energy requirements. Setting forth such norms and standards is a task that may be addressed in the context of global energy access and sustainability policies, but it lies beyond the scope of this document.

In countries with plentiful electricity, energy demand or "energy load" requirements for a health facility will usually be defined by a regulatory or hospital engineering standard defining an average of kWh/m2 or kWh/bed required for all building purposes. Load requirements for critical functions such as lighting, cooling and heating may be calculated separately to assess potential savings that may be achieved from energy efficiencies. Such standardized minimum baselines of electricity demand per unit area or per bed may not be relevant to the realities of resource-constrained facilities that may be able to access only minimal energy supplies.

In the interim, the multi-tiered metric proposed here can support local or national assessment of what could be described as a health facility's *electricity access gap* (Fig. 7) in relation to: (a) normative health services that should be available; (b) medical equipment and building facilities that should be available; or (c) medical equipment and building facilities that actually are available as identified from a bottom-up inventory of

Fig. 7. Health services, equipment and electricity access gaps



Thanh Ba district, *Phu Tho province, Viet Nam: Pilot tests of this solar-powered refrigerator found that the cold chain could be preserved for up to two weeks without electricity. (Photo: Project Optimize/PATH/Hai Le)*

equipment and building energy needs, as described in Chapter 3. This can still be extremely useful for informing local or national assessments and investments in energy systems.

However, for purposes of multi-country monitoring, the proposed multi-tiered framework discussed here does not attempt to establish a universal absolute minimum for electricity demand parameters that specify the amount of electricity that "should" be available at any particular level of the health system to power a given array of equipment and building functions.

This framework instead supports the simple and straightforward goal of mapping and monitoring electricity supply-side parameters in the health sector in terms of services actually provided. This leaves room for future determination of a universal energy access norm for health facilities that could yield more specific targets for energy demands in relation to different levels of health care facilities or levels of health services provision. Until then, individual countries need to determine what levels of electricity supply at different levels of the health system are adequate in order to move toward the overall goal of universal health service coverage.

7

Way forward

This report highlights the importance of energy access in health facilities, describing the current state of electricity access as well as factors affecting demand and supply. The emerging options for reliable and affordable electricity supply have been discussed, especially those using solar energy and combined heat and power systems. There is a need to harmonize and deepen data collection efforts regarding access to electricity in health facilities by incorporating information about key attributes of electricity supply. This report proposes a new framework for tracking electricity access that overcomes the limitations of current indicators and paves the way for more sensitive data collection to inform policy needs and decisions. The multi-tier framework introduces a methodology that identifies electricity supply deficiencies that directly affect delivery of health services based on refinement of available data and surveys. Limitations of these approaches are acknowledged while improvements in data collection tools also are proposed.

Next steps

Two parallel tracks can be envisaged to further improve energy access in health facilities. Firstly, improved measurement and tracking of energy access can be achieved through piloting, validation and broader application of a multi-tier framework. Secondly, scaling up energy access requires a range of actions, including:

a) Research to further define optimal energy technologies and packages in different settings, as well as defining priority health needs with the most acute need for rapid scale-up of energy investments;

b) Innovative financial and policy approaches to catalyze increased investment in electricity supply and maintenance in health facilities;

c) Capacity-strengthening to enable health facilities in low-income countries to efficiently manage their energy resources and sustain them.

What follows are summary recommendations and a brief discussion of the approaches that can be taken in each of these parallel tracks.

I. Improve monitoring of energy access

Build consensus on measurement and monitoring approaches. Expanded consultation should be conducted with relevant stakeholders and experts on proposed measurement frameworks and related survey tools in order to improve the methodology, address technical or practical concerns, and harmonize monitoring approaches. Such consultations should include international health organizations and development agencies (such as USAID and the Global Fund to Fight AIDS, Tuberculosis and Malaria) that regularly undertake health facility infrastructure surveys, along with national governments from developing country regions.

Integrate questions into existing survey instruments. Improved survey methods and questions should be added to existing survey tools such as the SARA, SPA, national surveys and existing health sector surveys. This will expand their use and enhance national capacity to measure energy access in health facilities without survey duplication or undue data collection burdens.

Pilot the measurement framework. The proposed methodology should be tested and validated through piloting in a number of countries. Pilot surveys allow fine-tuning of questions to ensure they are well understood by respondents and yield accurate results. In addition, data obtained could be used for compiling energy access ratings for each health facility surveyed, and a comparison analysis could be undertaken to test the multi-tier method.

Scale-up regular tracking efforts. After the framework is validated, efforts should focus on scaling-up tracking of health facility energy access through improved methods and tools, including a harmonized set of core questions and parameters for energy access measurement, as well as measurement of energy costs. Engagement with other stakeholders, including ministries of health and donor agencies, will help to include core questions in existing national surveys and multi-country surveys, without imposing undue new data collection burdens on countries.

WHO would collate all nationally representative data obtained in its existing Health Facility Energy Database for easy analysis and dissemination. Global tracking would support the monitoring of progress towards the overall goals of the SE4All initiative, and progress on specific, related efforts, such as the High Impact Opportunity activity of *Energy for Women's Health*.

II. Scale up energy access through a three-pronged approach including:

A. Research

Scale-up research to identify the energy technologies or hybrid systems most appropriate for different levels of health facility provision in grid and off-grid settings. Research into effective interventions can help define the optimal energy technologies and technology packages most suitable for health facilities in resource-constrained settings with reference to design, installation and maintenance issues.

Baseline data obtained through improved survey tools is invaluable in supporting research to determine which energy systems interventions best address deficiencies highlighted in the baseline survey in a cost-effective and sustainable way. Simulation models can be developed to assess energy interventions' effectiveness in improving health facilities' energy access.

Conduct health-systems research to better define the empirical linkages between energy access, health services and health. Available evidence on how energy access issues in health facilities affect delivery of services is broadly anecdotal; few studies clearly establish causal linkages. Further studies should focus on establishing these linkages through data analysis of health systems' performance and health outcomes. Research can also help to better define the priority health needs which most acutely require new energy investments – such as maternal/child health, non-communicable disease prevention and treatment, etc. This would support prioritization of the types of health services or facilities where improved electricity access can make the most immediate difference, as well as identify the countries or regions with greatest needs.

An aerial view *of University Hospital of Mirebalais, Haiti, reveals 1,800 solar panels on the hospital's rooftop. The 205,000-square foot, 300-bed facility provides primary care services to 185,000 people in Haiti's Central Plateau, as well as secondary and tertiary care to all of central Haiti and the city of Port-au-Prince. (Photo: Rebecca E. Rollins / Partners In Health)*

B. Policy and finance innovation

Develop evidence-based norms for minimum energy requirements. Norms should be developed with reference to: different health facility types; typical health services provided; equipment required for delivering such services; and the electricity needs of such equipment. These norms will reflect country needs and contexts and can help set interim and long-term energy access goals. International norms would inform and support the development of national standards and regulatory requirements related to the procurement, installation, maintenance and operation of emerging energy technologies in health care facilities.

Develop and pilot innovative business and policy models. Delivery of adequate, reliable and affordable energy to health clinics in low-income countries is hampered by multiple challenges. These include: arranging initial capital; funding operating expenses; and the timely maintenance, repair and replacement of equipment. Electricity utilities in many developing countries are themselves weak institutionally, financially and in terms of physical grid infrastructure.

Innovative business and policy models need to be explored to catalyze increased investment in modern energy systems, support wider access to electricity as well as good practices for sustainable delivery and use. Targeted delivery of electricity access to health clinics should include financial packages for piloting of different on-site, mini-grid and grid systems. These should be built and tested for their efficacy in sustaining access to energy. Such models should also consider revenue-generating mechanisms from on-site energy production that can help ensure operational sustainability. An enabling policy environment also needs to be created with appropriate fiscal incentives. Finally, public-private partnerships are needed that combine support from national and international health and energy budgets with private-sector investment. The ultimate goal is to catalyze interventions that strengthen health services' access to energy to ensure effective delivery of health services to all.

C. Capacity strengthening

Along with stimulating energy investments and a favorable policy environment, capacity to procure, manage and sustain energy systems needs to be strengthened. Small, medium and large health clinics' managers or administrators must be equipped with the tools and knowledge to assess and improve their own systems, to ensure sustainable financial and operational maintenance and to implement good practices in the procurement and effective use of electric medical devices. Given the time and skills demanded for such tasks, new forms of service agreements may be required, particularly for the smallest facilities lacking assessment and maintenance capacity on-site.

Conclusions

There is increasing awareness of the energy access gap that regularly leaves tens of thousands of health facilities across wide swathes of the developing world, quite literally, in the dark. This should stimulate policymaker interest and muster political will to bring about significant change.

An overarching message of this report is the need for closer cooperation between health and energy sectors at all levels. This report prepared jointly by the World Health Organization and the World Bank has attempted to sow the seeds for such an effort.

Cooperation can begin with better tracking of the state of energy access in health facilities, including a well-rounded profile of the "attributes" of available energy supply in terms such as reliability, power capacity, costs and sustainability, which are vital to assessment and planning of improvements. New policies and financing approaches also need to be designed to incentivize more efficient use of energy, stimulate capital investments, and strengthen the health sector's capacity to plan, implement and maintain energy systems. Strategies should be based on continued monitoring that provides feedback to decision-makers on the effectiveness of interventions.

Steps to implement the recommendations made here can be advanced through a wide range of channels, including new and existing energy sector initiatives as well as health sector programmes in maternal and child health, and other areas of disease prevention and control. Joint initiatives, such as the SE4All *High Impact Opportunity on Energy for Women's and Children's Health,* provide new opportunities for building momentum.

If the appropriate follow-up steps are taken, we can simultaneously expand access to modern energy services and access to critical public health services among the world's most underserved populations, advancing the dual goals of universal health coverage and sustainable energy for all.

ANNEX 1.

A proposed **SARA energy module**: sample survey questions for multi-tier measurement

This annex contains a proposed energy module for the WHO SARA questionnaire. It has been developed to inform further discussion on the measurement of energy access in health care facilities, including in the context of WHO expert consultations on the topic taking place in 2015. The draft energy module is intended to provide indicative examples of questions for further refinement and pilot testing.

The SARA questionnaire gathers the following information on health facilities' electricity supply (World Health Organization, 2013b):

- Whether the health facility has electricity from any source;
- Primary and backup electricity sources, including: grid sources, generators, solar systems or other;
- Uses of electricity in the facility (e.g. lighting and communications, lighting, communications and a few devices: all applications, etc.);
- Hours of health facility operation;
- Whether electricity supply was available at all times during the facility's service hours in the past week (with no interruptions of more than two hours at a time);
- Whether the generator is functional;
- Whether fuel is available or the battery is charged;
- Whether the solar system is functional.

Table A1 presents the draft of a proposed stand-alone *SARA Energy Survey Module* that could serve the purpose of baseline energy measurement and periodic tracking of energy access in health facilities in line with SE4ALL goals for energy access in health services and the multi-tiered framework described in Chapter 5 of this report. This tool would be intended to supplement the core energy questions in the existing SARA survey, which is administered annually.

The current energy survey questions in the core SARA infrastructure module are noted in *yellow* along with examples of proposed new questions for the stand-alone energy module in *blue*, which would cover more completely the diverse attributes of electricity supply and performance described in Chapter 5 of this report.

Table A1. Proposed structure for a SARA Energy Module based on SARA core infrastructure survey

Note: Existing SARA energy questions are highlighted in yellow. Numbering of existing questions has been preserved, but order of some questions has been changed so as to accommodate an expanded survey format. New questions are generally proposed as additions but some are refinements of existing questions.

Questions on capacity			
409	Does your facility have electricity from any source (e.g. electricity grid, generator, solar, or other) including for stand-alone devices (EPI cold chain)?	Yes	1
		No	2
409_01	What is the electricity used for in the facility? (Note: This question is only for facilities that replied "Yes" to having electricity – Q. 408)	Only stand-alone electric medical devices/appliances (e.g. EPUI cold room, suction apparatus, refrigerator, etc.)	1
		Electric lighting (excluding flashlights) and communications	2
		Electric lighting, communications and 1 to 2 medical devices/appliances	3
		All electrical needs of the facility	4
		All electrical needs of the facility and staff housing	5
409_02 (Proposed additional question)	If the facility has no electricity, what is its primary lighting source?	No source of lighting	0
		Kerosene lamps	1
		Candles	2
		Battery-operated lamps/flashlights	3
		Other (Specify)	96
410	What is the facility's main source of electricity?	Central supply of electricity (e.g. national or community grid)	1
		Generator (fuel or battery-operated)	2
		Solar system	3
		Other (Specify)	96
410 (Proposed refinement)	If the facility has electricity, what is its main source? Note: This means the electricity source that you rely upon most of the time.	Central supply electricity grid	1
		Local mini-grid	2
		On-site hybrid solar/generator	3
		On-site generator (with battery storage)	4
		On-site generator (no battery storage)	5
		On-site solar system (except lanterns)	6
		Dedicated hydropower system	7
		Dedicated wind power system	8
		Rechargeable battery system	9
		Solar lanterns	10
		Other (Specify)	96
411	Other than the main or primary source, does the facility have a secondary or backup source of electricity? IF YES: What is the secondary source of electricity?	No secondary source	0
		Central supply of electricity (e.g. national or community grid)	1
		Generator (fuel- or battery-operated)	2
		Solar system	3
		Other (Specify)	96
411 (Proposed refinement)	Other than the main or primary source, does the facility have a secondary or backup source of electricity? If so, what is the secondary source of electricity?	No back-up source	0
		Central supply electricity grid	1
		Local mini-grid	2
		On-site generator (with battery storage)	3
		On-site generator (no battery storage)	4
		On-site solar system (except lanterns)	5
		Dedicated hydropower system	6
		Dedicated wind power system	7
		Rechargeable battery system	8
		Solar lanterns	9
		Other (Specify)	96

411_01 (Proposed additional question)	If you have both a primary and a backup source, do you have an energy management system to switch automatically between the two sources?	Yes, automatic shift, with fuel efficiency optimization (for example with wind / solar) .... 1 Yes, automatic shift; but no efficiency optimization .... 2 No, a manual startup is needed 3
411_02 (Proposed additional question)	If you have no backup electricity source, what is your backup lighting source?	No back-up source of lighting .... 0 Kerosene lamps .... 1 Candles .... 2 Battery-operated lamps/flashlights .... 3 Other (Specify) 96
	Check questions 410 and 411:	
	Facility has a generator. **Go to questions 412_01 and 412_02 ↓**	Facility does not have a generator. **Skip questions 412_01 and 412_02 →**
412_01	Is the generator functional?	Yes .... 1 No .... 2 Don't know 98
412_02	Is there generator fuel or a charged generator battery available today?	Yes .... 1 No .... 2 Don't know 98
412_02A (Proposed refinement)	Does the generator have a charged battery available today?	Yes .... 1 No .... 2 Don't know 98
412_02B (Proposed refinement)	Does the generator have fuel available today?	Yes .... 1 No .... 2 Don't know 98
	Check questions 410 and 411:	
	Facility has a solar system or lantern. **Go to questions 412_03 and 412_04 ↓**	Facility does not have a solar system or lantern. **Skip questions 412_03 and 412_04 →**
412_03	Is the solar system functional?	Yes, functioning .... 1 Partially, battery needs servicing or replacement .... 2 No, not functional .... 3 Don't know 98
412_04 (Proposed additional question)	For how many hours a day, on average, does the solar system provide you with power?	4 hours or less .... 1 5 to 8 hours .... 2 9 to 16 hours .... 3 17 to 23 hours .... 4 24 hours 5
Questions on duration		
408	On average, how many hours per day is this facility open?	4 hours or less .... 1 5 to 8 hours .... 2 9 to 16 hours .... 3 17 to 23 hours .... 4 24 hours 5
408_01 (Proposed additional question)	On average, for how many hours in a 24-hour day is electricity available should you need to use it?	4 hours or less .... 1 5 to 8 hours .... 2 9 to 16 hours .... 3 17 to 23 hours .... 4 24 hours 5
Questions on evening supply		
408_02 (Proposed additional question)	On average, for how many hours during the evening (after 6 p.m.) and night is the facility open for services?	Never open after 6 p.m .... 1 Until 8 p.m. .... 2 Until 10 p.m. .... 3 Until midnight .... 4 All night long 5

408_03 (Proposed additional question)	On average, for how many hours during the evening (after 6 p.m.) and night is electricity available at the health facility?	Less than 1 hour	1
		1 to 2 hours	2
		3 to 4 hours	3
		5 to 8 hours	4
		8 to 14 hours	5
Questions on reliability			
412	During the past 7 days, was electricity available at all times (when it was needed*) from the main or any backup source when the facility was open for (regular or emergency*) services? (*proposed wording changes)	Always available (no interruptions)	1
		Often available (some interruptions of less than 2 hours per day)	2
		Sometimes available (frequent or prolonged interruptions of more than 2 hours per day)	3
413 (Proposed additional question)	If connected to the grid, on an average day, how many times does the facility face electricity supply interruptions from the grid?	No interruptions	1
		1-3 Interruptions per day	2
		More than 3 interruptions per day	3
413_01 (Proposed additional question)	If primarily using on-site generation, on an average day, how many times does the facility face electricity supply interruptions?	No interruptions	1
		1-3 Interruptions per day	2
		More than 3 interruptions per day	3
413_02 (Proposed additional question)	On an average day, what is the total duration of all supply interruptions taken together?	No interruptions	1
		Less than 30 minutes	2
		31 to 60 minutes	3
		61 minutes to 4 hours	4
		5 to 8 hours	5
		More than 8 hours	6
413_03 (Proposed additional question)	When are supply interruptions most common?	Daytime (before dark)	1
		Evening (after dark to midnight)	2
		Overnight (midnight to 8 a.m.)	3
Questions on quality			
414 (Proposed additional question)	Does the facility usually face a problem of low voltage or voltage fluctuations from the main source?	Yes	1
		No	2
414_01 (Proposed additional question)	Have voltage fluctuations (if any), to your knowledge, damaged equipment in the past year?	No	1
		Some equipment damaged	2
		Significant equipment damaged	3
Questions on financial sustainability			
415 (Proposed additional question)	If you use electricity from the grid, did you have sufficient budgetary allocation (funds available) for paying your electricity bills in the last two months?	Yes	1
		No	2
		Don't know	98
		Not applicable	99
415_01 (Proposed additional question)	If you use electricity from the grid, who pays the electricity bill for the health clinic?	Ministry of Health/district health office	1
		Donor	2
		Health facility	3
		Combined funds from donor, facility, ministry	4
		All electricity is metered and billed to patients	5
		Some electricity is billed to patients	6
		Don't know	7
415_02 (Proposed additional question)	Over the last two months, did you have sufficient budgetary allocation (funds available) for fuel for the stand-alone generator to operate at all times when it was needed?	Yes	1
		No	2
		Don't know	98
		Not applicable	99

415_03 (Proposed additional question)	Who pays for generator fuel?	Ministry of Health/district health office	1
		Donors	2
		Health facility	3
		Combination of facility, ministry, donor sources	4
		Private purchases by patients or staff	5
		Combination of private purchases and other sources.	6
		Don't know	98
		Not applicable	99
415_04 (Proposed additional question)	If you use a solar energy-based electricity solution, over the last year, did you have sufficient budgetary allocation (funds available) to replace light bulbs and battery for the solar panel?	Yes	1
		No	2
		Don't know	98
		Not applicable	99
415_05 (Proposed additional question)	If you use a solar energy-based electricity solution, who pays for light bulbs and solar parts replacement?	Ministry of Health/district health office	1
		Donor	2
		Health facility	3
		Patients	4
		Combination of facility, ministry, donor sources	5
		Private payments by staff or patients	6
		Combination of private purchases and other sources	7
		No one	8
		Don't know	98
		Not applicable	99
415_06 (Proposed additional question)	Over the last two months, did you have sufficient budgetary allocation (funds available) for maintenance of electricity supply equipment?	Yes	1
		No	2
		Don't know	98
		Not applicable	99
Questions on environmental sustainability			
416 (Proposed additional question)	Does your primary source of lighting (including kerosene lamps or candles) or electricity cause any pollution of air in the local area in or around the health clinic, through production of fumes or gases that potentially harm the health of the patients or the health workers?	Yes	1
		No	2
		Don't know	98
416_01 (Proposed additional question)	Does your primary source of lighting or electricity cause any pollution of water or soil in the local area in or around the health clinic, through improperly discharged oils, exhausts or other pollutants that potentially harm the health of the patients or the health workers?	Yes	1
		No	2
		Don't know	98
416_02 (Proposed additional question)	Does your primary source of electricity cause any significant noise pollution in the local area in or around the health clinic that potentially harms the health of the patients or the health workers?	Yes	1
		No	2
		Don't know	98

41X-1 (Proposed additional question)	Which of the following devices are available at the health facility? If available, does the facility have sufficient power to run them when needed during the day?	Total number of devices available	Does the facility have sufficient electricity to run them?	
			Yes	No
	LIGHTING			
01 A	Number of rooms with lights			
01 B	LED light bulbs			
01 C	CFL light bulbs			
01 D	Fluorescent lights (other than CFLs)			
01 E	Incandescent light bulbs			
01 F	Flashlights/portable electric lanterns/headlamps			
01 G	Kerosene lamps			
	INFRASTRUCTURE			
02	Cell phones			
03	Computer			
04	Internet			
05	Printer			
06	VHF radio			
07	Fan			
08	Evaporative cooler			
09	Air conditioner unit			
10	Space heater unit			
11	Central air conditioning for facility			
12	Heating for all facility			
13	Piped water			
14	Electric water pump			
	CLINICAL APPLIANCES			
15	Electric equipment sterilization autoclave (pressure and wet heat)			
16	Solar equipment sterilization autoclave			
17	Non-electric equipment sterilization autoclave			
18	Electric dry heat sterilizer			
19	Electric boiler or steamer (no pressure)			
20	Non-electric pot with cover for boiling/steam			
21	General purpose refrigerator (size in litres: _____)			
22	Heat source for non-electric equipment			
	CLINICAL MEDICAL DEVICES			
23	Micro-nebulizer			
24	Oxygen concentrator			
25	Vaccine/lab refrigerator (specify size: _____ litres)			
26	Suction apparatus			
27	Vacuum aspirator or D&C kit			
28	Incubator			
29	X-ray machine			
30	Anaesthesia machine			
31	Refrigerator for blood storage			
32	Blood chemistry analyzer			
33	Centrifuge			
34	CD4 counter			
35	LED microscope			
36	Bright light microscope			
37	Mercury or xenon microscope			
38	Halogen microscope			
39	ELISA equipment			
40	Vortex mixer			
41	Ultrasound equipment			
42	CT scanner			
43	ECG			
44	Waste autoclave or microwave			
45	Waste incinerator			

ANNEX 2.

Compendium of existing health services surveys

This annex provides a brief compendium of key initiatives related to mapping energy access in the health sector, as they exist today.

Data survey and collection initiatives

Service Availability and Readiness Assessment (SARA)

This methodology was developed as part of a joint collaboration between the World Health Organization, the United States Agency for International Development (USAID) and the International Health Facility Assessment Network (IHFAN) to measure and track progress in health system strengthening. It is a health facility assessment tool designed to monitor service availability and health sector readiness, and to build capacity in national health systems to conduct their own assessments as well as to analyze data and generate evidence to support health system planning and management.

***Objective*:** The objective is to generate information on service delivery aspects such as the availability of key human and infrastructure resources (including energy), basic equipment and amenities, essential medicines and diagnostic capacities and on the readiness of health facilities to provide basic health-care interventions.

***Methodology*:** The methodology builds upon previous and current approaches designed to assess service delivery, including the service availability mapping (SAM) tool developed by WHO, and the service provision assessment (SPA) tool that was developed under the USAID-funded *Monitoring and Evaluation to Assess and Use Results: Demographic and Health Surveys* (MEASURE-DHS) project. The framework includes an extensive survey encompassing seven sections (World Health Organization, 2013b). Service readiness is evaluated generally and for specific areas: (i) maternal and newborn health; (ii) child and adolescent health; (iii) communicable diseases; (iv) noncommunicable diseases; (v) surgery; (vi) diagnostics; and (vii) medicines/commodities. All categories are considered necessary components of national health care systems (Table A2).

To assess the readiness of each service, the equipment required to achieve the service in question is listed in the questionnaire, and the surveyor asks whether each item of functional equipment is available. For example, for childbirth and delivery services, this equipment might include an examination light, sterilization equipment, laboratory kits, etc. The energy-related equipment referenced in this report is primarily extracted from this list and presented along with indicative energy demands (Table 3 in Chapter 3).

In the current SARA, however, the same medical device or appliance may be referenced several times if it is used for multiple health services. Thus it is difficult to determine from the survey data the total number of electrified devices in a facility, and therefore difficult to estimate electricity requirements. As a result,

Table A2. SARA core infrastructure survey: main components

COVER PAGE		
• Interviewer visits • Facility identification • Geographical coordinates		
MODULE 1: SERVICE AVAILABILITY		
Section 1	**Services available**	
Section 2	**Staffing**	
Section 3	**Inpatient and observation beds**	
MODULE 2: SERVICE READINESS		
Section 4	**Infrastructure**	
	1. Communications	6. Processing of equipment for re-use
	2. Ambulance/transport for emergencies	7. Health-care waste management
	3. Power supply	8. Supervision
	4. Basic client amenities	9. Basic equipment
	5. Infection control	10. Infection control precaution
Section 5	**Available services**	
	1. Reproductive, maternal and newborn health	3. Communicable diseases
	• Family planning services	• HIV counseling and testing
	• Antenatal services	• HIV treatment
	• Prevention of mother-to-child transmission	• HIV care and support
	• Obstetric and newborn care services	• Sexually transmitted infections
	• Caesarean section	• Tuberculosis
	2. Child and adolescent health	• Malaria
	• Child immunization	4. Noncommunicable diseases
	• Child preventative and curative care services	• Diabetes
	• Adolescent health services	• Cardiovascular diseases
		• Chronic respiratory diseases
		• Cervical cancer
		5. Surgery
		• Surgical services
		• Blood transfusion
Section 6	**Diagnostics**	
Section 7	**Medicines and commodities**	

Source: Adapted from (World Health Organization, 2013b).

the proposed survey module presented in Annex A1 provides for the quantification of absolute numbers of individual equipment items in the entire facility, so as to permit an accurate estimate of electricity demand.

Based on the SARA questionnaire, tracer indicators (Table A3) are established for service availability and readiness (World Health Organization, 2013b) to summarize the information gathered and to provide objective information about whether a facility meets the conditions required to support the provision of basic or specific services with a consistent level of quantity and quality. The tracer indicator for power access is defined as: "Facility routinely has electricity for lights and communication (at a minimum) from any power source during normal working hours, there has not been a break in power for more than 2 hours during the past 7 days, or facility has functional generator with fuel."

Table A3. Service availability and readiness indicators

Domain	Tracer indicators, items or services
I. Service availability	
1. Health infrastructure	• Number of health facilities per 10 000 population • Number of inpatient beds per 10 000 population • Number of maternity beds per 1000 pregnant women
2. Health workforce	• Number of health workers per 10 000 population
3. Service utilization	• Outpatient visits per capita per year • Hospital discharges per 100 population per year
II. General service readiness	
1. Basic amenities	Mean availability of seven basic amenities items (%): power, improved water source, room with privacy, adequate sanitation facilities, communication equipment, access to computer with Internet, emergency transportation
2. Basic equipment	Mean availability of six basic equipment items (%): adult scale, child scale, thermometer, stethoscope, blood pressure apparatus, light source
3. Standard precautions for infection prevention	Mean availability of nine standard precautions items (%): safe final disposal of sharps, safe final disposal of infectious wastes, appropriate storage of sharps waste, appropriate storage of infectious waste, disinfectant, single-use disposable/auto-disable syringes, soap and running water or alcohol-based hand rub, latex gloves and guidelines for standard precautions
4. Diagnostic capacity	Mean availability of eight laboratory tests available on-site and with appropriate equipment (%): haemoglobin, blood glucose, malaria diagnostic capacity, urine dipstick for protein, urine dipstick for glucose, HIV diagnostic capacity, syphilis rapid diagnostic test and urine pregnancy test
5. Essential medicines	Mean availability of 20 essential medicines (%): amitriptyline tablet, amlodipine tablet or alternative calcium channel blocker, amoxicillin (syrup/suspension or dispersible tablets AND tablet), ampicillin powder for injection, beclometasone inhaler, ceftriaxone injection, enalapril tablet or alternative ACE inhibitor, fluoxetine tablet, gentamicin injection, glibenclamide tablet, ibuprofen tablet, insulin regular injection, metformin tablet, omeprazole tablet or alternative, oral rehydration solution, paracetamol tablet, salbutamol inhaler, simvastatin tablet or other statin and zinc sulphate (tablet or syrup)
III. Service-specific readiness	
For each service, the readiness score is computed as the mean availability of service-specific tracer items in four domains: staff and training; equipment; diagnostics; and medicines and commodities	• Family planning • Antenatal care • Basic obstetric care • Comprehensive obstetric care • Child health immunization • Child health preventive and curative care • Adolescent health services • Life-saving commodities for women and children • Malaria diagnosis and treatment • Tuberculosis services • HIV: (i) counselling and testing, (ii) care and support services, (iii) antiretroviral prescription and client management, (iv) prevention of mother-to-child transmission • Sexually transmitted infections diagnosis or treatment • Noncommunicable diseases diagnosis or management: (i) diabetes, (ii) cardiovascular disease, (iii) chronic respiratory disease, and (iv) cervical cancer screening • Basic and comprehensive surgical care, including: (i) incision and drainage of abscesses, (ii) wound debridement, (iii) acute burn management, (iv) suturing, (v) closed treatment (reduction) of fracture, (vi) cricothyroidotomy, (vii) male circumcision, (viii) hydrocele reduction, (ix) chest tube insertion • Blood transfusion • Laboratory capacity

Service Provision Assessment of USAID (MEASURE-DHS)

The Service Provision Assessment (SPA) is part of USAID's *Monitoring and Evaluation to Assess and Use Results: Demographic and Health Surveys* (MEASURE-DHS) programme (United States Agency for International Development, 2013). This health facility survey provides a comprehensive overview of a country's health service delivery. Until recently, most available data on electricity access rates in developing-country health facilities was published in SPA reports.

***Objective*:** The SPA survey uses four questionnaire types: inventory questionnaires, observation protocols, exit interview questionnaires and health worker interview questionnaires. These surveys address four groups of questions:

- What is the availability of different health services in a country? Specifically, what proportions of different facility types offer specific health services?
- To what extent are facilities prepared to provide health services? Do facilities have the necessary infrastructure, resources and support systems available? For example, what proportions of facilities have regular electricity or regular water supply?
- To what extent does the service delivery process follow generally accepted standards of care? Do the processes followed in service delivery meet standards of acceptable quality and content?
- Are clients and service providers satisfied with the service delivery environment?

***Methodology*:** The information collected focuses on availability and readiness to deliver different health services to answer these questions. The 10 key services and topics assessed in an SPA survey include infrastructure, resources and systems (water, electricity, latrines, infection control, etc.).[i]

The survey is conducted periodically to obtain an overview of a country's health service delivery, in collaboration with the respective governments (ministries of health and sanitation, etc.). Data is categorized by facility type, managing authority and region. A multiplier is used to ensure data is proportionate to facilities in the country.[ii] A SPA typically collects data from 400–700 facilities through interviews with knowledgeable respondents.

As part of the joint WHO/USAID/IHFAN collaboration on survey methodologies, the SPA inventory questionnaire[iii] was redesigned to harmonize with most of the service readiness indicators in WHO's SARA tool. The SPA surveys provide a breakdown of results according to the typology of health facility as defined by the country's health care system.

Regarding electricity access, however, the SPA survey remains limited to just three or four key questions, and does not capture the more detailed set of energy questions that were incorporated into WHO's SARA in 2013. The SPA energy questions typically consider electricity supply in terms of four questions:

- Does this facility have a generator for electricity? This may be a backup or standby generator? (Response options: Yes, observed/No).
- Does this facility ever obtain electricity from a source other than a generator? (Response options: Yes, central supply; Yes, solar or other source; No).
- Is electricity (not including any backup generator) always available during the times when the facility is providing services, or is it sometimes interrupted? (Response options: Always available; Sometimes interrupted).
- If sometimes interrupted, how many days during the past week was the electricity not available for at least two hours while the facility was open for services? (This includes emergency services.) (Response options: Number of days not available past week; Never interrupted for two hours or more).

It remains difficult therefore to fully assess from the surveys what are all the sources of electricity available, how they are used (e.g. primary or backup source), the total power capacity available to the facility, as well as what sources are more or less reliable. A discussion of the limitations of such survey questions can be found in Adair-Rohani et al. (2013).

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[i] Others include: child health, maternal and newborn health, family planning, HIV/AIDS, sexually transmitted infections, malaria, tuberculosis, basic surgery and noncommunicable diseases. Details available at: http://www.measuredhs.com/What-We-Do/Survey-Types/SPA.cfm

[ii] Available at: http://www.measuredhs.com/What-We-Do/Survey-Types/SPA.cfm

[iii] Available at: http://www.measuredhs.com/publications/publication-spaq1-spa-questionnaires.cfm

Living Standards Measurement Study

The Living Standards Measurement Study was established by the World Bank's Development Economics Research Group to identify ways to improve the type and quality of household data collected by statistical offices in developing countries with the aim of increasing use of such data in policy-making (The World Bank, 2007). Although it only includes questions regarding households and not health facilities, some questions pertain to health facilities.

***Methodology*:** Health-related data is available in 17 categories, including health care services, health facilities questionnaires and a wide range of services and treatments. No energy-specific categories or questions are included.

Health-related data categories are: health and fertility; illness or injury; health care services; expenses; vaccination; maternal and child health; reproductive health; fertility preferences; HIV/AIDS; insurance or benefits for health services; public health education; activities of daily living; anthropometrics; health behaviors; mental health; domestic violence; and a health facilities questionnaire.

A typical household questionnaire consists of hundreds of questions. An example of a question is: "Has [name] received a polio vaccine that is pink or white drops in the mouth. Answer YES, NO, or DON'T KNOW."

The data sets and questionnaires are available on the study website; data collected is uniform across every country.

National data collection initiatives

Individual countries are active in measuring and collecting data through government departments and initiatives. While this is undoubtedly happening in many countries, little information is accessible in the public sphere and it is not compiled for regions or globally. For instance, the Liberian Ministry of Health and Social Welfare collects annual data on electricity access, sources of access (e.g. grid, generator, solar or combination) and reliability of access for all public health facilities (Adair-Rohani et al., 2013). India's Ministry of Health and Family Welfare periodically collects data on two basic indicators of electricity access for primary health care facilities as well as health subcentres that includes several thousand facilities out of a national total of about 175,000 facilities (Ministry of Health and Family Welfare, 2011).

Significant efforts are required to introduce and coordinate systematic national data collection initiatives with new measures. Uganda has undertaken a similar effort; Table A4 presents data on energy sources by health facility type in Uganda.

Table A4. Uganda indicative rural electrification plan, 2008

	% of total	Grid or permanent mini-grid	Stand-alone diesel or solar system	Without access
Urban hospital	2	100 (except for a few district hospitals)	A few district hospitals	
Rural hospital (HV IV)	7	27–43 (NGO hospitals have higher access rates)	57–73	
Rural health centre (HC III)	27	14	52	34
Rural dispensary (HC II)	65	6	29	65

Source: (African Renewable Energy Access Program, 2010).

Energy modeling and data tracking tools

World Health Organization

Based on the SARA survey tool and other representative national studies, WHO is developing a database to track energy access in health facilities of developing countries for its Global Health Observatory.[iv] WHO maintains a database on availability of national standards or recommended lists of medical devices for most countries (World Health Organization, 2014b). Its *Baseline country survey on medical devices* provides country information on availability of specific medical devices, policies, guidelines, standards and services and maintains country-wide lists of medical devices for different types of health care facilities or specific procedures (World Health Organization, 2010a).

USAID's Powering Health

The USAID Powering Health programme (United States Agency for International Development, 2013a) has developed an overall off-grid energy information package to help energy experts and procurement officers collect and analyse information, plan cleaner and more efficient on-site power systems in off-grid health centres, and develop specifications and bidding documents. The range of tools includes an energy audit tool for use by practitioners in health facilities. This tool provides a list of appliances and their estimated energy requirements to permit easy calculation of the amount of energy facilities require, as well as daytime and night-time loads. Another tool models and assesses renewable, fuel-based and hybrid energy optimization scenarios that could then meet the load requirements, including data on investment, operating costs, and pollution and carbon emissions for alternative systems. This tool makes use of the National Renewable Energy Laboratories HOMER optimization model demonstrated in Chapter 4 (United States Agency for International Development, 2012).

World Health Statistics 2012

The World Health Statistics Report (World Health Organization, 2014c)is an annual WHO publication of health-related data from 194 Member States. The report collects data on 10 focus areas, including health infrastructure, although no energy-specific indicators are included. The data are available online at the Global Health Observatory website, which provides access to over 50 datasets on priority health topics including mortality and burden of disease, Millennium Development Goals and health systems.

[iv] (http://www.who.int/gho/en/)

ANNEX 3.

Categorization of health care facilities

Table A5 provides some indicative examples of how health facilities may be classified and categorized by different organizations and in different countries. While there are clearly common denominators to the levels of care, these examples also illustrate the complexity of the task of deriving universal standards for this area.

Table A5. Categorization of health facilities – indicative examples

Categorization based on national health care system in selected countries				Categorization by selected organizations		
Kenya	**Uganda**	**Bangladesh**	**India (National Rural Health Mission)**	**USAID Powering Health**	**EC ENABLE project**	**WHO**
Hospitals	Hospitals	Union health and family welfare centres/rural dispensaries	District hospitals	Category III health clinics (antiretroviral treatment clinics)	Provincial/ general hospitals	Regional/ provincial hospitals
Health centres	Health centre IV	NGO health facilities	Community health centres	Category II health clinic (blood banks, pharmacies, stand-alone labs)	District hospitals	District hospitals
Primary care facilities including: • Maternity clinics • Dispensaries • Stand-alone voluntary counselling and testing	Health centre III	Upazila health complexes	Primary health centres	Category I health clinic (health posts, blood banks, pharmacies, stand-alone labs)	Subdistrict/ cottage hospitals	Health centres
–	Health centre II	–	Health subcentres	–	Health centres	Health posts
(USAID/Measure Health, 2010)	(USAID/Measure Health 2007)	(USAID/Measure Health, 2000)	(Government of India, Planning Commission, 2011)	(United States Agency for International Development, 2012)	(European Commission, 2006)	(World Health Organization, 2010a)

ANNEX 4.

Comparing Costs and Emissions of Alternative Energy Strategies in a Scenario Using Conventional Medical Devices and Energy-Efficient Devices

1. Introduction

A simulation was conducted to compare the costs of different stand-alone power supply technologies to a hypothetical health clinic in rural Kenya. This simulation tested and compared power supply arrays reliant upon a fuel-based generator, a PV solar system, and hybrid PV and generator combinations, with and without battery backup. It looked at costs of the different supply options (both initial and long-term), as well as at pollution and climate emissions.

The simulation further explored these supply options for two demand scenarios: one using conventional medical devices and one using more energy-efficient medical devices that reduce the clinic's overall energy demand.

The hypothetical health facility described here is characteristic of real-life situations prevalent in rural health clinics in many parts of sub-Saharan Africa. The clinic contains a limited array of basic medical equipment, has little or no access to a power grid, and is thus dependent primarily upon on-site power production. While fuel-based diesel generators are generally inexpensive and available, fuel costs are high. Ample solar resources make solar energy a potentially attractive option over the long term. However, the balance of costs and benefits for the different options can vary significantly – and this is what the simulation can test objectively.

The simulation model is based on USAID's Health Clinic Power System Design tool. This online software tool employs NREL's HOMER optimization model to assist health care providers in designing appropriate power systems for rural health clinics using available combinations of grid power, diesel generators, battery storage and renewable energy arrays (e.g. PV solar, pico-hydro and wind turbines). (United States Agency for International Development, 2012).

2. Baseline assumptions (component costs, solar resources and "noise" variance)

2.1. Cost of key components (including hardware, installation and labour) and interest rate for capital investments

PV System cost (US$ 2/Wp)

The cost of PV panels on the Kenyan market was estimated as US$ 0.600/Wp based on prices cited by Kenyan suppliers (based on the cost of a module of 1210 x 808 x 35 mm size generating 130 watts of peak power (Wp DC) in controlled conditions)[v]. Based on expert opinion[vi], this was adjusted upward to US$ 2/Wp to account for other support components that are required, also known as balance of system (BOS) parts, such as cables, charge controller with Maximum Power Point Tracker, lightening protection, as well as delivery/labour and installation costs.

Inverter cost (US$ 0.320/Wp)

The cost of an inverter, based on prices cited by Kenyan suppliers, was US$ 0.320/Wp[vii].

Battery cost (US$ 180/kWh)

The cost of a 6V/225Ah lead acid battery on the Kenyan market was found to be in the range of US$ 172[viii]. Including, balance of system (BOS) components and labour/installation costs, the capital cost for the battery arrays was adjusted upward to US$ 180/kWh, based on expert opinion.[vi] The precise number of batteries required for each option is then determined by the simulation.

Generator Cost (US$ 1000/kW)

The capital cost of the genset includes the generator itself (usually diesel or gasoline), as well as BOS costs and labour/installation costs. On the Kenyan local market, a generator of smaller range (2–5kVA) was priced at about US$ 991[ix]. Including BOS and labour/installation costs, the total price was estimated at around US$ 1,000 per kW load, based on expert opinion[vi].

Fuel cost (US$ 1.2/L)

The source for this estimate was the Kenyan official market rate as of October 2014[x]. Amount of fuel for each option is determined by the simulation.

Interest rate – 7.5%

Interest rates vary widely, and can be particularly high in developing countries, having a profound impact on the cost-benefit assessment. Interest rates on Kenyan commercial bank loans may be as high as 15%[xi], while a rate for subsidized loans from bilateral or intergovernmental agencies (e.g. World Bank) was estimated at around 5%. A mid-way figure of 7.5% was selected for this case study.

2.2. Solar resources data for latitude 1°2' South, longitude 39°30' East

The solar resources available at the location are critical to the simulation, as they define the operational capacity of the solar panels throughout the year. Fig. A1 shows that solar radiation is relatively steady throughout the year in this location, although there are slight peaks and dips in dry and rainy seasons.

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[v] Cost of the PV panel was estimated based on the pricing from two sources, Ubbink East Africa Ltd., listed by ENergy Focus (ENF) (available from: https://www.enfsolar.com), and Alibaba.com factory-direct sale (available from: http://www.alibaba.com/product-detail/OEM-price-per-watt-130w-solar_1705582279.html?spm=a2700.7724857.35.1.aH1tzs&s=p).

[vi] Personal communication with Professor Brahmanand Mohanty, Asian Institute of Technology, School of Environment, Resources and Development, Thailand.

[vii] Cost of the inverter was based on the pricing from firm Sollatek Electronics, listed by ENergy Focus. Available from: https://www.enfsolar.com.

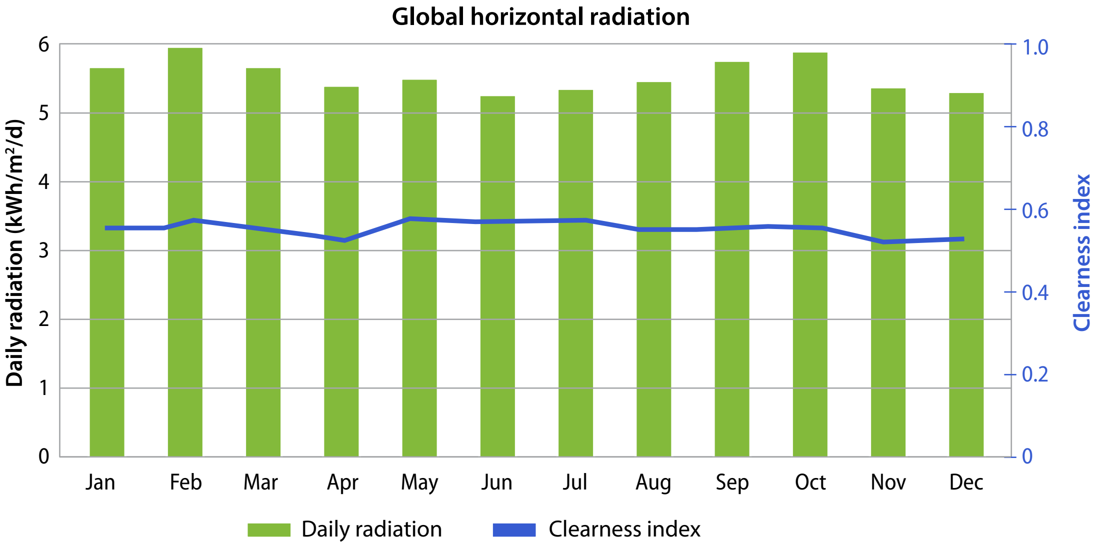
[viii] Cost of lead acid batteries for small, off-grid power applications based on pricing from the Center for Alternative Technologies, Nairobi, Kenya. Kenyan local price was estimated at Ksh 17 356. Available from: http://cat.co.ke/store/trojan-t-105–6-volt-deep-cycle-flooded-battery/.

[ix] Personal communication with the firm Davis and Shirtliff: Water and Energy Solutions for Africa regarding the price of a 2–5 kVA generator. Kenyan local price was estimated at Ksh 100 000. Available from: https://www.davisandshirtliff.com.

[x] Kenya Energy Regulatory Commission. Available from: http://www.erc.go.ke/index.php?option=com_content&view=article&id=162&Itemid=666.

[xi] Kenya Bank Lending Rate was cited in *Trading Economics*. Available from: http://www.tradingeconomics.com/kenya/bank-lending-rate.

Fig. A1: Solar resource data for latitude 1°2'S, longitude 39°30'E



Source: Graphic portrayal of solar resource data simulation based upon the *Powering Health* tool (United States Agency for International Development, 2012).

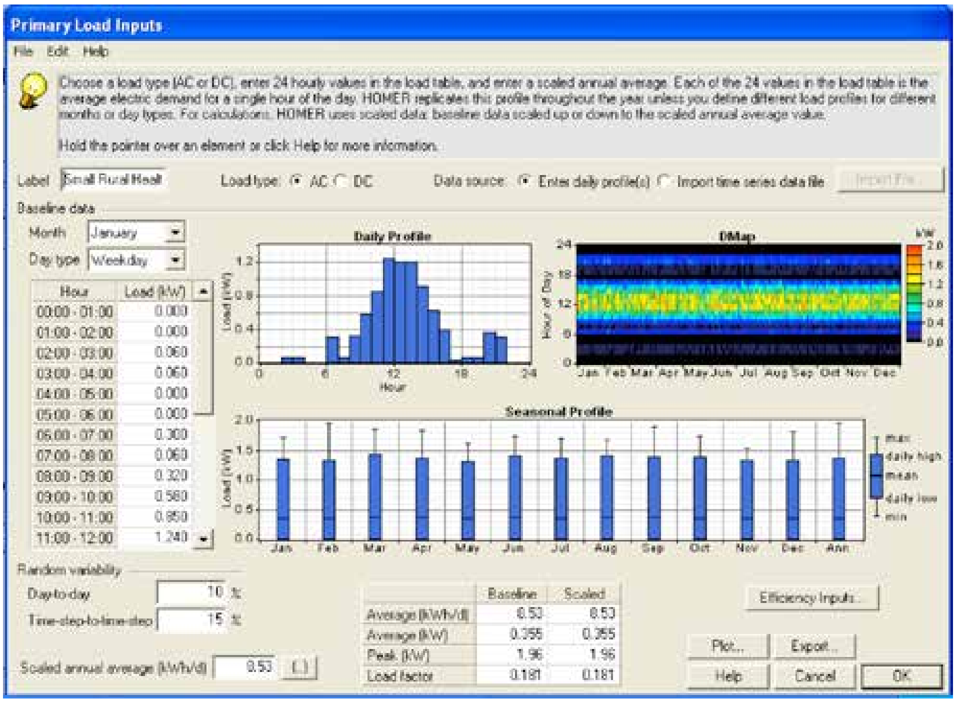
2.3. Daily (day-to-day) and hourly (time-step-to-time-step) noise

Variations in the actual demand for power and clinic operations are considered in the model as "noise". Daily and hourly "noise" refers to variations in the load that are likely to occur in any power system on an hourly or daily basis. Without any added noise, the load profile repeats precisely day after day. In reality, the size and shape of the load profile will vary, so we can add daily and hourly noise to the HOMER model to make load data more realistic.

The assumption in this case study was that there would be a 10% daily noise and 15% hourly noise variance. Using these inputs, the HOMER model randomly perturbs the daily load profile, once daily, from a normal distribution with a mean of zero and a standard deviation equal to the daily noise input value. It randomly perturbs the hourly load profile once every hour from a normal distribution with a mean of zero and a standard deviation equal to the hourly noise input value. The result is that the load retains the same overall shape for each day but it may be scaled upwards or downwards slightly (Fig. A2).

Fig. A2. Baseline data with daily noise of 10% and hourly noise of 15% for (a) conventional medical devices, and (b) energy-efficient medical devices

Source: Screenshot of online *Powering Health* tool simulating electricity load demands (United States Agency for International Development, 2012).



Choose a load type (AC or DC), enter 24 hourly values in the load table, and enter a scaled annual average. Each of the 24 values in the load table is the average electric demand for a single hour of the day. HOMER replicates this profile throughout the year unless you define different load profiles for different months or day types. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value.

Hold the pointer over an element or click Help for more information.

Label: Small Rural Healt

Load type: ● AC ○ DC

Data source: ● Enter daily profile(s) ○ Import time series data file

Baseline data

Month: January

Day type: Weekday

Hour	Load (kW)
00:00 - 01:00	0.000
01:00 - 02:00	0.000
02:00 - 03:00	0.060
03:00 - 04:00	0.060
04:00 - 05:00	0.000
05:00 - 06:00	0.000
06:00 - 07:00	0.300
07:00 - 08:00	0.060
08:00 - 09:00	0.320
09:00 - 10:00	0.580
10:00 - 11:00	0.850
11:00 - 12:00	1.240

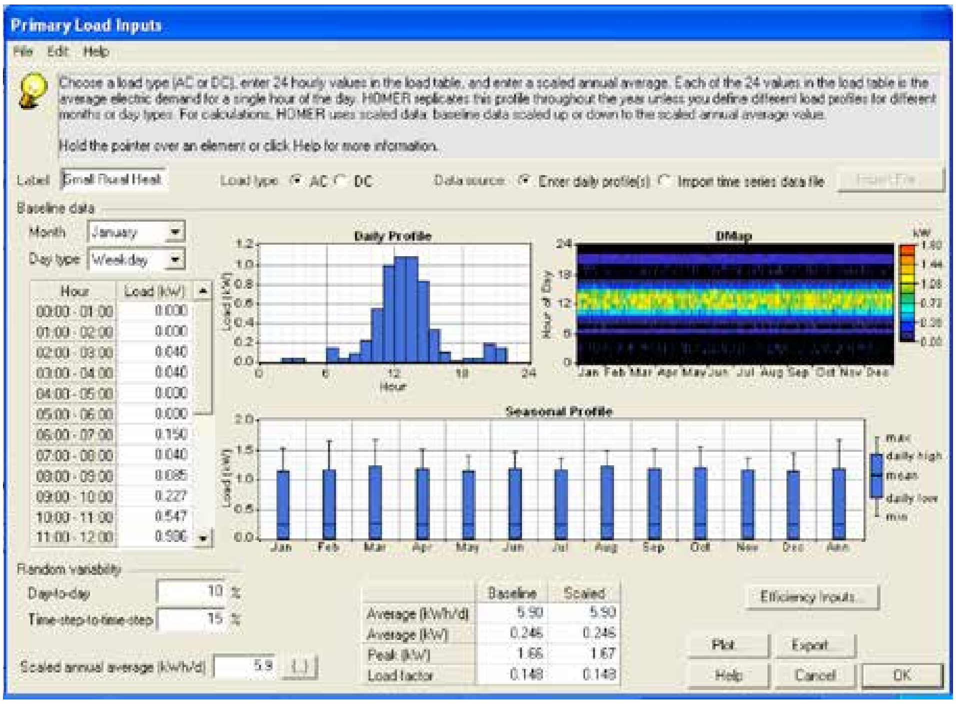
Random variability

Day-to-day: 10 %

Time-step-to-time-step: 15 %

Scaled annual average (kWh/d): 8.53

	Baseline	Scaled
Average (kWh/d)	8.53	8.53
Average (kW)	0.355	0.355
Peak (kW)	1.96	1.96
Load factor	0.181	0.181



Choose a load type (AC or DC), enter 24 hourly values in the load table, and enter a scaled annual average. Each of the 24 values in the load table is the average electric demand for a single hour of the day. HOMER replicates this profile throughout the year unless you define different load profiles for different months or day types. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value.

Hold the pointer over an element or click Help for more information.

Label: Small Rural Healt

Load type: ● AC ○ DC

Data source: ● Enter daily profile(s) ○ Import time series data file

Baseline data

Month: January

Day type: Weekday

Hour	Load (kW)
00:00 - 01:00	0.000
01:00 - 02:00	0.000
02:00 - 03:00	0.040
03:00 - 04:00	0.040
04:00 - 05:00	0.000
05:00 - 06:00	0.000
06:00 - 07:00	0.150
07:00 - 08:00	0.040
08:00 - 09:00	0.085
09:00 - 10:00	0.227
10:00 - 11:00	0.547
11:00 - 12:00	0.596

Random variability

Day-to-day: 10 %

Time-step-to-time-step: 15 %

Scaled annual average (kWh/d): 5.9

	Baseline	Scaled
Average (kWh/d)	5.90	5.90
Average (kW)	0.246	0.246
Peak (kW)	1.66	1.67
Load factor	0.148	0.148

3. Scenario for clinic equipped with conventional medical devices

3.1. Power requirements and load demand

For this scenario, medical device and appliance power requirements were presumed to be at the higher end of the range. (see Table 3, Chapter 3: Indicative power requirements of electrical devices for health services).

A load profile of the health clinic was then developed based on estimates of these medical device and appliance power requirements at different times of the day and night – while patterns may vary a great deal, in this case the presumption was that the clinic is only open in the daytime (7.00am–6.00pm) – with essential appliances like the refrigerators operating intermittently during the night.

An estimate of total daily energy required is then developed based on an analysis of the electricity load profile (Table A6) and a presumed distribution of the daily load demands between day, evening and night-time hours for each scenario (Table A7 and Fig. A3). The peak load occurring at any given time of the day or night is 1.24 kW; the least load is 0.03 kW (Fig. A4). The clinic was presumed to require 8.61 kWh/day to run available health services.

Table A6: Load profile for facility equipped with conventional medical devices

S/no	Power Consumption	Qty	Power (Watts)	Total (Watts)	Daytime hours (07:00–17:59)	Evening hours (18:00–21:59)	Night hours (22:00–06:59)	Total Hours/ day	Total Energy (kWh/ day)
1	Refrigerator-Vaccine	1	60	60	5	3	2	10	0.60
2	Refrigerator-non-medical	1	300	300	2	2	1	5	1.50
3	Centrifuge	2	242	484	4			4	1.94
4	Microscope	2	20	40	6			6	0.24
5	Blood Chemical Analyzer	1	88	88	4			4	0.35
6	Hematology Analyzer	1	230	230	4			4	0.92
7	CD4 Machine	1	200	200	4			4	0.80
8	Radio	1	30	30	2			2	0.06
9	Tube fluorescent lights	4	40	160	8			8	1.28
10	Desktop Computer	1	230	230	4			4	0.92

Fig. A3: Graphic portrayal of hourly electrical demand profile (as per Table A7)

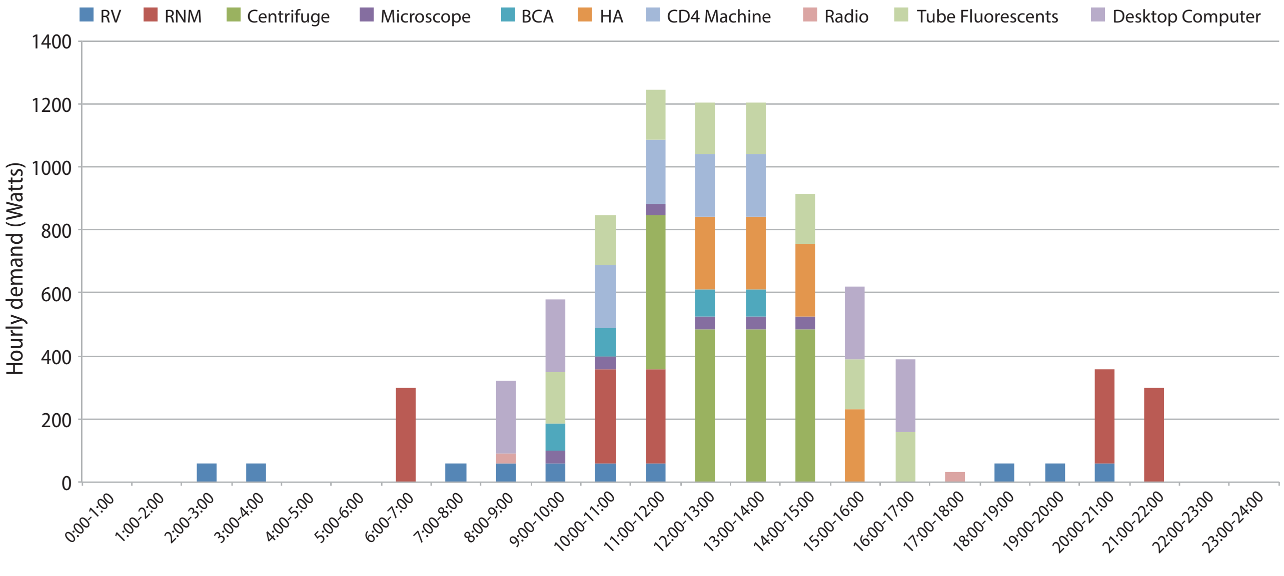
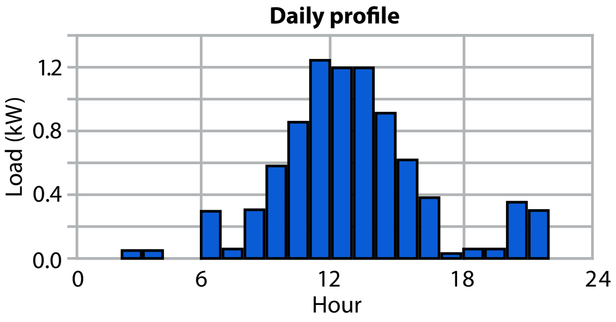


Table A7: Hourly distribution of load demands

Time	DAILY LOAD DEMANDS (WATT)										Total Energy (Wh/d)
	RV	RNM	Centrifuge	Microscope	BCA	HA	CD4 Machine	Radio	Tube Fluorescents	Desktop Computer	
0.00–0.59											
1.00–1.59											
2.00–2.59	60										**60**
3.00–3.59	60										**60**
4.00–4.59											
5.00–5.59											
6.00–6.59		300									**300**
7.00–7.59	60										**60**
8.00–8.59	60							30		230	**320**
9.00–9.59	60			40	88				160	230	**578**
10.00–10.59	60	300		40	88		200		160		**848**
11.00–11.59	60	300	484	40			200		160		**1 244**
12.00–12.59			484	40	88	230	200		160		**1 202**
13.00–13.59			484	40	88	230	200		160		**1 202**
14.00–14.59			484	40		230			160		**914**
15.00–15.59						230			160	230	**620**
16.00–16.59									160	230	**390**
17.00–17.59								30			**30**
18.00–18.59	60										**60**
19.00–19.59	60										**60**
20.00–20.59	60	300									**360**
21.00–21.59		300									**300**
22.00–22.59											
23.00–23.59											
Total	**600**	**1 500**	**1 936**	**240**	**352**	**920**	**800**	**60**	**1 280**	**920**	**8 608**

Abbreviations: RV (Refrigerator-Vaccine); RNM (Refrigerator-non-medical); BCA (Blood Chemical Analyzer); HA (Hematology Analyzer).

Fig. A4: Electric load variation summary for facility using conventional medical devices



3.2. Cost and emissions outcomes for the different power arrays – facility equipped with conventional devices

Table A8 provides the comparative costs of different power supply options for the hypothetical clinic equipped with conventional medical devices. Table A9 provides estimates of the annual CO_2 and pollution emissions for each power supply option.

Table A8: Comparative costs of power supply options

Configuration	PV capacity (kW)	Generator capacity (kW)	No. of batteries (6V/225Ah)	Converter capacity (kW)	Initial capital (US$)	Annual generator usage (hours)	Annual quantity of diesel (L)	Total net present cost (US$) for 25 years	Cost of energy (US$/kWh)	Renewable fraction
Generator only		2.0	-	-	2 000	6 570	2 258	62 862	1.981	0.00
PV + generator	4.0	2.0	-	2.0	10 640	3 714	1 157	43 139	1.359	0.74
Generator + battery		2.0	18	2.0	7 014	2 327	1 395	39 917	1.258	0.00
PV + battery	3.5	-	16	2.0	11 528	-	-	13 992	0.441	1.00
PV + generator + battery	3.0	2.0	8	2.0	10 584	253	91	13 778	0.434	0.96

Table A9: Comparative emissions of power supply options

Configuration	Pollutant Emissions (kg/yr)						Fuel consumption (L/yr)	Operational hour of diesel generator (hr/yr)
	CO_2	CO	*UHC	*PM	SO_2	NO_X		
Generator only	5 947	14.70	1.630	1.110	11.90	131.00	2 258	6 570
PV + generator	3 046	7.52	0.833	0.567	6.12	67.10	1 157	3 714
Generator + battery	3 673	9.07	1.000	0.684	7.38	80.90	1 395	2 327
PV + battery	-	-	-	-	-	-	-	-
PV + generator + battery	239	0.59	0.066	0.045	0.48	5.27	91	253

*Note: PM refers to total particulate matter. UHC refers to unburned hydrocarbons

4. Scenario for clinic equipped with energy-efficient medical devices

In this scenario, a different load profile was constructed using the same suite of medical devices, but referring to the most energy efficient options now available on the market (see Chapter 3, Table 3). Use of such devices, many of which may also operate from batteries and off of DC current, reduces the total energy load required for the facility due to the efficiencies introduced on the demand side. And along with that, the high capital costs for introducing PV panels decline – insofar as a smaller array of PV panels is required to produce the required power.

4.1. Power requirements and load demand

The clinic was presumed to require 5.95 kWh/day to run available health services. These estimates of total energy required are based on an analysis of the electricity load profile (Table A10) and a presumed distribution of the daily load demands between day, evening and nighttime hours for each scenario (Table A11 and Fig. A5). The peak load occurring at any given time of the day or night is 1.07 kW; the least load is 0.02 kW (Fig. A6).

Table A10: Load profile of facility equipped with energy-efficient medical devices

S/no	Power Consumption	Qty	Power (Watts)	Total (Watts)	Daytime hours (07:00–17:59)	Evening hours (18:00–21:59)	Night hours (22:00–06:59)	Total Hours/ day	Total Energy (kWh/day)
1	Refrigerator-Vaccine	1	40	40	5	3	2	10	0.40
2	Refrigerator-non-medical	1	150	150	2	2	1	5	0.75
3	Centrifuge	2	242	484	4			4	1.94
4	Microscope	2	20	40	6			6	0.24
5	Blood Chemical Analyzer	1	45	45	4			4	0.18
6	Hematology Analyzer	1	230	230	4			4	0.92
7	CD4 Machine	1	200	200	4			4	0.80
8	Radio	1	15	15	2			2	0.03
9	Tubular LED lights	4	18	72	8			8	0.58
10	Desktop Computer	1	30	30	4			4	0.12

Table A11: Hourly distribution of load demands

Time	DAILY LOAD DEMANDS										Total Energy (Wh/d)
	RV	RNM	Centrifuge	Microscope	BCA	HA	CD4 Machine	Radio	Tubular LED lights	Desktop Computer	
0.00–0.59											
1.00–1.59											
2.00–2.59	40										**40**
3.00–3.59	40										**40**
4.00–4.59											
5.00–5.59											
6.00–6.59		150									**150**
7.00–7.59	40										**40**
8.00–8.59	40							15		30	**85**
9.00–9.59	40			40	45				72	30	**227**
10.00–10.59	40	150		40	45		200		72		**547**
11.00–11.59	40	150	484	40			200		72		**986**
12.00–12.59			484	40	45	230	200		72		**1 071**
13.00–13.59			484	40	45	230	200		72		**1 071**
14.00–14.59			484	40		230			72		**826**
15.00–15.59						230			72	30	**332**
16.00–16.59									72	30	**102**
17.00–17.59								15			**15**
18.00–18.59	40										**40**
19.00–19.59	40										**40**
20.00–20.59	40	150									**190**
21.00–21.59		150									**150**
22.00–22.59											
23.00–23.59											
Total	**400**	**750**	**1 936**	**240**	**180**	**920**	**800**	**30**	**576**	**120**	**5 952**

Abbreviations: RV (Refrigerator-Vaccine); RNM (Refrigerator-non-medical); BCA (Blood Chemical Analyzer); HA (Hematology Analyzer).

Fig. A5: Graphic portrayal of hourly electrical demand profile (as per Table A11)

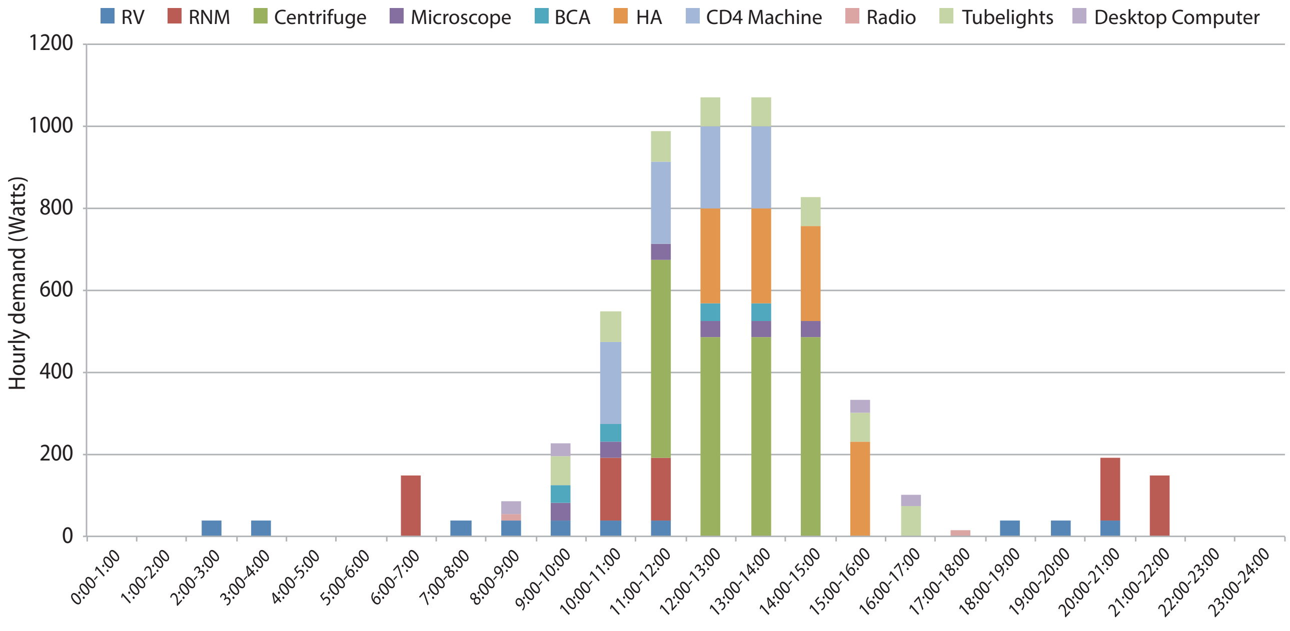
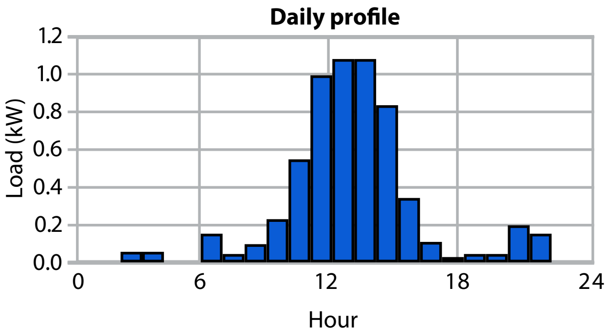


Fig. A6: Electric load variation summary for facility using energy-efficient medical devices



4.2. Cost and emissions outcomes for the different power arrays – facility equipped with energy efficient devices

Table A12 provides the comparative costs of different power supply options for a rural clinic with energy-efficient medical devices. Table A13 provides estimates of the annual CO2 and pollution emissions for each power supply option.

Table A12: Comparative costs of power supply options

Configuration	PV capacity (kW)	Generator capacity (kW)	No. of batteries (6V/225Ah)	Converter capacity (kW)	Initial capital (US$)	Annual generator usage (hours)	Annual quantity of diesel (L)	Total net present cost (US$) for 25 years	Cost of energy (US$/kWh)	Renewable fraction
Generator only		1.7	-		1 700	6 570	1908	53 285	2.427	0.00
PV + generator	3.0	1.7	-	1.7	8 244	3 470	921	34 034	1.550	0.73
Generator + battery		1.7	12	1.7	5 160	2 240	1010	29 799	1.357	0.00
PV + battery	2.5		12	1.7	8 460	-	-	10 305	0.469	1.00
PV + generator + battery	2.0	1.7	6	1.7	7 702	251	74	10 233	0.466	0.95

Table A13: Comparative emissions of power supply options

Configuration	Pollutant Emissions (kg/yr)						Fuel consumption (L/yr)	Operational hour of diesel generator (hr/yr)
	CO_2	CO	*UHC	*PM	SO_2	NO_X		
Generator only	5 023	12.40	1.370	0.935	10.10	111.00	1 908	6 570
PV + generator	2 424	5.98	0.663	0.451	4.87	53.40	921	3 470
Generator + battery	2 658	6.56	0.727	0.495	5.34	58.60	1 010	2 240
PV + battery	-	-	-	-	-	-	-	-
PV + generator + battery	195	0.48	0.053	0.036	0.39	4.29	74	251

*Note: PM refers to total particulate matter. UHC refers to unburned hydrocarbons

5. Discussion

5.1. Scenario using conventional medical devices

The diesel generator without batteries has the lowest capital cost (US$ 2000), but also the highest lifetime cost (US$ 62 862) due to the large and continuous fuel requirements. Adding batteries to the diesel system increases the capital cost but reduces fuel requirements and electricity costs, insofar as storage of excess power generated in off-peak times clearly optimizes fuel efficiency. The capital cost of a PV configuration with batteries is 64% higher than that of a generator and battery combination (US$ 11 528), but the net present cost, representing cost over the lifetime of the system, about one-third of the generator and battery combination (US$ 13 992).

Finally, a PV-diesel hybrid solution supported by battery storage is the most cost-effective over time

(US$ 13 778). The net present cost (NPC) of the PV + diesel + battery hybrid is also slightly lower than the NPC of the PV + battery combination. This is because the PV + battery array has 16 (6V/225Ah) batteries as compared to only 8 batteries in the PV + generator + battery option – and battery maintenance and replacement is comparably expensive. On the other hand, the generator needs to run only for 253 hours in a year, meaning that the net present costs (associated with both the generator purchase and the fuel costs of running the generator) are slightly lower than the capital and maintenance cost of additional batteries. If fuel is generally available, the hybrid system may also be more reliable in regions with prolonged periods of cloudy weather. Conversely, if fuel is not easily available, and solar radiation more stable, then the PV + battery system with a larger battery array may be more reliable – and the cost difference would be fairly negligible.

Notably, the differences in fuel consumed in each array are not always precisely proportional to the differences in operational hours of the fuel generator system. For instance, compare the generator's hours of operation and its fuel consumption in the generator + battery system and the PV + generator array (Table A9).

In the generator + battery system, the generator operates at full power to meet the health clinic load demand as well as to simultaneously charge the battery until the state-of-charge setpoint (SOC_S) is reached. So the battery functions as another type of "load" on the generator. With this extra load (charging the battery), the generator burns considerable fuel in fewer operational hours than in the case of the PV + generator system. In the PV + generator array, the generator operates for comparatively more hours (3714 hours), but consumes less fuel (1157L). This is due to the fact that the PV + generator system has no battery to charge, and therefore has no extra load demanding extra fuel as well. Moreover, it should be kept in mind that every kWh supplied by the battery requires around 1.3 kWh to be fed into the battery because of the efficiencies of conversion of electricity into chemical energy in the battery and of chemical energy into electricity needed for the appliances.

As for emissions of key pollutants, these typically decline proportionate to fuel consumption – which is the key source of pollution (Table A9). Since fuel is also costly, there is a win-win achieved, in terms of fuel savings and reduced emissions of harmful air and climate pollutants – including CO_2, a greenhouse gas, as well as particulates and NOx, which may contribute directly and indirectly to short-lived climate emissions (e.g. black carbon and ozone), as well as CO, which can be fatal if released in a closed environment.

The simulation provides an interesting example of how optimal combinations of photovoltaic and diesel generation with appropriate energy storage can yield multiple gains: lower overall cost of energy, a shift to renewable energy, and a reliable supply for all health facility energy needs.

5.2. Scenario using energy-efficient medical devices

As per the conventional scenario, the power arrays that include PV power supply are more expensive at the outset, but less expensive over time, due to the fuel savings costs enjoyed. Similarly, emissions are significantly reduced.

However, the investments in energy-efficient medical devices also significantly reduce the initial capital investment required for most energy supply options as compared to the scenario using more conventional device options – the greatest savings is US$ 3068 for the PV + battery array (Table A14). For the generator-only option, capital cost savings are much less meaningful – only about US$ 300.

At the same time, in terms of net present cost, savings are comparatively greatest for the generator only option (US$ 9577) insofar as more efficient devices yield an ongoing savings in fuel costs. However, net present costs for the other options also declines significantly so that the best overall buys in energy supply still remain the PV + batteries or PV + generator + battery hybrid systems in terms of net present value.

Table A14: Comparative costs of power supply for clinic equipped with conventional versus energy efficient medical devices

Configuration	PV capacity (kW)		Genset capacity (kW)		No. batteries 6V/225Ah		Initial capital (US$)		Total NPC (US$) 25 years	
	Conventional	Energy-efficient	Conventional	Energy-efficient	Conventional	Energy-efficient	Conventional	Energy-efficient	Conventional	Energy-efficient
Generator only	-	-	2.0	1.7	-	-	2 000	1 700	62 862	53 285
PV + generator	4.0	3.0	2.0	1.7	-	-	10 640	8 244	43 139	34 034
Generator + battery	-	-	2.0	1.7	18	12	7 014	5 160	39 917	29 799
PV + battery	3.5	2.5	-	-	16	12	11 528	8 460	13 992	10 305
PV + generator + battery	3.0	2.0	2.0	1.7	8	6	10 584	7 702	13 778	10 233

Presuming that the incremental investment needed for purchasing more energy-efficient medical devices (as compared to conventional counterparts) is roughly US$ 1200 – US$ 1500, the added cost of purchasing more expensive energy efficient devices would not justify the mere US$ 300 savings in capital costs that could be obtained from buying a smaller generator. However, these energy efficiency measures could still be justified by the far lower net present costs, due to the generator fuel savings over time.

On the other hand, for PV + generator, PV + battery options or PV + generator + battery options, if the presumed added cost of investing in more energy efficient devices remains in the range of US$ 1200–1500, the savings in outright capital outlays is very meaningful – in the range of US$ 2400–3100.

Most notably, capital cost of the hybrid PV + generator + battery option is reduced to US$ 7702 if a suite of more energy-efficient medical devices is used. That reduces the *capital cost* of the hybrid system to a level that is nearly equal to the *capital cost* of the generator + battery only option – a traditional energy choice for off-grid health clinics. And once again, the hybrid system will yield very large savings in running costs over time.

6. Conclusion

In conclusion, this simulation demonstrates how investments in more energy-efficient medical devices, even if purchased at somewhat higher costs, can help reduce the required capital investment in energy supply for a rural health clinic, and thus remove a significant barrier to the purchase of energy systems that use clean modes of renewable energy, with lower costs over time.

For new clinics with profiles similar to the one described in this case study, the judicious selection of energy-efficient medical devices along with a hybrid PV + generator + battery supply option is likely to guarantee the lowest overall running costs (NPC) while also assuring the quality and reliability of energy services delivered.

In terms of retrofitting older clinics, the cost of just adding more supply capacity with a generator (US$ 2000) may initially appear attractive. However, if net present cost is considered, investments in more energy efficient devices can reduce generator fuel costs considerably over time. Yet even so, the best combination remains energy efficiencies + more efficient supply configurations, such as the PV or PV hybrid options modeled here.

One limitation of this model is that the capital cost and maintenance costs of purchasing newer, and more energy efficient medical devices is not fully quantified, but only roughly approximated. Defining these costs more fully is an area worthy of further exploration, in the context of creating improved cost-benefit assessment models. However, it is clear from this exercise that for clinics with limited budgets, and facing difficult choices between investing in new energy supply or more efficient devices, scenario modeling that fully considers both supply and demand side options can help create a precise assessment of costs and benefits, based on the options available locally.

ANNEX 5.

Links to sources of values on indicative electricity demand for appliances and devices (Table 3)*

1. Basic lighting refers to both "general lighting" to increase the luminance in a room and "task" lighting. Lighting requirements are presented here in terms of lumens (lm), a standard measure of visible light that is useful for comparing lighting efficacy between different electric as well as non-electric (e.g. kerosene) technologies. For instance, a tungsten incandescent light bulb will provide approximately 12.5–17.5 lm/W, while a fluorescent lamp provides 45–65 lm/W and an LED lamp 60–90 lm/W. Thus a 15 W CFL or 10 W LED light will provide about the same illumination as a 60 W incandescent bulb (900 lumens). Some LED lights provide even higher efficiencies (United States Department of Energy, 2013; RapidTables Online Reference and Tools, 2013). Conversions from incandescent to CFL and LED vary by device, and are presented here as approximations only.
2. For health clinics, no international basic lighting standard exists – although a higher minimum is presumed than that for households. Reference to 162 lumens/m^2 is based on the Indian hospital building code as an indicative national standard (United States Agency for International Development/India ECO-III, 2011). Specialized rooms such as operating theatres require more light, while rooms such as nurseries have lower lighting requirements. A typical solar-powered lighting package offered by one NGO to small off-grid clinics includes 3 LED lights of 3–6 watts each (~504–1000 lumens), one for ambient light and one procedure light (Hal Aronson, We Care Solar, personal communication, 3 October 2013).
3. LED Lighting (RAB): http://www.rabweb.com/solarled.php
4. Security Lighting: (Ani & Emetu, 2013): http://repositoriodigital.uct.cl:8080/xmlui/bitstream/handle/123456789/1465/05-anayochukwu.pdf?sequence=1
5. Mobile phone battery (iGo): http://www.amazon.com/iGo-Auto-Universal-DC-charger/dp/B00PJN2ZG
6. Desktop computer (Aleutia): http://www.aleutia.com/products
7. Desktop computer: (Absak): *Average Power Consumption of Household Appliances.*
   Available at: www.absak.com/library/power-consumption-table
8. Desktop computer: (Ani & Emetu, 2013): http://repositoriodigital.uct.cl:8080/xmlui/bitstream/handle/123456789/1465/05-anayochukwu.pdf?sequence=1
9. Desktop computer (Aleutia): http://www.aleutia.com/products
10. Laptop computer: http://www.humaninet.org/laptop.html
11. Internet: Annette Kuesel, UNDP/UNICEF/World Bank/WHO Special Programme for Research and Training in Tropical Diseases (TDR), Assessment of electricity device demands conducted in 2006 for a new research facility in Bolahun, Liberia, *unpublished data*, 20 January 2014.
12. Internet (TS2): http://www.ts2.pl/en/LinkStar
13. Printer, ink jet: (Ani & Emetu 2013): http://repositoriodigital.uct.cl:8080/xmlui/bitstream/handle/123456789/1465/05-anayochukwu.pdf?sequence=1
14. Printer, ink jet: (Absak): www.absak.com/library/power-consumption-table
15. Printer, ink jet (HP): http://www.amazon.com/HP-Officejet-100-Mobile-Printer/dp/B004TGHIS8/ref=pd_sim_e_1
16. Printer, laser: http://www.kilowatts.com.au/power-consumption-office-equipment.php
17. VHF radio receiver, stand-by: (United States Agency for International Development). *Powering health: electrification options for rural health centers.* Available at: http://www.poweringhealth.org/Pubs/PNADJ557.pdf
18. VHF radio receiver, transmitting: (United States Agency for International Development). *Powering health: electrification options for rural health centers.* Available at: http://www.poweringhealth.org/Pubs/PNADJ557.pdf
19. Ceiling fan (Absak): www.absak.com/library/power-consumption-table

19a Ceiling fan: http://www.orbitgreens.com/

20 Ceiling fan (GenPro): http://www.genproenergy.com/appliance-dc-ceiling-fan.html

21 Ceiling fan: http://www.hansenwholesale.com/ceilingfans/reviews/ceiling-fans-dc-motors.asp

22 Ceiling fan: http://www.lumens.com/fan-buyers-guide/why-choose-dc-fans.html

23 Refrigerator: Comparative Product Testing. In: (VOICE): http://www.consumer-voice.org/Comparative-Product-Testing.aspx, accessed 8 November 2008; Pushpa Girimaji. Check Power Consumption of Appliances. The Times of India. Sep 22, 2003 (http://articles.timesofindia.indiatimes.com/2003-09-22/delhi/27208255_1_energy-efficiency-energy-consumption-brands (accessed 20 January 2014).

24 Refrigerator (Sundanzer): http://www.sundanzer.com/documents/SunDanzerDCPowered.pdf

25 Portable electric space heater (Absak): www.absak.com/library/power-consumption-table

26 Portable air conditioner (Absak): www.absak.com/library/power-consumption-table.

27 Solar-powered air conditioner (GenPro): http://www.genproenergy.com/docs/genpro_docs_2012/Solar-Powered-AC-Unit.pdf

28 Countertop autoclave: http://www.serico-china.com/Autoclave-desk-top.htm

29 Countertop autoclave: http://www.frankshospitalworkshop.com/equipment.html

30 Dry heat sterilizer: http://www.frankshospitalworkshop.com/equipment.html

31 Dry heat sterilizer (United States Agency for International Development, 2012): *Powering health. Health clinic, power system design*: http://tools.poweringhealth.org/

32 Small waste autoclave (PATH, 2008): http://www.path.org/publications/files/TS_sm-scale_autoclaves_guide_bklt.pdf

33 Water pump: http://www.backwoodssolar.com/products/water-pumps?cat=122

34 Water pump: Annette Kuesel, UNDP/UNICEF/World Bank/WHO Special Programme for Research and Training in Tropical Diseases (TDR), Assessment of electricity device demands conducted in 2006 for a new research facility in Bolahun, Liberia, *unpublished data*, 20 January 2014.

35 UV water purifier (Sterilight): http://www.pure-earth.com/uv.html

36 UV water purifier (Bio-logic): http://www.ultraviolet.com/water/biologo6.htm

37 Reverse osmosis/other water purifier (United States Agency for International Development, 2012): *Powering health. Health clinic, power system design*. Available at: http://tools.poweringhealth.org

38 Reverse osmosis/other water purifier (Black et al., 2012): http://eetd.lbl.gov/sites/all/files/lbnl-6084e.pdf

39 Micro-nebulizer: https://www.fbo.gov/?s=opportunity&mode=form&id=c439a4adff2aaec5a87025b08a0af37a&tab=core&_cview=0ua; (Respironics): http://www.mikesmed.com/Catalog/Online-Catalog-Product.aspx?pid=318

40 Micro-nebulizer (Philips): http://www.healthcare.philips.com/main/homehealth/respiratory_drug_delivery/minielite/default.wpd#&&/wEXAQUOY3VycmVudFRhYlBhdGgFFkRldGFpbHM6U3BlY2lmaWNhdGlvbnOKh+5fzpW/Rh82+nJNs/BzMC6HpA==

41 Nebulizer (UNICEF, 2014): https://supply.unicef.org/

42 Oxygen concentrator (Philips): http://evergo.respironics.eu/Specifications.asp; (DeVilbiss Healthcare): http://www.specialty-medical.com/DV525DS.html

43 Pulse oximeter (UNICEF, 2014): https://supply.unicef.org/

44 Pulse oximeter-AA battery-operated (Philips): http://www.isearch.philips.com/search/search?q=oximeter&s=medical&l=global&h=medical&sid=header

45 Refrigerator (Vestfrost) (World Health Organization, 2013d): http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/

46 Solar-charged battery vaccine refrigerator (Dometic) (World Health Organization, 2014a): http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/

47 DC solar-charged direct drive vaccine refrigerator (Sure Chill) (World Health Organization, 2014a): http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/

48 LED light: (World Health Organization, 2013c): http://www.who.int/medical_devices/innovation/compendium_med_dev2011_8.pdf

49 Suction apparatus (Devilbiss): http://www.specialtymedicalsupply.com/devilbiss-portable-vacu-aide-suction-machine.html

50 Vacuum aspirator or D&C kit (Dometic): http://www.dometic.com/358d1a31-0ba3-4c46-99ab-a10944db4c0a.fodoc

51 Neo-natal incubator (UNICEF, 2014): https://supply.unicef.org/

52 Neo-natal incubator (Black et al., 2012): http://eetd.lbl.gov/sites/all/files/lbnl-6084e.pdf

53 Neo-natal infant warmer (World Health Organization, 2013c): http://www.who.int/medical_devices/innovation/compendium_med_dev2013_7.pdf?ua=1

54 Neo-natal infant warmer (Embrace): http://www.embraceinnovations.com/products/how-it-works/

55 Fetal heart monitor (Doppler): (UNICEF, 2014): https://supply.unicef.org/

56 Fetal heart monitor (Doppler): Brent Moellenberg, We Care Solar, Power test measurement of power usage of a Bistos HiBebe Fetal Doppler, personal communication, 10 October 2013.

57 Ultrasound (UNICEF, 2014): https://supply.unicef.org/

58 Portable ultrasound (World Health Organization, 2013c): http://www.who.int/medical_devices/innovation/compendium_med_dev2013_2.pdf?ua=1

59 Portable ultrasound (GE): http://www3.gehealthcare.in/en/Products/Categories/Diagnostic_ECG/Resting/MAC_i

60 Portable ultrasound (SonoSite): http://www.sonosite.fr/%C3%A9chographe-produits/edge-ultrasound-machine/caract%C3%A9ristique

61 Portable ultrasound (SonoSite): http://www.sonosite180.com/pdf/sonosite180.com/Sonosite_180_Plus_Specifications.pdf

62 Portable ultrasound: Brent Moellenberg, We Care Solar, DC power test measurement of Sonosite 180 ultrasound, personal communication, 10 October 2013.

63 Laboratory refrigerator (United States Agency for International Development, 2014): Load analysis and example calculations: http://www.poweringhealth.org/index.php/topics/management/load-analysis-and-example-calculations

64 Laboratory refrigerator: Annette Kuesel, UNDP/UNICEF/World Bank/WHO Special Programme for Research and Training in Tropical Diseases (TDR), Assessment of electricity device demands conducted in 2006 for a new research facility in Bolahun, Liberia, unpublished data, 20 January, 2014.

65 Laboratory refrigerator (Sundanzer): http://www.sundanzer.com/documents/SunDanzerDCPowered.pdf . *note: daily energy consumption increases with ambient air temperature: 21–43°C

66 Centrifuge (UNICEF, 2014): https://supply.unicef.org/

67 Mini-centrifuge (Bio-lion): http://bio-lion.com/Mini_Centrifuge.html

68 Haematology analyser (UNICEF, 2014): https://supply.unicef.org/

69 Haematology analyser (United States Agency for International Development, 2014): http://www.poweringhealth.org/index.php/topics/management/load-analysis-and-example-calculations#labs

70 Blood chemistry analyser (United States Agency for International Development, 2012): http://tools.poweringhealth.org/

71 Blood chemistry analyser (United States Agency for International Development, 2014): http://www.poweringhealth.org/index.php/topics/management/load-analysis-and-example-calculations

72 Blood chemistry analyser, hand-held: http://www.researchgate.net/publication/13197848_Use_of_a_handheld_battery-operated_chemistry_analyzer_for_evaluation_of_heat-related_symptoms_in_the_backcountry_of_Grand_Canyon_National_Park_a_brief_report

73 Blood chemistry analyser, hand-held (Abbott Point of Care): http://www.abbottpointofcare.com/Customer-Info-Center/User-Documentation.aspx

74 CD4 counter (Partec): http://www.cyto.purdue.edu/cdroms/cyto10a/sponsors/media/partec/cyflowcounter.pdf

75 CD4 counter: http://www.poweringhealth.org/index.php/topics/management/load-analysis-and-example-calculations

76 Brightfield white light microscope (United States Agency for International Development, 2014): http://www.poweringhealth.org/index.php/topics/management/load-analysis-and-example-calculations

77 LED microscope (FIND): http://www.finddiagnostics.org/about/what_we_do/successes/find-negotiated-prices/primo-star-iled.html

78 LED microscope (Zeiss): http://applications.zeiss.com/C125792900358A3F/0/7A7EC5073084A917C125790600481174/$FILE/60-2-0017_e.pdf

79 LED microscope (Lumen Dynamics): http://www.ldgi.com/x-cite/120led/

80 LED microscope: Sylvain Bieler, FIND diagnostics, Power consumption of the Primo Star iLED, personal communication, 17 January 2014.

81 Mercury/xenon fluorescence microscope (Olympus): http://www.olympusmicro.com/primer/anatomy/sources.html

82 Mercury/xenon fluorescence microscope: http://micro.magnet.fsu.edu/primer/techniques/fluorescence/fluorosources.html

83 **Indicative examples of X-ray power requirements**

Product	Company	Power requirement	Source(s)
Q-Rad Digital DRX Series Radiographic Systems (series of products)	Quantum Medical Imaging, Division of Carestream	Powered by an 80 kW generator	http://www.compray.com/quantum.html
High-frequency Mobile X-Ray Systems	Wolverine X-Ray	Available in models powered by 20 kW, 32 kW, 40 kW and 50 kW generators	http://www.wolverinexray.com/michigan_dr_systems.html
OTC12D Overhead Tube Crane System	Del Medical	Available in models powered by 50 kW, 65 kW or 80 kW generators	http://www.umgxray.com/pdf/delmedicalotc12D.pdf
OEC 9800 Plus Digital Mobile Imaging System	GE Medical Systems	Powered by 15–20 kW generator (120 VAC)	http://www.allstarxray.com/assets/pdf/OEC9800.pdf
Kodak DirectView DR 3500 System	Triangle X-Ray	Powered by 64–80 kW generator (380–480 VAC)	http://www.trianglexray.com/pdfs/Carestream/dr3500_brochure.pdf
300mA Medical Diagnostic X-ray Machine TR300A	TRIUP International Corp.	Powered by 37.5 kW generator (220–380 VAC)	http://www.triup.com/product/523–300ma-medical-diagnostic-x-ray-machine-tr300a-66c3/

84 Portable X-ray machine (United States Agency for International Development, 2012): Electric load inputs: http://tools.poweringhealth.org/

85 Portable X-ray machine (All Star X-Ray): http://www.allstarxray.com/assets/pdf/CloudDR-Portable-1417-Wireless.pdf

86 Laboratory incubator (Torrey Pines Scientific): http://www.torreypinesscientific.com/products/incubators/echotherm-in30-in35-in40-and-in45-bench-top-incubators#footer

87 Vortex mixer (Maples Scientific): http://www.maplescientific.co.uk/products/mixers/vortex-mixer

88 Vortex mixer (Thermo Scientific): http://www.thermoscientific.com/content/tfs/en/product/maximix-ii-vortex-mixer.html

89 Note: These estimates are for LED or halogen-lit microscopes. Mercury-lit microscopes also are used but the bulbs have a higher energy consumption (about 50–200 watts) as well as a very short lifespan (200–300 hours), making them far less suitable for small clinics and laboratories (Hanscheid, 2008). Available at: http://www.sciencedirect.com/science/article/pii/S0035920308000928

90 Sputum-smear microscopy (Zeiss): http://applications.zeiss.com/C125792900358A3F/0/7A7EC5073084A917C125790600481174/$FILE/60-2-0017_e.pdf

91 Sputum-smear microscopy (FIND): http://www.finddiagnostics.org/about/what_we_do/successes/find-negotiated-prices/primo-star-iled.html

92 GeneXpert MTB/RIF diagnostic (GeneXpert): http://www.cepheid.com/us/support/technical-faqs

93 GeneXpert MTB/RIF diagnostic: Christopher Gilpin, Global TB Programme, WHO, Energy requirements of medical equipment in Uganda, personal communication, 26 June 2013.

94 ELISA test reader: https://supply.unicef.org/unicef_b2c/app/displayApp/(cpgsize=5&layout=7.0-12_1_66_69_115_2&uiarea=2&carea=4F0906F939BB068AE10000009E711453&cpgnum=1&citem=4F0906F939BB068AE10000009E7114534FD5D23E570-F1D55E10000009E71143E)/.do?rf=y

95 Portable ECG: http://www.analog.com/library/analogDialogue/archives/29-3/low_power.html

96 Portable ECG (General Electric): http://www3.gehealthcare.in/en/Products/Categories/Diagnostic_ECG/Resting/MAC_i

97 Defibrillator with ECG (Black et al., 2012): http://eetd.lbl.gov/sites/all/files/lbnl-6084e.pdf

98 Defibrillator with ECG: http://www.who.int/medical_devices/innovation/electrocardiograph.pdf

99 Defibrillator with ECG (Physio-control): http://www.physio-control.com/uploadedFiles/Physio85/Contents/Emergency_Medical_Care/Products/Brochures/LP15_Prehospital_Brochure_3301019_D.pdf

100 Blood glucose monitor (Freescale): http://www.freescale.com/files/microcontrollers/doc/user_guide/MDAPPUSGDRM118.pdf?&Parent_nodeId=1252002199484716807B40&Parent_pageType=application#page=34

101 Anaesthesia machine (Black et al., 2012): http://eetd.lbl.gov/sites/all/files/lbnl-6084e.pdf

102 Low-energy anaesthesia machine (World Health Organization, 2013c): http://www.who.int/medical_devices/innovation/compendium_med_dev2013_10.pdf?ua=1

103 Anaesthesia machine: Ismael Cordero, Gradian Health Systems, Energy requirements of an anaesthesia machine, personal communication, 7 May 2014.

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Access to Modern Energy Services for Health Facilities in Resource-Constrained Settings

A Review of Status, Significance, Challenges and Measurement

Universal health coverage and universal access to efficient modern energy services are both global development goals. Rarely, however, have they been explored in tandem. This document sets out key issues, opportunities and synergies. Health facilities are community institutions where access to adequate, reliable and sustainable energy requires particular attention. Modern energy access in health facilities is a critical enabler of access to many medical technologies, and thus to health services access. Without access, particularly to electricity, many life-saving health-care interventions simply cannot be undertaken.

This report focuses on the energy needs of health facilities which have very limited access to energy – a common problem in many facilities of low-income countries or emerging economies, but also present in resource-constrained settings of middle-income countries. Available evidence regarding patterns of energy access and its impacts on health services is considered along with trends in the use of new energy technologies. This evidence is used to develop a rationale and approach for tracking and monitoring energy access in health facilities. This report's findings are most relevant to clinics and health centres at the primary and secondary tiers of health systems, often struggling to access sufficient energy to power lighting, refrigeration and basic medical devices. While hospitals' energy needs are more complex, certain messages and findings presented here also are relevant for larger facilities. This report supports improved measurement, monitoring and design of clean, modern energy interventions that can optimize health services delivery at all levels. More broadly, it supports advancement in the health sector towards the *Sustainable Energy for All (SE4All)* goals of universal access to modern energy services along with increased energy efficiencies and reliance upon renewable energy sources.

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