WORLD RESOURCES INSTITUTE

TECHNICAL NOTE

A GIS-based demand assessment methodology to estimate electricity requirements for health care facilities: a case study for Uganda

Santiago Sinclair-Lecaros, Dimitrios Mentis, Eng. Sitra Mulepo C.S., Giacomo Falchetta, and Nicolò Stevanato

CONTENTS

Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.

Suggested Citation: Sinclair-Lecaros, S., D. Mentis, E.S. Mulepo C.S., G. Falchetta, and N. Stevanato. 2023. "A GIS-based demand assessment methodology to estimate electricity requirements for health care facilities: a case study for Uganda." Technical Note. Washington, DC: World Resources Institute. Available online at: https://doi.org/10.46830/writn.21.00093.

ABSTRACT

In Sub-Saharan Africa, more than 640 million people are served by health care facilities that either lack electricity access or have unreliable service. On average, 15 percent of the region's health facilities lack any access to electricity, and only 40 percent have reliable electricity[1] (WHO 2023). This has substantial implications for access to health services, including the cold chain for vaccine, blood, and pharmaceutical storage. Additionally, the COVID-19 crisis has underscored inequalities in access to electrified health care services, especially in remote rural areas and refugee settlements. Updated information on health facilities is critical for decision-makers, enabling them to identify opportunities and formulate policies, strategies, plans, and programs. Data on the electrification status of health facilities are usually scarce or scattered. Furthermore, data on a facility's electricity demand are hard to come by and limited to small samples that are often outdated. Assessing electricity needs at the facility level is key for evidence-based decision-making and impactful electrification programs.

This technical note introduces a methodology to estimate electricity requirement ranges in unserved and under-served health care facilities. It combines a bottom-up approach to assessing the electricity requirements at the facility level with a GIS-based analysis based on geographic information systems (GIS). The methodology is applied to a case study for existing facilities in Uganda in close collaboration with the Ugandan Ministry of Health and the Energy Sector GIS Working Group. Outputs of the analysis will be integrated into Energy Access Explorer, overlaid with information on current and potential supply, and made available for a dynamic, multicriteria prioritization analysis and the development of customized reports. This methodology will provide a data-driven, integrated approach to planning for the expansion of energy services in health care.

1. INTRODUCTION

Access to reliable electricity enables health care facilities to provide better services. Facilities can acquire and optimize electrical medical equipment such as ventilators and vaccine refrigerators as well as access basic utility services, including lighting, water, sanitation, and hygiene services. However, one of the impediments to electrifying health facilities is the data gap on the energy requirements of such facilities, which is essential for data-driven planning. In developing economies, health facility data related to electrification status, the reliability of supply, and electricity needs are often scarce, scattered, outdated, or nonexistent. This makes developing data-driven policies, strategies, programs, and plans a slow and often challenging task. Decision-makers can utilize the advancements made in geospatial technology to identify health care electrification opportunities and prioritize electrification plans, funds, and investments aimed at facilities, provinces, and communities.

This technical note introduces a methodology to estimate plausible ranges of electricity requirements for health care facilities, especially unserved[2] and under-served[3] facilities. It combines a bottom-up approach[4] to assessing the electricity requirements at the facility level with an analysis based on geographic information systems (GIS) to assess the catchment population of each facility. The estimated electricity requirement range per facility is the prospective demand to provide the required quality health services according to the health center level and its catchment population. The results are not intended to be an estimate of current electricity use. This methodology will provide a data-driven, integrated approach to planning for the expansion of energy services in health care. Through more granular geospatial information and on-the-ground data on health facilities' electricity requirements, government agencies, financial institutions, donors, impact investors, and development organizations can identify and prioritize funds, resources, and assistance to have a greater impact. By understanding the electricity requirement ranges, government agencies, such as Uganda's Ministry of Health (MoH), can assess plausible options for providing electricity to the different types of unserved or under-served facilities. The outputs obtained will provide important input information for data-driven planning and decision-making at the start of a project through its various phases. This can reduce costs and time-intensive data collection and analysis efforts to identify relevant health care facilities and their energy needs.

The methodology is applied to a case study for existing health facilities that represent a spectrum of services corresponding to those from Uganda's health center level.[5] In Uganda, health services are delivered according to a tiered hierarchical system that increases in scope and complexity from the village health teams (VHTs) at the community level up to the national referral hospitals. In between these levels are health center II, health center III, health center IV, general hospital, and regional referral hospital (MoH 2016). The health center level (II, III, IV) has a high presence across the country, especially in remote rural areas; thus, it is often the first point of access to health services. Solutions focused on these health centers are therefore key for health facility electrification planning.

Analysis outputs are integrated into Energy Access Explorer (EAE).[6] EAE is an online, open-source, and interactive geospatial platform that enables users to identify high-priority areas where energy access can be expanded to achieve important development outcomes. The tool synthesizes geospatial data related to energy demand and supply. Together, these data sets can help enable better, more integrated and inclusive energy-planning accounting for multiple dimensions of energy access. The analysis outputs can be overlaid with information on current and potential supply for a dynamic, multicriteria prioritization analysis and the development of customized reports.

This technical note begins with the "Review of existing methodologies," which discusses GIS-based approaches for estimating health facility electricity demand. The "Proposed methodology" section introduces the input and output data and the tools utilized throughout the different stages, and the "Data processing" section outlines the various data processes and their relevant subproducts. The "Results" section presents the aimed results from the methodological approach, and the following section discusses the limitations of the approach and proposes ways forward. The final section of the note offers findings and conclusions from the proposed methodology. The appendices present more detailed results as well as different outputs and inputs available.

2. REVIEW OF EXISTING METHODOLOGIES

Our research shows that five GIS-based approaches (three of which are open source) have focused on estimating electricity demand for health facilities. These approaches were applied in a limited number of geographies, mostly in Sub-Saharan Africa. For example, Sahlberg et al. (2018) focused on Benin; Korkovelos (2020) concentrated on the district of Mecanhelas, Mozambique; Falchetta et al. (2021) examined Kenya; Pakravan and Johnson (2021) focused on Uganda; and Moner-Girona et al. (2021) employed a regional approach for Sub-Saharan Africa.

Most authors built their methodologies on open-source tools and models: Sahlberg et al. (2018) and Korkovelos (2020) used the Open Source Spatial Electrification Tool (OnSSET)

(Mentis et al. 2017); Falchetta et al. (2021) used Remote-Areas Multi-energy systems load Profiles (RAMP), an open-source, bottom-up stochastic model (Lombardi et al. 2019); and Moner-Girona et al. (2021) used the travel-times-to-health-facilities model (Weiss et al. 2020).

The reviewed approaches commonly used "number of beds" as a unit of measurement to better understand the size of a facility, scale of electricity demand, and amount of equipment. The reviewed approaches did not include countrywide data regarding current facility-level data on electrification status and reliability or data regarding generation source. Here, we will review further details regarding the different approaches.

Many of the reviewed GIS-based electricity demand assessments were based on high-level parameters and global or regional assumptions. The most likely reason for this shared approach is the scarcity of open-access granular-level data at the facility level. For example, an initial general challenge for energy planning has been understanding the spatial distribution of population density/clusters and the urban/rural classification. In health facility electrification efforts, this translates as facility-level population estimates (i.e., catchment population). In most cases, this common issue was addressed by using population estimates based on recent census data and high-resolution satellite imagery. To attain these estimates, blocks of satellite data were classified based on whether or not they contained buildings. Next, proportional allocation was used to distribute population data from subnational census data to the settlement extents. The resulting data show population estimates in persons per grid or cluster, as can be found in Facebook Connectivity Lab and CIESIN (2016) and Bondarenko et al. (2020).

Obtaining accurate and updated data on facility location and services has been a challenge for health electrification planning. The methodology in Sahlberg et al. (2018) bridges this data gap by allocating the health facility type and its locations through gridded population density and urban/rural split data. Now, recent work from the World Health Organization (WHO) and Maina et al. (2019) has provided a comprehensive, open-access spatial inventory on public health facilities across Sub-Saharan Africa. This has and will continue to be an important input for several assessments reviewed in this section.

Nevertheless, attributes related to electrification status, electricity sources, and reliability are still difficult to find. If available, they tend to be scattered and fragmented across different stakeholders and do not capture the full spectrum of the current electrification status and reliability of facilities within a geography. This lack of health facility electrification data has led to approaches such as Korkovelos (2020), Sahlberg et al. (2018), and Moner-Girona et al. (2021), which use existing central power gridline spatial data, in some cases combined with satellite imagery on the presence of nighttime lights, to estimate the electrification status of a population as well as the proximity of health facilities in relation to the power gridlines. For example, previous studies frequently assumed that if a facility was more than two kilometers (km) away from the central grid, then that facility could be considered "unserved" by the grid, and vice versa. Although this is a useful assumption, especially if electrification data are scarce, it could be inaccurate in some cases because proximity to the grid does not necessarily signify that a facility is connected.

A high-level parameter approach that builds on nongeospatial data is mostly used to standardize and represent the health facility type or level according to the WHO global reference categories (WHO and World Bank 2015). Based on the facility category type, there are standard global assumptions, such as the number of beds, the catchment population served, and the annual energy consumption. In many cases, energy consumption tiers per health facility category are used to assign a standard energy demand on health facilities that fall under one of the predetermined categories. Although this is a valid approach, global standardization of health facility categories could pose some issues in the analyses because the definitions of these categories and the services they provide can vary significantly across countries.

Bottom-up approaches for estimating health facility energy demand were also found, although less commonly, in the methodologies from both Falchetta et al. (2021) and Pakravan and Johnson (2021). Both methods included more facility electricity data, which were collected through sample data audits and/or questionnaires at the facility level. Facility-level sample data can be collected through a cloud-based survey (Pakravan and Johnson 2021), in-person energy audit visits (Falchetta et al. 2021), or through results collected from previous audits/surveys carried out by other stakeholders. Bottom-up approaches offer details such as the facility type, the number of appliances and medical equipment, and their power requirements. In some cases, these approaches also present more specific data on the number of beds per facility as well as load profiles.

Because of the granularity of the bottom-up approach, up-to-date assessments of this sort are uncommon and require more effort and resources (i.e., time and costs) to design, collect, process, and harmonize primary data and/or secondary data from specific stakeholder electricity audits and questionnaires. In most cases, these data sets represent a specific province or facility type. A challenge of the bottom-up approach is the ability to scale if not combined with GIS data and analytics. This is particularly problematic if the sample data are not representative at the national level and/or if the facility services need to be grouped into broader categories, which might not always reflect their energy demand; hence, it is important to apply a combined method that leverages a GIS-based analytical approach with bottom-up facility-level electricity requirement data.

This technical note introduces a methodology for estimating electricity requirement ranges for unserved and under-served health facilities, combining both bottom-up and GIS-based analysis approaches. This publication will add to existing knowledge in the following ways:

- It provides the option of an applied GIS-based demand assessment methodology to estimate electricity requirement ranges for health care facilities that considers different health facility levels—according to provided services—and facility sizes within each level.
- A case study, customized with granular data from Ugandan health facilities, provides additional insights and analysis to build on and enhance the RAMP tool (Lombardi et al. 2019). RAMP is utilized in the methodology to model health facility electricity demand curves (refer to Appendix C).
- Results from the case study of Ugandan health centers can be used as a reference to compare and validate facility-level data in Uganda for existing tools, such as the Clean Energy Access tool and the Decision Response Energy Assessment Management tool.[7]
- Updated health facility mapping inventories, including additional attributes such as electricity status (on-grid, off-grid, and unelectrified), electricity supply options, and electricity requirements per facility, supplement the current inventory attributes (geolocation, facility name, category, and ownership) in Uganda's 2018 Health Facility Inventory (MoH 2018), the spatial database of health facilities in Sub-Saharan Africa (Maina et al. 2019), and the Healthsites.io platform.
- An evaluation of least-cost electrification scenarios in Uganda, with estimated electricity requirement data per facility, built from more granular, bottom-up data from Ugandan health facilities, offers new information and approaches to the methodology used by Korkovelos (2020), which utilizes a high-level approach with facility-type standard data assumptions.

3. PROPOSED METHODOLOGY

The proposed methodology links a bottom-up approach that integrates load profiles and the number of beds for different facility types with a GIS-based analysis approach that leverages geospatial data on facility location, population density, and travel friction surfaces. The methodology comprises two main stages: estimation of the electricity requirement range per facility type and estimation of the catchment population per facility.

3.1 Estimation of the electricity requirement range per facility type

Archetype load profiles

As previously mentioned, the case study for this publication will focus only on the Ugandan health center level (II, III, IV) (for more details on health centers, refer to Appendix A). In addition to the different electricity requirements for health center types (II, III, IV), the proposed methodology seeks to also analyze how electricity requirements differ within each of the health center types. Not all facilities follow the standard size according to their level. This is most apparent in the bed number range for each level; in some cases, the range can be between 8 and 24 beds (Table 1). Therefore, to integrate and analyze the differences within each of these health center levels, different archetypes were developed.

First, we built archetype load profiles for the health centers (II, III, IV) based on input data from Uganda's MoH classification, including facility levels, and the sizes of the facilities within each level based on the number of beds (i.e., categories of small, standard, and large facilities). The facilities vary in size, location, available medical equipment, and services provided. To estimate ranges of electricity requirements for facilities, health facility load profiles will be modeled for different Ugandan health center archetypes based on appliance ownership and use patterns.

The initial input data used to build the archetypes are the health center level profiles (Table 1) and the availability of equipment per health center level (Table 2). The center-level profiles (i.e., basic buildings, services, defined number of beds, and defined catchment population) in Table 1 are from Uganda's MoH facility classification. Data on the available equipment per health center level were collected from the energy audits and surveys carried out by the MoH for the Energy for Rural Transformation Program and the United Nations Foundation's Powering Health Project.

Table 1 | Health facility level services and characteristics

HEALTH UNIT	BASIC BUILDINGS	HEALTH CARE SERVICES	NUMBER OF BEDS	MOH-DEFINED CATCHMENT POPULATION
Health center II	▪ Outpatient department block	Preventive and promotive, outpatient, curative health services, and emergency delivery	2–3	Parish: 5,000
Health center III	▪ Outpatient department block with laboratory ▪ Maternity ward/general ward block	Preventive and promotive, outpatient, curative health services, maternity, inpatient, and laboratory services	8–24	Subcounty: 20,000
Health center IV	▪ Outpatient department block with laboratory ▪ Maternity ward ▪ General ward ▪ Theater ▪ Mortuary	Preventive and promotive, outpatient, curative health services, maternity, inpatient, laboratory services, obstetric ultrasound, emergency/simple surgery (caesarean sections and lifesaving surgical operations), blood transfusion services, and mortuary	25–59	County: 100,000

Notes: The table is based on the Ugandan Ministry of Health (MoH) classification for health center levels and services provided. The analysis focused on medical buildings and therefore does not include staff houses, latrines, or gatehouses.

Source: MOH 2021.

Table 2 | Medical equipment and appliances per health facility level

MEDICAL EQUIPMENT AND APPLIANCES	HEALTH FACILITY LEVEL		
	HC II	HC III	HC IV
Indoor compact fluorescent light bulb	X	X	X
Indoor tubes, T5 1200 mm	X	X	X
Outdoor compact fluorescent light bulb, IP44	X	X	X
Radio	X	X	X
Printer		X	X
Router		X	X
Photocopy			X
Electric heater			X
Pump			X
Phones	X	X	X
Heating, ventilating, and air-conditioning		X	X
Dispenser			X
Anesthesia unit			X
Autoclave, electric, 40 L			X
Autoclave, electric 20 L	X	X	X

MEDICAL EQUIPMENT AND APPLIANCES	HEALTH FACILITY LEVEL		
	HC II	HC III	HC IV
Centrifuge, manual		X	X
Deep freezer, vaccine			X
Dental unit, complete			X
Differential counter			X
Examination light	X	X	X
Hot air oven (sterilizer)			X
Operating light, mobile			X
Operating table, electric			X
Oxygen concentrator	X	X	X
Pulse oximeter		X	X
Refrigerator, general purpose		X	X
Refrigerator, blood bank			X
Refrigerator, vaccine	X	X	X
Suction apparatus, electric	X	X	X
Ultrasound scanner (black and white)			X

Table 2 | **Medical equipment and appliances per health facility level, continued**

MEDICAL EQUIPMENT AND APPLIANCES	HEALTH FACILITY LEVEL		
	HC II	HC III	HC IV
Vacuum extractor		X	X
GeneXpert machine (CD4)			X
Infant incubator		X	X
Infant warmer		X	X
Automatic biochemistry analyzer			X
Automatic hematology analyzer			X
VDRL shaker			X
Audio visual equipment	X	X	X
Flat iron			X
Electric kettle	X	X	X
Computer unit		X	X
Mortuary refrigerator			X
Patient monitor 4 parameter (temp, pulse oximetry, NIBP)			X
X-ray			X

Notes: Refer to Appendix B for more details. HC = health center. NIBP = noninvasive blood pressure.

Source: MOH 2021.

Table 3 | **Health facility archetype category**

HEALTH FACILITY LEVEL	ARCHETYPE	NUMER OF BEDS
Health center II	1	2
	2	3[a]
Health center III	3	8
	4	12
	5	14[a]
	6	16
	7	20
	8	24
Health center IV	9	25
	10	29[a]
	11	36
	12	44
	13	52
	14	59

Note: a. Indicates the standard facility size per health center level.

Sources: Based on MoH (2012a, 2012b, 2012c, 2016).

The load profiles are modeled for 14 Ugandan health facility archetypes (Table 3). The archetypes are based on the health center level (II, III, IV) and the facility sizes shown by the number of beds. The number of beds per facility are allocated from the estimated catchment population and are within the ranges of the number of beds per facility level as defined in the health center classification (refer to Table 1). The type of services, medical equipment, and appliances within a health facility level will remain constant for facility categories/sizes (refer to Tables 1 and 2). However, the equipment, appliances, and use patterns will vary according to the archetype.

The parameters, assumptions, and applied variability for each modeled load profile will be based on a local standard-sized facility that provides full health services according to each level. Modeled health facilities with a smaller or greater number of beds, compared to the standard case, are treated according to experience in Multisectoral Latent Electricity Demand (M-LED) methodology[8] and the expert-based approach found in Falchetta et al. (2021) through the following parameters and assumptions:

- **Multiply by an appliance factor to change the number of equipment and appliances available in relation to the standard facility for a level**. The appliance-multiplier factor is estimated from the ratio between the number of beds of the *Xth* archetype, belonging to the *Yth* health facility tier, and the number of beds of the standard archetype of the same *Yth* health facility tier. For example, with Archetype 5 as the standard facility, Archetype 3 has 8/14 times the lights than Archetype 5, and Archetype 8 has 24/14 times the lights of Archetype 5. Therefore, to model the load profile of small and large facilities in relation to the standard within each level, the appliance-multiplier factor is used to estimate the amount of specific equipment needed.[9] There was no precedence of one approach over another. When the appliance-multiplier factor was required, the equipment was analyzed according to each specific case.

- **Decrease equipment size or use pattern.** For facilities that are smaller than the standard, this is used when the number of equipment and appliances cannot be reduced. Three types of approaches were adopted according to a case-by-case scenario: decrease equipment size (nominal power in kilowatts [kW]), decrease the total daily use of the equipment, and/or set to a percentage of the occasional use during the day/week. These assumptions reduce the overall load of the specified equipment or appliance.
- **Increase equipment size or use pattern.** The same logic as the previous assumption is used when equipment and appliances need to be increased in amount for facilities that are larger than the standard. In these cases, it might be more logical to increase the size of equipment (nominal power in kW), increase an extra cycle of use in a day/week, and/or move from occasional use to full-time use during a day/week.

These options are treated according to the specific equipment and apply to each of the facility categories within the health facility levels. A simplified example of a decrease in equipment size or use pattern would be when modeling a smaller facility in relation to the equipment sizes and use patterns of a standard facility in that level. The model could include a decrease in the size (kW) of electric heaters, a 20 percent decrease in the total daily use (hours) of examination lights, and setting a 50 percent occasional use of an autoclave that applies during the daily use window. The same logic in the simplified example above can be used for an increase in equipment size or use pattern when modeling for a large facility in relation to a standard facility in that level.

Stochastic modeling of annual load curves

The load profiles for each facility archetype are used as an input data for the RAMP tool[10] (Lombardi et al. 2019) to model a bottom-up process that computes the load curve of the user each day of a year, with a one-minute time resolution—that is, the watts per minute required during the day for a full year. The load curves are modeled for each of the 14 archetypes.

Electricity and power requirements are estimated based on the outputs from the load curve models

The results of the stochastic modeling will provide daily load curves for a full year corresponding to each of the 14 archetypes. With the load curve data, we can obtain minimum, average, and peak power requirements (kW) as well as daily and annual electricity demand (kilowatt-hours [kWh]). These estimates are developed for each facility archetype and therefore show more insight on the variability obtained within each of the three facility levels. The estimated electricity demand results for each archetype are then assigned to the facilities (refer to "Facility-level electricity requirement range").

3.2 Estimation of the catchment population per facility

To allocate the electricity demand results to the correct facilities, we need to classify each facility into one of the 14 archetypes. To do so, we must understand the facility's characteristics (facility level, catchment population, estimated number of beds, and category). For this objective, we first utilize the existing MoH health facilities master list data, which include health facility level, to classify between level II, III, and IV. Next, we need to identify the facility's category and size; only then can we assign a specific archetype. Because available facility-level data in Uganda do not include the number of beds for each facility, we used a catchment population proxy.[11] The catchment population shows the potential population that is likely to be served by a specific health facility according to the distance and/or the travel time from a populated area to the facility. For this occasion, we use a walking travel time within 60 minutes or less to a health facility. This specific travel time was chosen because it is roughly equivalent to a 5 km radius, which is used as a standard parameter by the MoH for estimating catchment population. The walking travel time improves accuracy because it is estimated through a GIS analysis that includes the geolocation of facilities, a friction layer (describing the average time to move within a specific grid cell based on local road and infrastructure availability as well as terrain obstacles), and high-resolution gridded population settlements.

Estimated travel time to health facilities

In the process of identifying the catchment population per facility, we first estimated the travel time to each facility. This step was carried out through a GIS least-cost-path algorithm (Weiss et al. 2020) process that integrated two main data sets: the geolocation of all facilities in Uganda (MoH et al. 2020) and a national-level friction map from the global friction surfaces maps (Weiss et al. 2020). These contain the estimated time required to travel through each pixel without a motorized vehicle. The global friction surfaces maps include several geospatial data sets, including roads, road speed data, topography, and water bodies.

Estimated travel time to health facilities from populated areas

With the estimated travel time to health facilities from different geographic points in the country, we proceed to calculate the travel time required for people to reach a specific health facility from a population settlement (i.e., city, town, neighborhood, etc.). For this, we utilize the previous output from the estimated travel time to health facilities and add the latest 2020 high-resolution gridded population settlements (Facebook Connectivity Lab and CIESIN 2016). The population settlements data set provides estimates of human population distribution at a high resolution of approximately 30 meters. The population estimates are based on recent census data for Uganda and high-resolution satellite imagery of buildings. The outputs from this process will provide more information on the travel time required from population settlements to different health facilities.

Estimated catchment population

Finally, utilizing the number of people that have a lower travel time to specific health facilities, we estimate the catchment population of one facility versus another. One of the main assumptions in this process is that people within these travel-time buffer areas will likely choose one of these facilities over another based on the shortest travel time. Although Ugandan health services delivery is based on a referral system, this does not fully apply today. People will be served by the facility of their choice, usually the closest one that offers the required service. In other words, they will not be turned away from a higher-tiered facility (i.e., health center IV versus II). Another key assumption in estimating the catchment population is that facilities with overlapping population buffer areas will equally split the allocated share of the population according to the number of facilities in the same area (Falchetta et al. 2020).

Allocation of the number of beds

After estimating the catchment population for each facility, we can then correlate this to a facility's number of beds. In this allocation, we first used the catchment population per health facility level, defining intervals within the catchment population according to the health facility archetype and its corresponding number of beds (Table 4).

Table 4 | **Facility archetype, number of beds, and catchment population**

HEALTH FACILITY LEVEL	ARCHETYPE	NUMER OF BEDS	MOH-DEFINED HEALTH CENTER LEVEL CATCHMENT POPULATION[a]	ARCHETYPE CATCHMENT POPULATION: POLYNOMIAL INTERPOLATION (ALL LEVELS)[c]
Health center II	1	2	5,000 (parish)	≤ 4,903
	2	3[b]		≤ 5,000
Health center III	3	8	20,000 (subcounty)	≤ 6,327
	4	12		≤ 8,398
	5	14[b]		≤ 9,770
	6	16		≤ 11,367
	7	20		≤ 15,235
	8	24		≤ 20,000
Health center IV	9	25	100,000 (county)	≤ 21,332
	10	29[b]		≤ 27,219
	11	36		≤ 39,683
	12	44		≤ 57,296
	13	52		≤ 78,499
	14	59		≤ 100,000

Notes: a. Based on the Ugandan Ministry of Health (MoH) classification.

b. Indicates the standard facility size per health center level.

c. Interpolation based on the MoH classification.

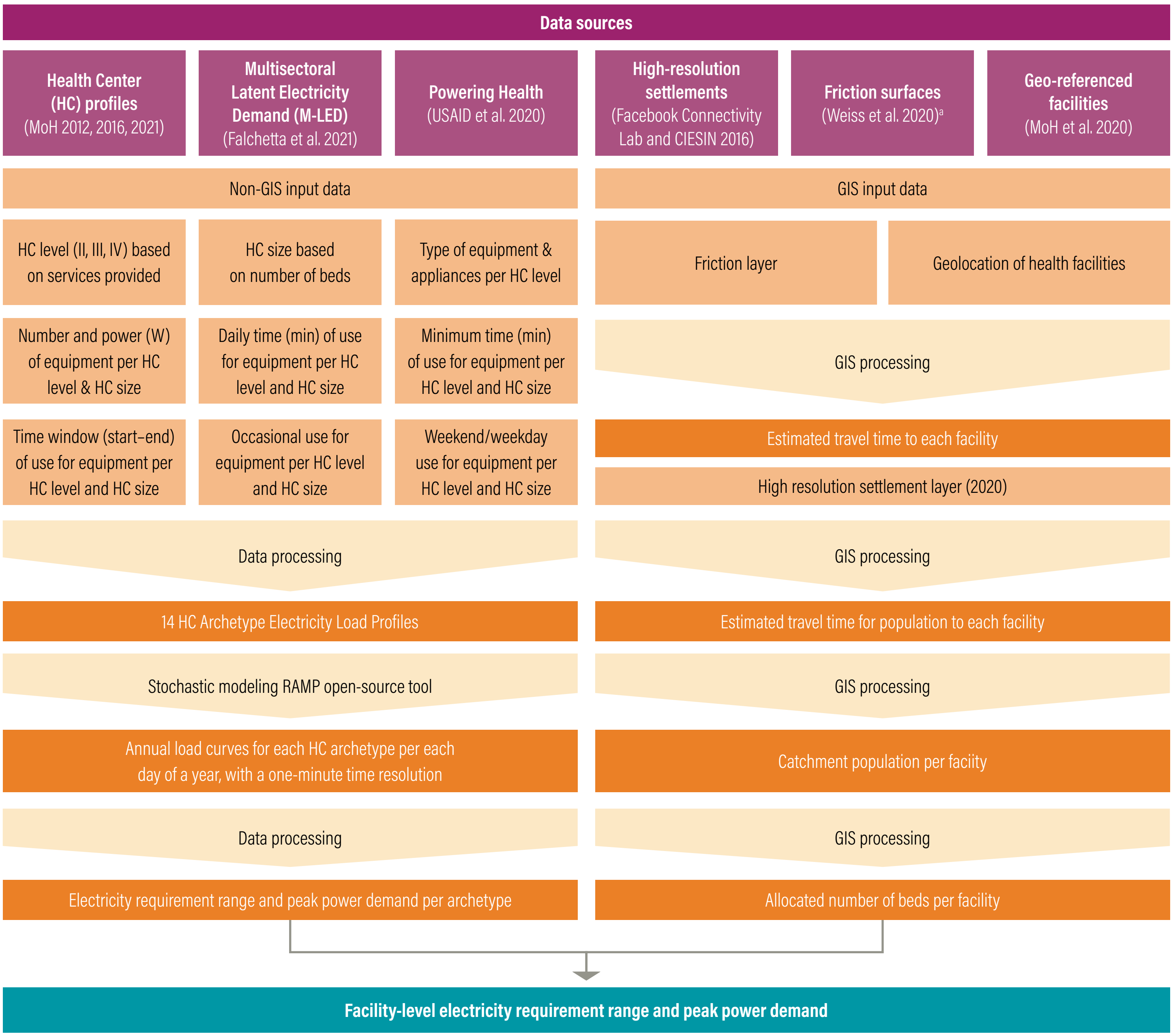
Sources: Based on the Ugandan Ministry of Health classification and MoH (2012a, 2012b, 2012c, 2016).

Facility-level electricity requirement range

Finally, each health facility is assigned to one of the specific archetypes. This allocation is based on each health facility's characteristics (i.e., health services level, estimated catchment population, and number of beds). Once all facilities have a corresponding archetype, we can allocate the results from the estimated electricity requirement for the peak hour, day, and year (see "Electricity and power requirements are estimated based on the outputs from the load curve models"). The allocated electricity requirement per facility is the prospective demand for each archetype to provide the required quality health services according to the health center level and its catchment population.

Facilities allocated to a specific archetype are assumed to have its specific load profile (i.e., number of equipment, appliances, and use patterns). The results are not intended to be an estimate of current electricity use. These estimated outputs will be integrated into a static health facility database as well as EAE. Through EAE, the data sets can then be overlaid with information on current and potential supply and made available for a dynamic multicriteria prioritization analysis and the development of customized reports.

Figure 1 | **Methodology to estimate electricity requirement ranges for health care facilities**



Note: a. Author's output. The methodology/algorithm used to develop the GIS least-cost-path layer per facility is described in Weiss et al. (2020).

4. DATA PROCESSING

This section presents the data processes that led to the resulting ranges of electricity requirements at the facility level. These are described within the two main stages of the proposed methodology: estimation of the electricity requirement range per facility type and estimation of the catchment population per facility. The subproducts from the data processing presented below include load profile and annual load curve per health archetype as well as the catchment population and number of beds per facility. These subproducts are also integrated as additional attributes to the health care facility database.

4.1 Estimation of electricity requirement range

Health facility archetype load profiles

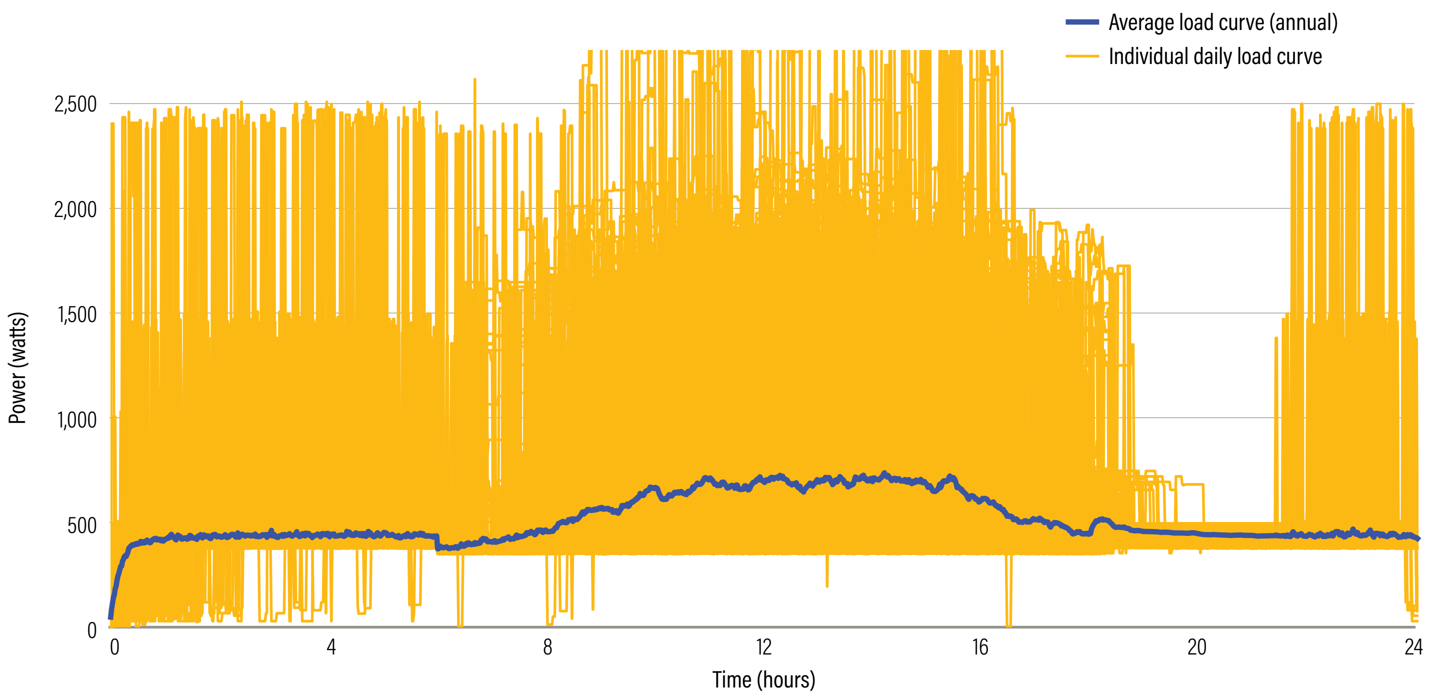
Fourteen health facility archetype load profiles were developed for the present research assessment. The load profiles aim to represent the spectrum of different services and health facility sizes provided by Ugandan health centers. The load profiles are the main input for the stochastic modeling of each load curve. Inputs to build the load profiles were based on the information provided by the MoH on health services, standard drawings and required equipment, ranges of catchment population, and number of beds by level of facility. Appendix B details the resulting load profiles for three archetypes representing standard facilities from health center levels II, III, and IV. The load profiles include data, parameters, and assumptions from the MoH based on a local standard-sized facility according to each level. Modeled health facilities with a smaller or greater number of beds, compared to the standard case, are treated according to experience in M-LED methodology and the expert-based approach found in Falchetta et al. (2021). The load profiles include the following input data:

- Required equipment according to services[12]
- Number of pieces of equipment according to the size category of the facility[13]
- Nominal power of equipment[14]
- Equipment daily use patterns[15]
    - Daily time of use (minutes)
    - Variability in daily time of use (percentage)
    - Minimum daily time of use (minutes)
    - Daily windows of use (start and end time)
    - Variability in daily windows of use
    - Occasional use

Annual archetype load curves

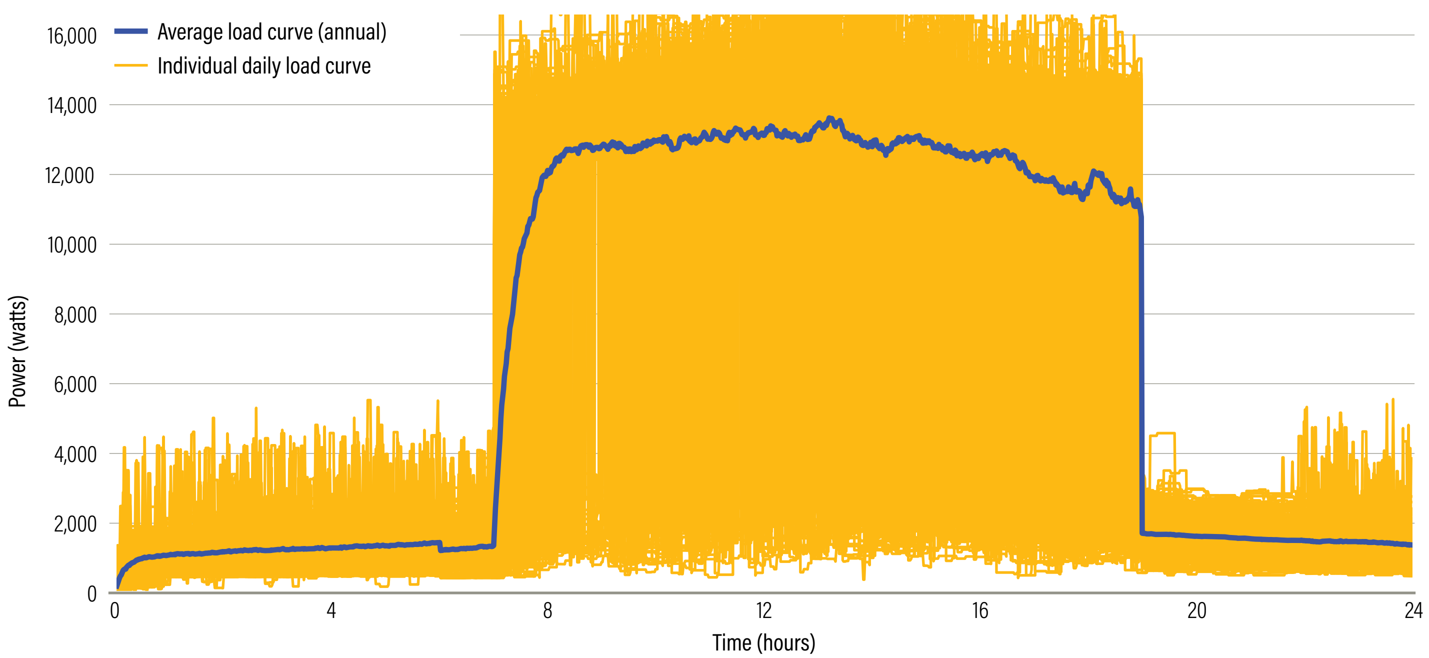
Annual archetype load curves were developed for each day of a year, with a one-minute time resolution. The load curves represent 168 customized permutations (14 archetypes multiplied by 12 months each). The results of each model include daily graphical representations for a complete year. Figures 2–4 show the resulting average load curves for three archetypes representing standard facilities from health center levels II, III, and IV, where the solid blue line represents the average of all the simulated days, and the yellow cloud represents all the single days. The load curves vary per health center, reflecting the availability and number of pieces of equipment and their nominal power; the variation also provides insights into the daily use patterns related to the typical operating hours, inpatient services, critical loads for maternity, accidents, emergency services, and so forth. (For more details on Ugandan health center services, please refer to Table 1 and Appendix A).

Figure 2 | **Average load curve: Standard health center II**



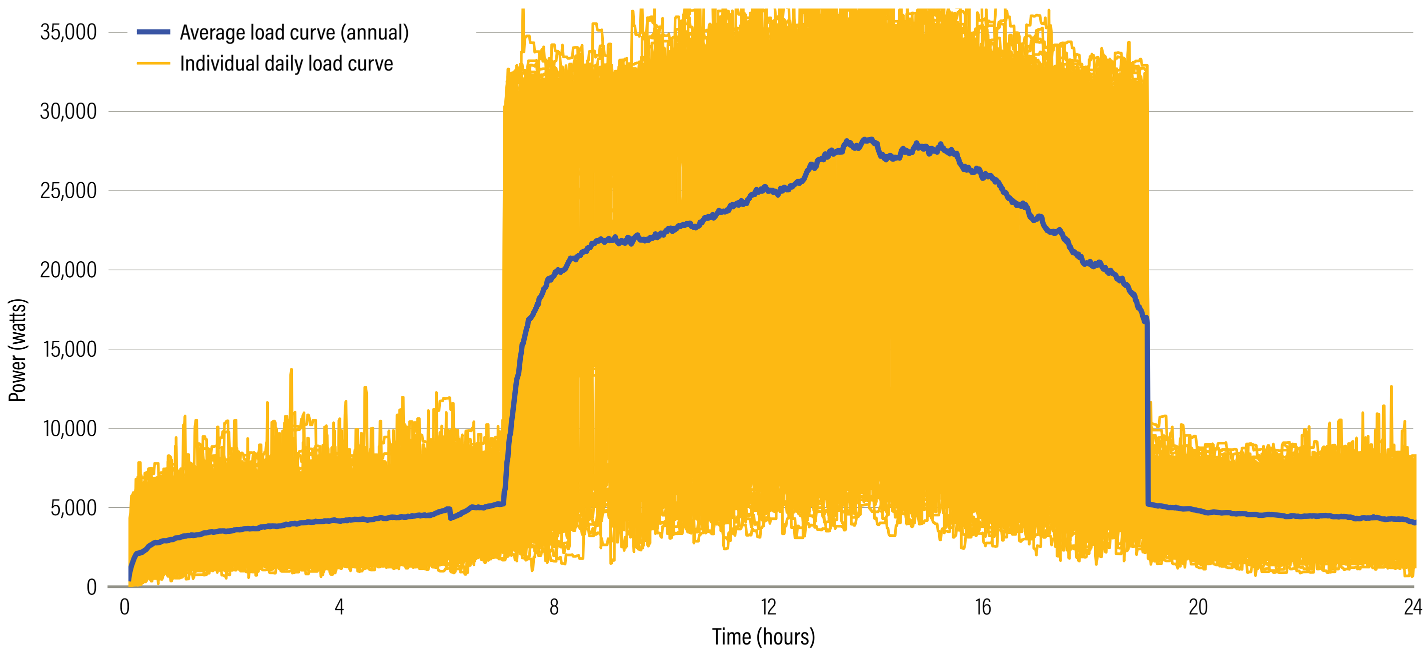
Source: Authors' outputs. RAMP tool used to develop the load curve is described in Lombardi et al. (2019).

Figure 3 | **Average load curve: Standard health center III**



Source: Authors' outputs. RAMP tool used to develop the load curve is described in Lombardi et al. (2019).

Figure 4 | **Average load curve: Standard health center IV**



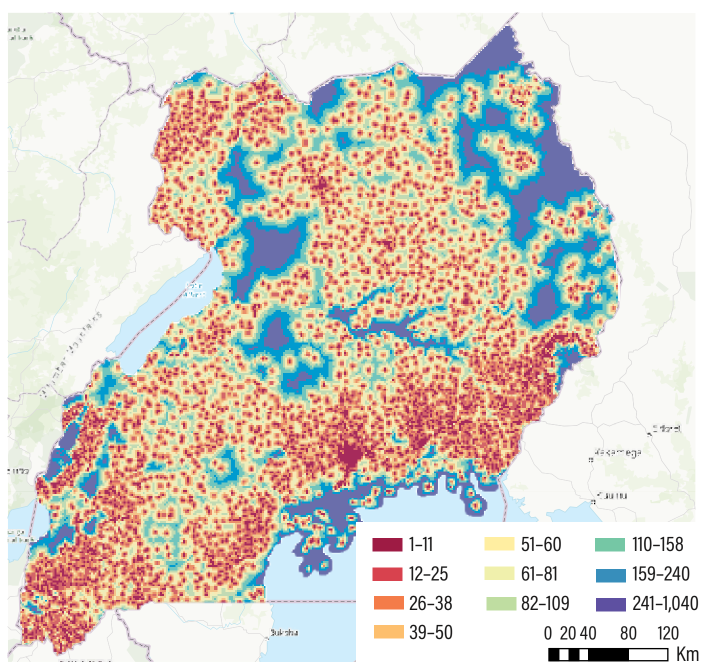
Source: Authors' outputs. RAMP tool used to develop the load curve is described in Lombardi et al. (2019).

4.2 Estimation of the catchment population per facility

Travel time to health facilities in Uganda

First, the estimated time required to travel to Ugandan health facilities from different points in the country is mapped. Travel time is per each 1 km^2 resolution without a motorized vehicle, estimated through a GIS least-cost-path algorithm (Weiss et al. 2020). Figure 5 shows the estimated walking travel time to health facilities.

Figure 5 | **Estimated walking travel time to health facilities (minutes)**



Source: Authors' outputs. The methodology/algorithm used to develop the GIS leastcost-path layer per facility is described in Weiss et al. (2020).

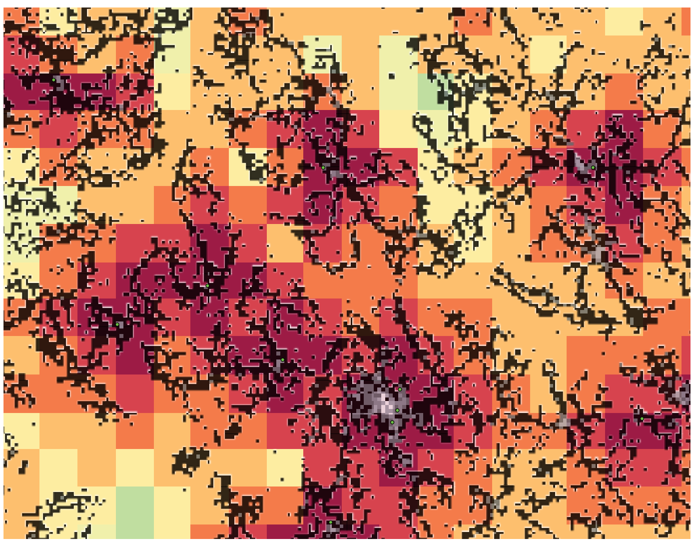
Travel time to health facilities from populated areas only

Next, the travel time to reach a specific health facility from a population settlement (i.e., city, town, neighborhood, etc.) is calculated. Figure 6 shows a zoomed-in view of the estimated travel time to health facilities from population settlements. The warmer colors (red/orange) represent areas with short travel times. Also included in the figure are "health facilities" (green points) and "population settlement" input data, which show areas with higher and lower populations. These data sets give us a better understanding of the "estimated travel time to facilities from populated areas" output.

Catchment population

Figure 7 shows the estimated catchment population per facility. For visual purposes, the map is categorized and color-coded into five main groups. However, each facility has a unique catchment population value. The unique catchment population value estimated for each health center is then used to identify the health facility archetype within its level and defined catchment population interval.

Figure 6 | **Estimated catchment population per facility**



Health facilities

Population

2–17 | 17–34 | 34–51 | 51–67 | 67–102

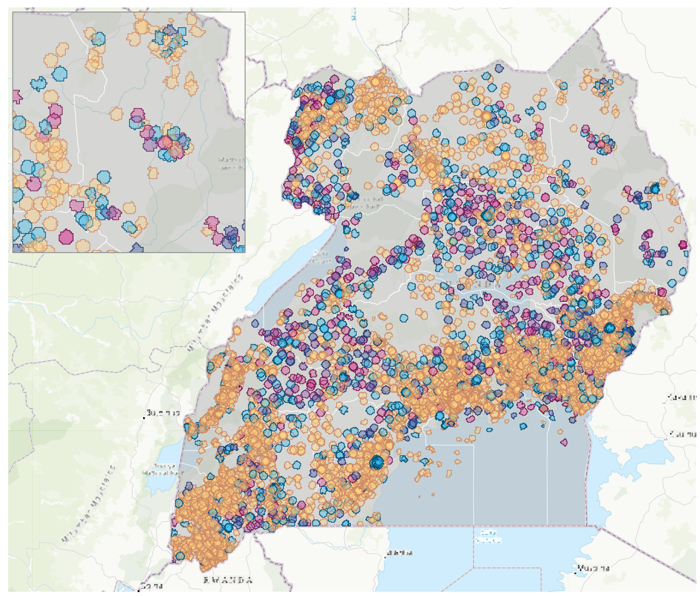
Travel time (minutes)

1–11 | 12–25 | 26–38 | 39–50 | 51–60 | 61–81 | 82–109 | 110–158 | 159–240 | 241–1,040

0 0.45 0.9 1.8 2.7 Km

Source: Authors' outputs. The methodology/algorithm used to develop the GIS leastcost-path layer per facility is described in Weiss et al. (2020).

Figure 7 | **Estimated catchment population per facility**

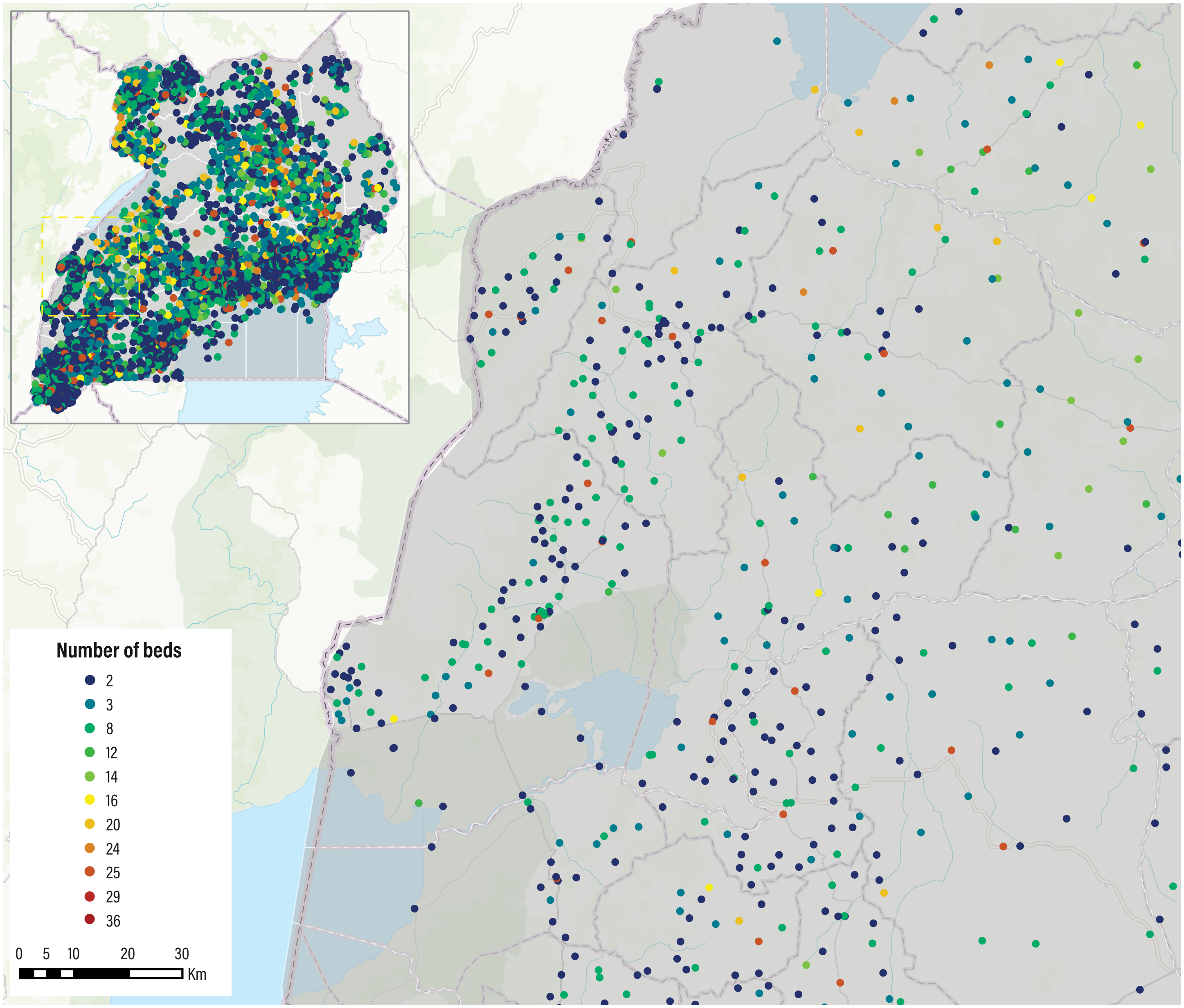


< 5,000 | < 8,400 | < 11,400 | < 20,000 | < 27,200 | < 57,300

0 20 40 80 120 Km

Source: Authors' outputs. The methodology/algorithm used to develop the catchment population is described in Falchetta et al. (2021).

Figure 8 | **Allocated number of beds per facility**



Source: Authors' outputs.

We correlated the estimated catchment population of each facility with the defined catchment population interval per archetype. With this input, we were able to allocate the number of beds per facility according to the corresponding archetype (refer to Table 4).

5. RESULTS

This section presents the results of the geospatial assessment, which include the findings from the present research, indicating ranges of annual and daily electricity demand (kWh) as well as power requirements (kW) for different types of health facilities. These results are integrated as additional attributes to the health care facility database.

5.1 Facility-level electricity requirement range

From the modeled load curves for each archetype (refer to "Electricity and power requirements are estimated based on the outputs from the load curve models"), we can estimate three types of results: the estimated power requirement range (kW),[16] the estimated electricity requirement range per day (kWh_{day}), and the annual estimated electricity requirement (kWh_{year}). Table 5 shows the three different results per archetype (row) and as yearly statistics and daily statistics (columns).

According to its archetype, each health facility is allocated the different results from the estimated requirements. These estimated outputs are then integrated into a static health facility database and mapped per facility and as an aggregate per administrative boundary, as shown in the figures below. The georeferenced facility-level data will also be integrated into EAE. The mapped facilities would then include new attributes concerning ranges of estimated electricity demand and power requirements that would provide further health facility electrification information for integrated, data-driven planning. Through EAE, the health facility data sets can then be overlaid with current and potential supply, demographic, environmental, and financial data and made available for a dynamic, multicriteria prioritization analysis and the development of customized reports.

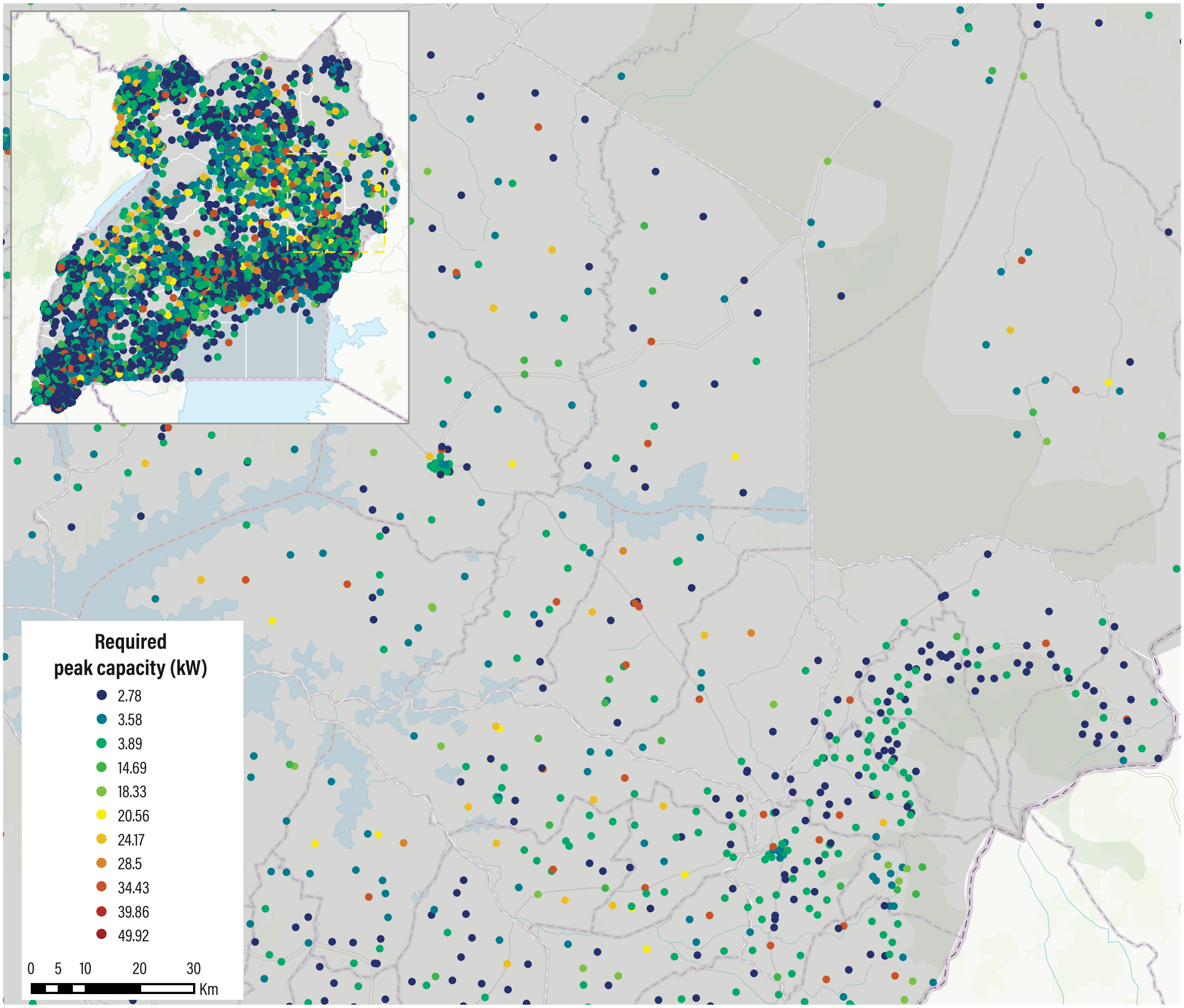
Table 5 | **Electricity and power requirements per archetype**

CATEGORY	ARCHETYPE	YEARLY STATISTICS				DAILY STATISTICS		
		PEAK POWER (kW)	AVERAGE POWER (kW)	ANNUAL CONSUMPTION (kWh)	LOAD FACTOR	HIGHEST CONSUMING DAY (kWh/DAY	AVERAGE CONSUMING DAY (kWh/DAY)	LOWEST CONSUMING DAY (kWh/DAY)
HC II	1	2.78	0.35	3,037	0.12	10.41	8.32	6.25
	2	3.58	0.51	4,459	0.14	14.65	12.21	9.15
HC III	3	3.89	1.11	9,736	0.29	30.51	26.67	22.21
	4	14.69	5.58	48,904	0.38	153.94	133.97	112.35
	5	18.33	6.75	59,093	0.37	187.68	161.90	134.13
	6	20.56	7.78	68,122	0.38	214.61	186.64	150.19
	7	24.17	9.55	83,694	0.40	255.57	229.29	197.06
	8	28.5	10.9	95,488	0.38	305.71	261.67	209.29
HC IV	9	34.43	12.32	107,944	0.36	365.57	295.70	213.41
	10	39.86	13.51	118,346	0.34	406.44	324.23	223.47
	11	49.92	17.15	150,199	0.34	531.57	411.41	274.95
	12	59.39	21.45	187,868	0.36	642.81	514.69	360.30
	13	75.74	22.51	197,213	0.30	764.46	540.36	375.82
	14	81.93	27.36	239,681	0.33	809.78	656.54	418.45

Notes: HC = health center; kW = kilowatt; KWh = kilowatt-hour.

Source: Authors' results.

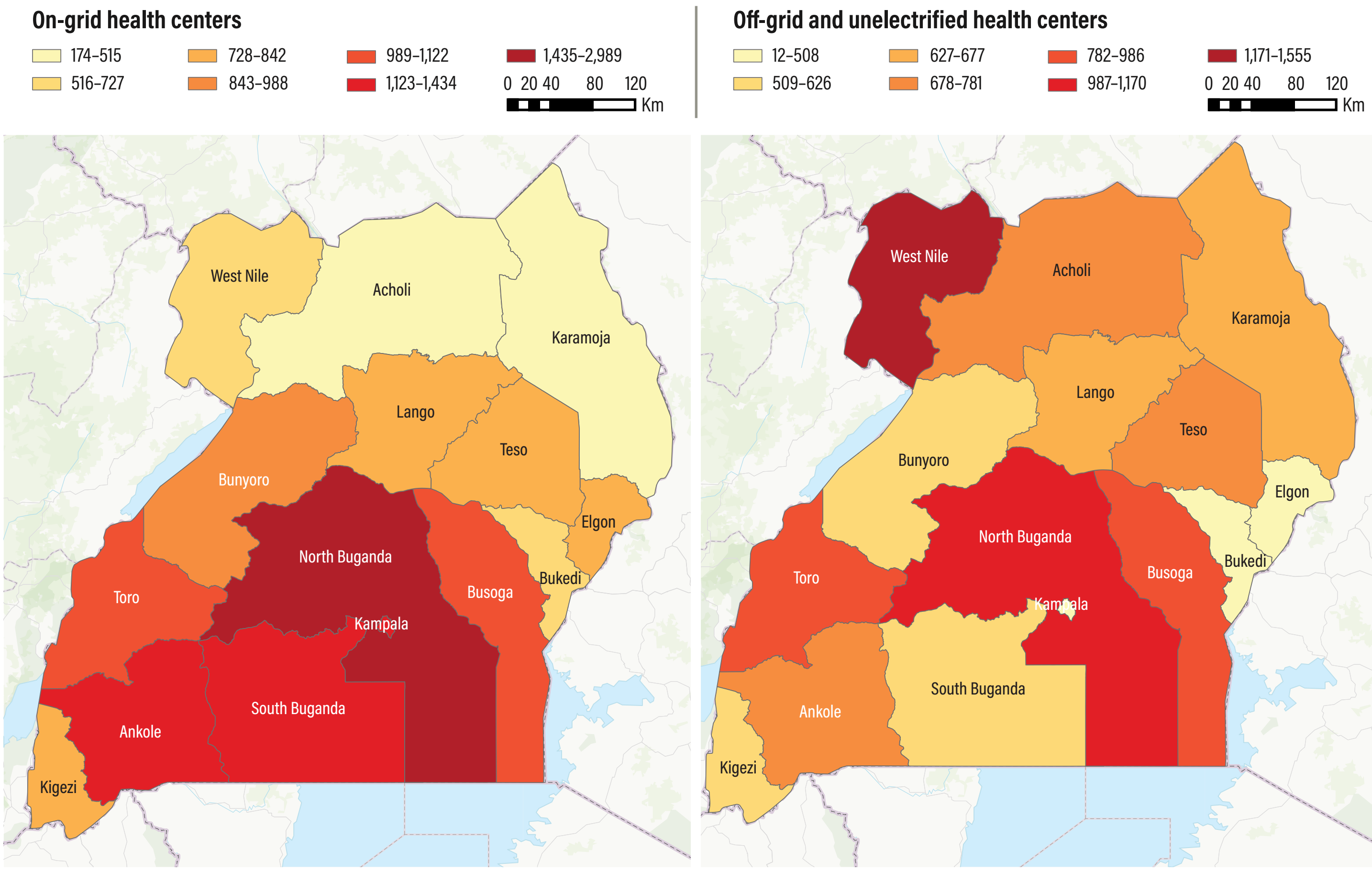
Figure 9 | **Peak capacity (kW) at the facility level**



Source: Authors' results.

Figure 9 shows the peak capacity per health center. It provides information regarding the energy supply system's size and design according to the required power capacity demanded (kW) for each facility. The data in the map shows the magnitude of energy supply solutions needed per health center. When aggregated, the above results can also show the magnitude of energy supply solutions at the national or subnational level (i.e., subregional level; refer to Figure 10). Additionally, having power requirement (kW) granular-level data inputs (i.e., health centers) that can also be aggregated as needed will allow national or regional governments to estimate the related cost ranges (e.g., capital costs, operations and maintenance costs) when designing and implementing plans and policies to electrify health centers.

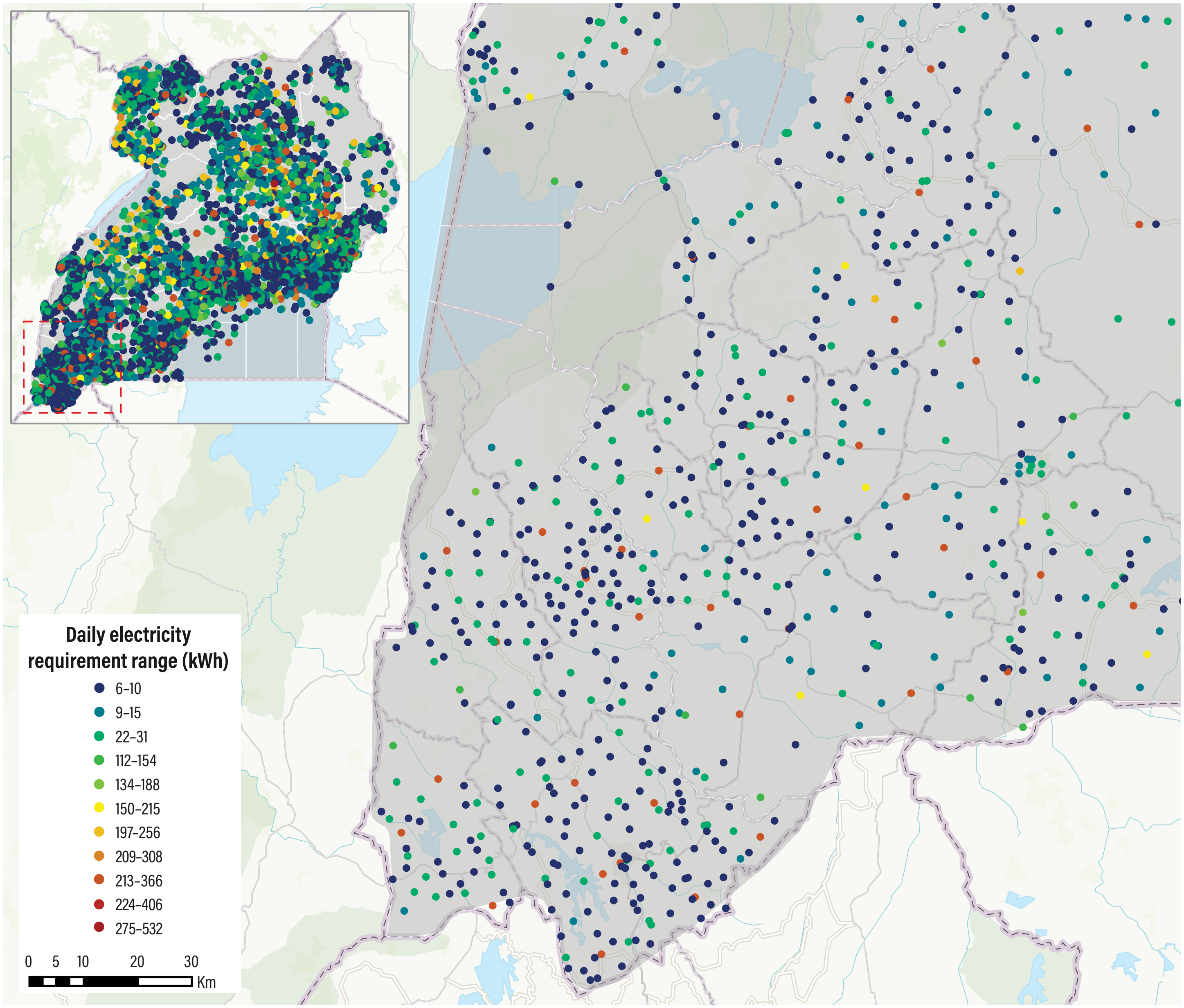
Figure 10 | **Peak capacity (kW) for health centers aggregated at the subregional level**



Source: Authors' results.

Furthermore, data regarding the electrification status and energy source would help identify the gap between unelectrified, underelectrified, and unreliably electrified facilities. Likewise, understanding the estimated power requirements and facility locations would allow decision-makers to better estimate the type and scope of implementation plans and policies as well as to prioritize certain areas accordingly. Moving forward, the estimated power requirements, combined with additional data regarding under-served health centers,[17] would allow decision-makers to plan for and design properly sized, reliable electricity supply solutions for quality health services.

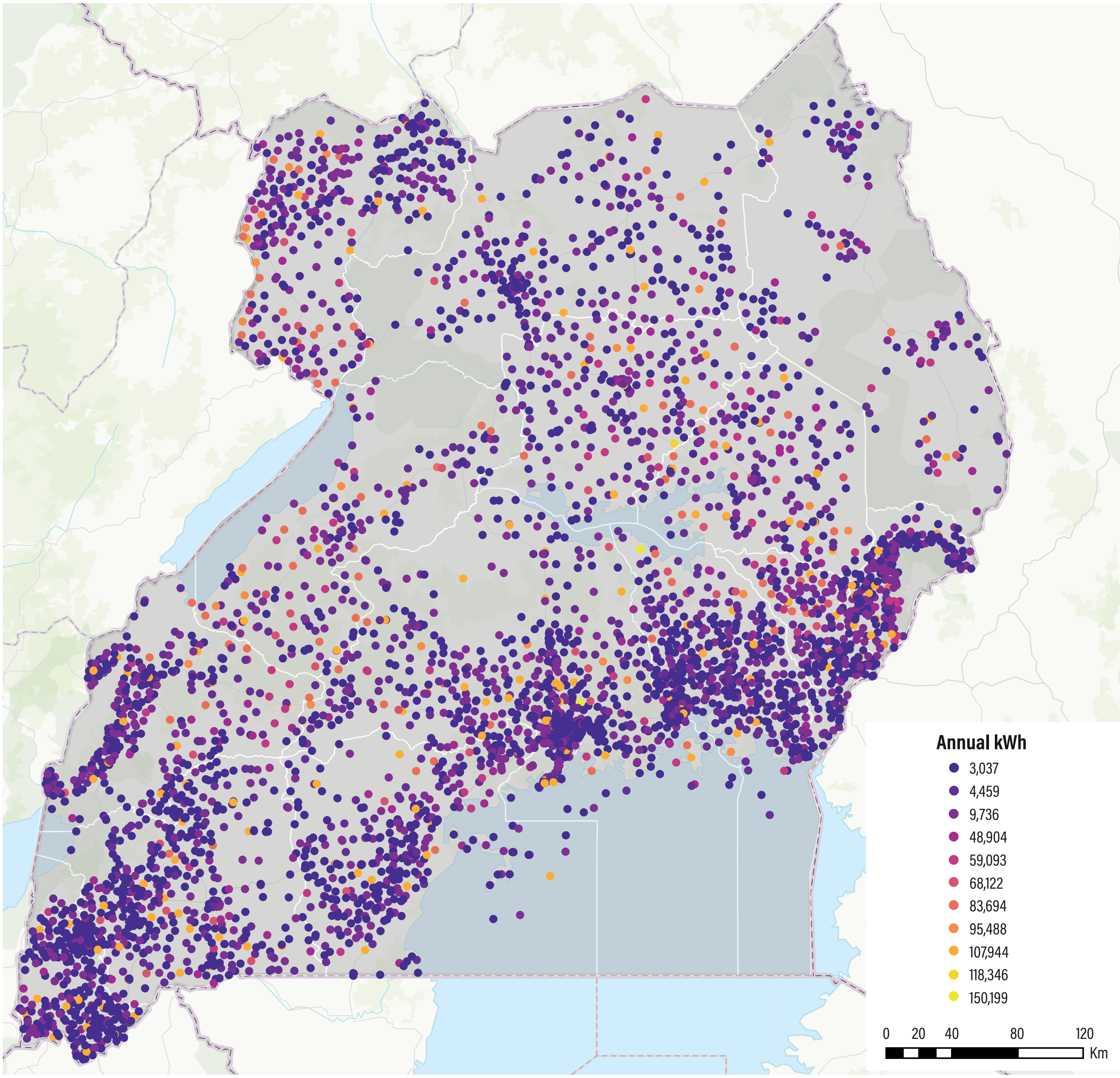
Figure 11 | **Daily electricity requirement range at the facility level (kWh)**



Source: Authors' results.

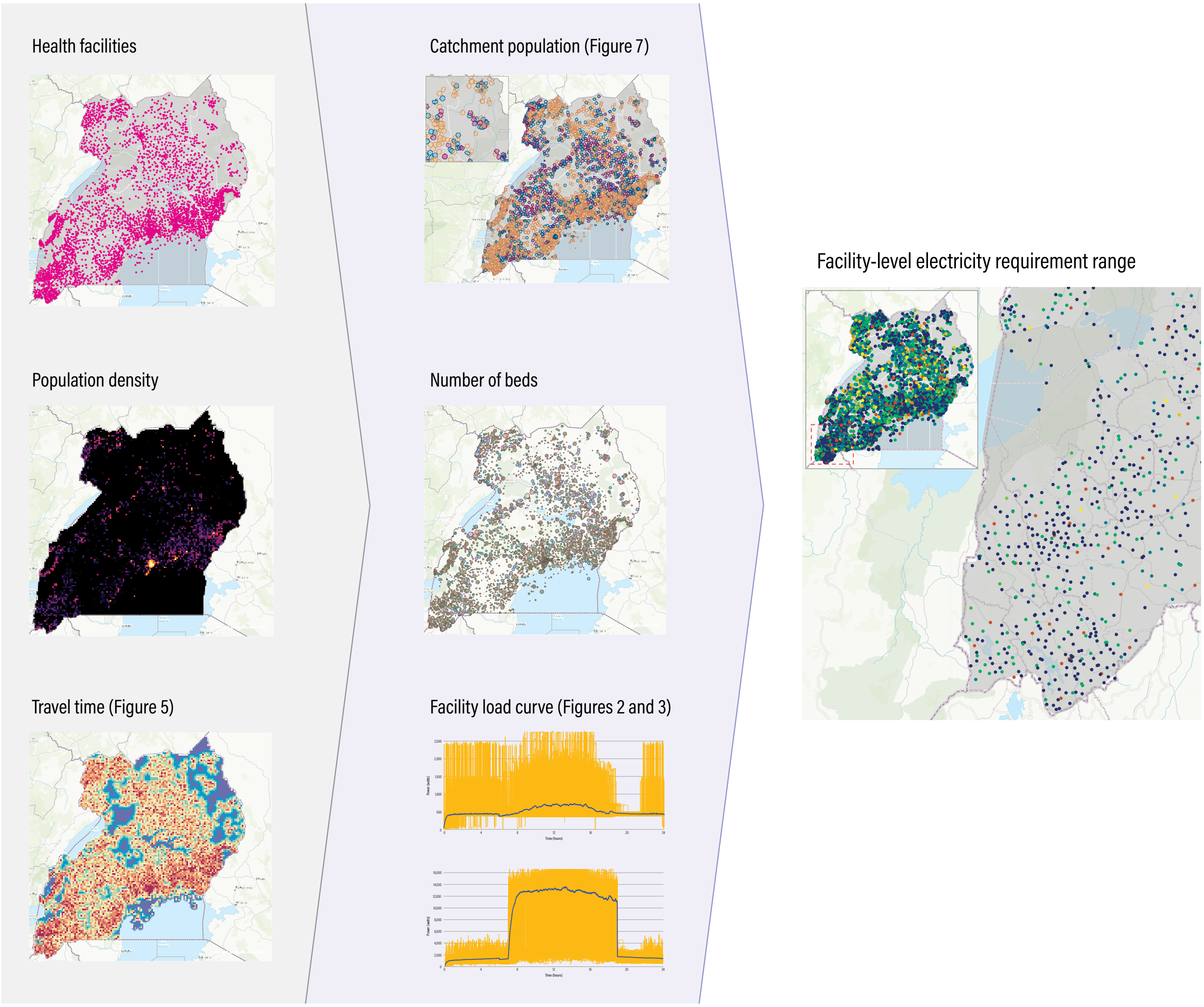
The results for the estimated daily and annual electricity requirement range (kWh) in Figures 11 and 12 provide information on the magnitude of potential electricity consumption according to the patterns of use for different health center sizes and levels. At the facility level, these results would be helpful inputs when analyzing least-cost electrification solutions, either through national grid (e.g., grid extensions or densification) or decentralized renewable energy sources (e.g., minigrids, stand-alone systems). Finally, the estimated daily and annual electricity requirement range (kWh) is especially helpful when planning for sustainable operations and maintenance models for health center electricity systems and their related costs.

Figure 12 | **Annual electricity requirement at the facility level (kWh)**



Source: Authors' results.

Figure 13 | **Summary of data processing and results**



Note: The six figures on the left are the inputs used for the obtained result shown in the right map as the facility-level electricity requirement range.

Source: Authors' results.

6. WAYS FORWARD

Although this technical note introduces a novel methodology for GIS-based assessments of electricity requirements for health care facilities, the following aspects should be considered in future studies to ameliorate its applicability and the insights gained.

- **Integration of other health facility levels.** As previously mentioned, this methodology includes health facilities that represent a spectrum of services corresponding to those from Ugandan health centers. Health centers have a wide presence across Uganda, making it extremely important to target solutions to these centers when developing electrification plans. As such, the location of other private clinics and larger hospitals, according to Ugandan facility classification, were considered when estimating the catchment population. However, estimating the electricity requirements for these other private clinics and larger hospitals went beyond the scope of this study and should be considered in future studies. This methodology can be expanded to different health facility levels and services within Uganda as more data become available and profiles can be built for these.
- **Sensitivity analysis to build more representative demand assessment model estimates for each facility.** For example:
  - More information is needed about seasonal energy demands. This would allow sensitivity analysis of the demand profile variations, assisting in the final energy requirement estimation for the facility archetypes.
  - More data is required to identify areas that have a higher disease rate. This would capture locations and facilities with a higher number of visits, medical specialization, and/or use of different appliances and medical equipment. This, in turn, will also result in facilities with higher or lower daily load profiles and different use hours and equipment/appliances numbers.
  - Developing an additional analysis using a targeted catchment population estimation based on a facility's specific health services provided may be beneficial. The current catchment population estimate uses all health facilities in Uganda based on the general access to health service main parameter. This approach was considered because, in practice, people can be served at any facility today and are not required to visit their referral facility. However, an alternative catchment population could be estimated by separately analyzing population for each health center level, providing more focused catchment population estimates.
  - In this methodology, the aggregated catchment population area of all facilities captures the majority of the population. However, it is likely that a percentage is still outside the radiuses of analysis. Further processing of the outputs of this technical note can help identify any population that is not currently captured so it can be integrated and addressed.
- **Scalability.** The methodology introduced through this technical note could also be applied by health ministries in other countries. Minimum requirements would include data on geolocated facilities as well as defined facility profiles according to the services they provide, such as the defined catchment population and number of beds per facility level as well as the required type and number of appliances and medical equipment per facility level. Other important inputs—ideally, but not exclusively, from local sources—include the following:
  - Power (in watts) for different types of equipment/appliances per facility level
  - Daily time of use of equipment/appliances (minutes) per facility level
  - Minimum time of use for equipment/appliances (minutes) per facility level
  - Time window (start/end) of use for equipment/appliances (minutes) per facility level
  - Occasional use of equipment/appliances (minutes) per facility level
  - Weekend/weekday use of equipment/appliances (minutes) per facility level

  Furthermore, the findings and outputs from this publication, as well as the visualizations and analyses of the data through EAE or GIS software of preference, would provide inputs to support local, regional, or global planning and research for health ministries and service development organizations.

- **Sustainability.** This publication offers an alternative approach to existing methodologies by combining facility-level load data with geospatial analysis to assess electricity requirement ranges in health facilities. The methodology, parameters, and assumptions utilized will help health/energy professionals replicate the methodology and update the facility electricity demand estimate data for years to come. It also provides an opportunity to incorporate new data attributes as they become available for further analysis (e.g., medical equipment, system reliability, etc.) to build upon this publication. The output data of the assessment, the estimated electricity requirement range per facility, and its metadata will be integrated into EAE, where it can be visualized, overlayed, and used in multicriteria analyses to design data-driven health electrification programs. The methodology is shared both on the EAE platform as well as through EAE's GitHub.

7. CONCLUSIONS

Data at the health facility level are often scarce, scattered, outdated, or nonexistent—especially data concerning facility-level electrification status (including unelectrified, underelectrified, and unreliably electrified) and electricity requirements. Furthermore, many recommended health services delivery packages and related "checklists" fail to assess power availability or include "electricity" as a necessity for facility and/or service readiness. Without accurate, up-to-date facility-level data, including adequate and reliable electrification, it is difficult to identify opportunities and prioritize and implement projects. This makes it a cumbersome task to formulate data-driven policies, programs, and plans addressing these issues.

As reviewed in this technical note, geospatial data and technology aim to narrow this data gap and estimate electricity requirement ranges for unserved and under-served facilities. This can be done by combining the best-available facility-level information with satellite imagery and geospatial data on demographics to build more representative demand estimates for each facility.

The results of the case study in this publication show the benefits of a GIS-based approach. Among the main benefits is that it allows for extrapolation of bottom-up sample data from current health-facility-level energy audits, questionnaires, and surveys, and scales it to estimate electricity requirement ranges for unserved and under-served health facilities of similar characteristics. Furthermore, the resulting estimated electricity requirements can then be inputs for least-cost electrification modeling tools to estimate technology and investment outlooks on optimal supply configurations (grid extension or intensification, minigrids, and off-grid solutions).

The estimation of health facility energy demand somewhat relies on initial energy audits and questionnaires. This makes it difficult to scale if information is outdated and not combined with geospatial data and analysis. Therefore, moving forward, more cross-sectoral coordination between health, energy, and planning stakeholders is required (i.e., the MoH and Ministry of Energy; subnational governments; and the power utility). These stakeholders can be beneficial in improving the collection of granular information on energy access from both a supply and demand perspective; they also provide valuable insights on energy requirements at the facility level. Additionally, beyond cross-sectoral coordination, governments must intentionally invest in building robust data in health and other sectors. It is clear from the preceding analysis that with more data, the tools are available for synthesizing that information into forms that support sound investment and policy decisions. Investing in building a robust data and analytic foundation is one of the foundational pillars for effective development interventions. However, in many instances, development partners prefer to invest in hard assets (i.e., solar panels), forgetting the critical role of soft assets (i.e., data) in creating an enabling environment for success in the long term. Furthermore, a better understanding of the situation on the ground will improve the assumptions and parameters used while planning for the provision or expansion of energy services in the health facilities. It is essential to work alongside health and energy stakeholders to consolidate representative and updated information on the various health facilities and their provided services and electrification status, including available equipment, reliability, and power sources.

The global health sector currently uses several facility-level data resources, such as health facility digital management platforms (e.g., DHIS2) and digital surveys (e.g., mTrac), which are updated periodically and can simultaneously be used to collect and integrate information regarding electricity to further refine such GIS-based assessments. In resource-constrained settings, developing dynamic information systems can help expand both health and energy services. These systems are able to collect and track information on the health electrification nexus and combine it with data on power infrastructure, resource availability, and so forth.

Overall, geospatial data and software are becoming important tools for planning national-level electrification and performing site assessments at scale; several countries have already adopted geospatial analysis to build their national electrification plans. Combining the use of both GIS and non-GIS data, when available, would enable robust, dynamic, integrated, and data-driven planning that can be further validated, scaled, and monitored.

APPENDIX A. MINIMUM STANDARDS FOR UGANDAN HEALTH CENTERS

This appendix is a summary of the minimum standards for health centers in Uganda as described in Service Standards and Service Delivery Standards for the Health Sector (MoH 2016).

Health center II: Operates eight or more hours a day based on the needs of the community, providing a range of basic curative and preventive services.

Health center III: In addition to the services provided in health center II, it provides 24-hour maternity, accident, and emergency services as well as beds where patients can be observed for a maximum of 48 hours; it also has a laboratory.

Health center IV: This is mainly a primary health care referral facility where patients are assessed, diagnosed, stabilized, and either treated or referred to a lower or higher level of health facility. The health center IV outpatient department functions as the entry point to the health system when there are no lower-level health units (LLHUs) within 5 km. It is the first point of entry for referrals from the LLHUs and for self-referrals in case of an emergency. It brings inpatient and emergency services, including emergency obstetric care, closer to the population in rural areas. A crucial service provided by this health center is 24-hour comprehensive emergency obstetric care.

APPENDIX B. STANDARD HEALTH CENTER INPUT PARAMETERS

Table B1 | **Standard health center II**

STANDARD (3 BEDS)	NUMBER	POWER (WATTS)	DAILY TIME (MINUTES)	TIME (%)	MIN. TIME (MINUTES)	W1 START	W1 END	W2 START	W2 END	W3 START	W3 END	WINDOW (%)	OCCASIONAL USE	WE/WD
Indoor CFL bulb	5	18	300	0.2	120	8:00	17:00	—	—	—	—	0.2	no	wd
Indoor tubes, T5 1200 mm	11	28	300	0.2	120	8:00	17:00	—	—	—	—	0.2	no	wd
Indoor tubes, T5 600 mm	2	18	300	0.2	120	8:00	17:00	—	—	—	—	0.2	no	wd
Outdoor CFL IP44 bulb	4	26	720	0	720	18:00	0:00	0:00	6:00	—	—	0	no	none
Radio	1	7	120	0.2	30	12:00	15:00	—	—	—	—	0.35	no	wd
Heater	1	1,000 (+/- 0.3)	60	0.2	30	8:00	17:00	—	—	—	—	0.2	no	wd
Phones	6	7	300	0.2	60	8:00	17:00	—	—	—	—	0.2	no	wd
Autoclave sterilizer, electric, 20 L	1	1,254	30	0.2	15	8:00	17:00	—	—	—	—	0.2	no	wd
Examination light	1	10	180	0.2	90	8:00	17:00	22:00	7:00	—	—	0.2	no	wd
Refrigerator, vaccine	1	42	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	no	none

Table B1 | **Standard health center II, continued**

STANDARD (3 BEDS)	NUMBER	POWER (WATTS)	DAILY TIME (MINUTES)	TIME (%)	MIN. TIME (MINUTES)	W1 START	W1 END	W2 START	W2 END	W3 START	W3 END	WINDOW (%)	OCCASIONAL USE	WE/WD
Suction apparatus, electric	1	180	30	0.2	15	8:00	17:00	—	—	—	—	0.2	no	wd
Audio visual equipment	1	250	230	0.2	60	8:00	17:00	—	—	—	—	0.35	0.3	none
Electric kettle	2	1,000	6	0.2	1	22:00	7:00	—	—	—	—	0.35	no	wd
Oxygen concentrator	1	350	1,440	0	1,440	0:00	0:00	—	—	—	—	0	no	none

Source: Input data for the health facility profiles are based on the following sources: MoH 2012a, 2012b, 2012c, 2016, 2021; Falchetta et al. 2021; Pakravan and Johnson 2021; USAID 2011; USAID et al. 2020. CFL = compact fluorescent lamp; W = window; we/wd = weekend/weekday.

Table B2 | **Standard health center III**

STANDARD (14 BEDS)	NUMBER	POWER (WATTS)	DAILY TIME (MINUTES)	TIME (%)	MIN. TIME (MINUTES)	W1 START	W1 END	W2 START	W2 END	W3 START	W3 END	WINDOW (%)	OCCASIONAL USE	WE/WD
Indoor CFL bulb	14	18	540	0.2	300	5:00	22:00	—	—	—	—	0.35	no	none
Indoor tubes T5, 1200 mm	38	28	540	0.2	300	5:00	22:00	—	—	—	—	0.35	no	none
Indoor tubes T5, 600 mm	2	18	540	0.2	300	5:00	22:00	—	—	—	—	0.35	no	none
Outdoor CFL IP44 bulb	16	26	720	0	720	0:00	6:00	18:00	0:00	—	—	0	no	none
Radio	1	7	120	0.2	30	12:00	15:00	—	—	—	—	0.35	no	wd
Printer	1	40	20	0.2	1	8:00	17:00	—	—	—	—	0.2	no	wd
Router	1	6	1,440	0	1,440	0:00	0:00	—	—	—	—	0	no	none
Heater	1	1,000 (+/- 0.3)	60	0.2	30	8:00	17:00	—	—	—	—	0.2	no	wd
Phones	20	7	300	0.2	60	0:00	0:00	—	—	—	—	0	no	none
Autoclave, electric, 20 L	2	1,254	30	0.2	15	8:00	17:00	—	—	—	—	0.35	no	none

Table B2 | **Standard health center III, continued**

STANDARD (14 BEDS)	NUMBER	POWER (WATTS)	DAILY TIME (MINUTES)	TIME (%)	MIN. TIME (MINUTES)	W1 START	W1 END	W2 START	W2 END	W3 START	W3 END	WINDOW (%)	OCCASIONAL USE	WE/WD
Centrifuge, manual	1	15	60	0.2	30	8:00	17:00	—	—	—	—	0.35	no	none
Examination light	1	10	420	0.2	210	8:00	17:00	22:00	7:00	—	—	0.35	no	none
Refrigerator, general purpose	1	42	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	no	none
Refrigerator, vaccine	1	42	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	no	none
Suction apparatus, electric	1	180	30	0.2	15	8:00	17:00	—	—	—	—	0.35	0.5	none
Vacuum extractor	1	50	60	0.2	30	22:00	7:00	—	—	—	—	0.35	no	none
Infant incubator	2	300	1,440	0.2	1,440	0:00	0:00	—	—	—	—	0	0.75	none
Infant warmer	2	300	120	0.2	30	8:00	17:00	—	—	—	—	0.35	no	none
Audio visual equipment	1	250	230	0.2	60	8:00	17:00	—	—	—	—	0.35	0.3	none
Electric kettle	3	1,000	6	0.2	1	22:00	7:00	—	—	—	—	0.2	no	wd
Computer unit	1	45	540	0.6	420	8:00	17:00	—	—	—	—	0.2	no	wd
Heating, ventilating, and air-conditioning	1	12,000	1,440	0	1,440	0:00	0:00	—	—	—	—	0	no	none
Oxygen concentrator	2	350	1,440	0	1,440	0:00	0:00	—	—	—	—	0	no	none
Pulse oximeter	1	5	480	0.2	240	22:00	7:00	—	—	—	—	0.35	no	none

Notes: CFL = compact fluorescent lamp; W = window; we/wd = weekend/weekday.

Sources: Input data for the health facility profiles are based on the following sources: MoH 2012a, 2012b, 2012c, 2016, 2021; Falchetta et al. 2021; Pakravan and Johnson 2021; USAID 2011; USAID et al. 2020.

Table B3 | **Standard health center IV**

STANDARD (29 BEDS)	NUMBER	POWER (WATTS)	DAILY TIME (MINUTES)	TIME (%)	MIN. TIME (MINUTES)	W1 START	W1 END	W2 START	W2 END	W3 START	W3 END	WINDOW (%)	OCCASIONAL USE	WE/WD
Indoor CFL bulb	21	18	960	0.2	720	0:00	0:00	—	—	—	—	0	no	none
Indoor tubes, T5 1200 mm	154	28	960	0.2	720	0:00	0:00	—	—	—	—	0	no	none
Outdoor CFL IP44 bulb	41	26	720	0	720	0:00	6:00	18:00	0:00	—	—	0	no	none
Radio	6	7	300	0.2	180	7:00	18:00	—	—	—	—	0.35	no	none
Printer	2	40	60	0.2	1	8:00	17:00	—	—	—	—	0.35	no	none
Router	1	6	1,440	0	1,440	0:00	0:00	—	—	—	—	0	no	none
Photocopy	2	400	60	0.2	1	8:00	17:00	—	—	—	—	0.35	no	none
Electric heater	2	1,200 (+/- 0.3)	60	0.2	15	0:00	6:00	18:00	0:00	—	—	0	0.2	none
Pump	1	750	120	0.1	60	6:00	8:00	—	—	—	—	0.2	no	none
Phones	50	7	600	0.2	60	0:00	0:00	—	—	—	—	0	no	none
Heating, ventilating, and air-conditioning	2	12,000	720	0	540	7:00	19:00	—	—	—	—	0	no	none
Dispenser	2	200	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	no	none
Anesthesia unit	2	100	360	0.2	180	8:00	17:00	—	—	—	—	0.35	no	none
Autoclave, electric, 40 L	1	2,000	30	0.2	15	8:00	17:00	—	—	—	—	0.35	no	none
Autoclave, electric 20 L	4	1,254	30	0.2	15	8:00	17:00	—	—	—	—	0.35	no	none
Centrifuge, manual	1	100	60	0.2	30	8:00	17:00	—	—	—	—	0.35	no	none
Deep freezer, vaccine	1	127	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	no	none
Dental unit, complete	1	550	300	0.2	60	8:00	18:00	—	—	—	—	0.35	0.7	none
Examination light	2	10	420	0.2	210	8:00	17:00	22:00	7:00	—	—	0.35	no	none
Hot air oven (sterilizer)	1	500	30	0.2	15	8:00	17:00	—	—	—	—	0.35	no	none

Table B3 | **Standard health center IV, continued**

STANDARD (29 BEDS)	NUMBER	POWER (WATTS)	DAILY TIME (MINUTES)	TIME (%)	MIN. TIME (MINUTES)	W1 START	W1 END	W2 START	W2 END	W3 START	W3 END	WINDOW (%)	OCCASIONAL USE	WE/WD
Operating light, mobile	1	150	360	0.2	180	8:00	17:00	—	—	—	—	0.35	no	none
Operating table, electric	1	925	360	0.2	180	8:00	17:00	—	—	—	—	1.35	no	none
Oxygen concentrator	6	350	1,440	0	1,440	0:00	0:00	—	—	—	—	0	no	none
Pulse oximeter	2	5	480	0.2	240	22:00	7:00	—	—	—	—	0.35	no	none
Refrigerator, general purpose	1	42	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	no	none
Refrigerator, blood bank	1	42	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	no	none
Refrigerator, vaccine	1	30	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	Specific cycle	no	none
Suction apparatus, electric	8	180	30	0.2	15	8:00	17:00	—	—	—	—	0.35	no	none
Ultrasound scanner (B/W)	1	200	240	0.2	120	8:00	17:00	—	—	—	—	0.2	no	none
Vacuum extractor	1	50	60	0.2	30	22:00	7:00	—	—	—	—	0.35	no	none
GeneXpert machine (CD4)	1	100	480	0.2	240	8:00	17:00	—	—	—	—	0.35	no	none
Infant incubator	1	300	1,440	0	1,440	0:00	0:00	—	—	—	—	0	no	none
Infant warmer	5	300	120	0.2	60	8:00	17:00	—	—	—	—	0.35	no	none
Automatic biochemistry analyzer	1	75	60	0.2	30	8:00	17:00	—	—	—	—	0.35	no	none
Automatic hematology analyzer	1	60	360	0.2	180	8:00	17:00	—	—	—	—	0.35	no	none
VDRL shaker	1	10	240	0.2	120	8:00	17:00	—	—	—	—	0.35	no	none

Table B3 | **Standard health center IV, continued**

STANDARD (29 BEDS)	NUMBER	POWER (WATTS)	DAILY TIME (MINUTES)	TIME (%)	MIN. TIME (MINUTES)	W1 START	W1 END	W2 START	W2 END	W3 START	W3 END	WINDOW (%)	OCCASIONAL USE	WE/WD
Audio visual equipment	1	250	230	0.2	60	8:00	17:00	—	—	—	—	0.35	0.3	none
Flat iron	1	800	120	0.2	60	8:00	17:00	—	—	—	—	0.35	0.3	none
Electric kettle	5	1,000	6	0.2	1	22:00	7:00	—	—	—	—	0.2	no	none
Computer unit	8	45	540	0.6	420	8:00	17:00	—	—	—	—	0.35	no	none
Mortuary refrigerator	1	650	1,440	0	1,440	0:00	0:00	—	—	—	—	0	no	none
Patient monitor 4 parameter (temp, pulse oximetry, NIBP)	6	100	360	0.2	180	8:00	17:00	—	—	—	—	0.35	no	none
X-ray	1	600	360	0.2	120	8:00	17:00	—	—	—	—	0.35	0.3	none

Notes: B/W = black and white; CFL = compact fluorescent lamp; NIBP = noninvasive blood pressure; VDRL = venereal disease research laboratory; W = window; we/wd = weekend/weekday.

Sources: Input data for the health facility profiles are based on the following sources: MoH 2012a, 2012b, 2012c, 2016, 2021; Falchetta et al. 2021; Pakravan and Johnson 2021; USAID 2011; USAID et al. 2020.

APPENDIX C. RAMP MODELING TOOL

RAMP is a bottom-up tool based on a stochastic methodology to generate load profiles for the load demand of different energy drivers (Lombardi et al. 2019). Through a set of parameters (see Tables 1–3), the tool is able to define categories of users (i.e., health facilities) and characterize the appliance ownership and use patterns of the typical user. By randomly simulating the appliance use of every user and the relative electricity consumption, RAMP can estimate the one-minute time resolution load curve.

The inputs are provided to the model as a set of python scripts (.py), which can be downloaded from the GitHub repository, where it is possible to define the categories of users (e.g., health facilities, schools, low-income households, medium-income households, etc.) and the number of users per each category. Table C-1 describes the set of inputs for each user category.

The model follows a stochastic process to simulate load curves: for every simulated day, each user inside a user category is randomly turning on and off appliances, reaching the total daily functioning time of each appliance spread over the total available time in the defined window of use. Both the total time of use during the day and the window's duration can vary inside a range defined among the inputs. The same process is repeated for every appliance, independently for every user inside each user category. Special efforts are made to avoid overlapping the same appliance use inside a single user; distributing the probability of use among the existing appliances simulates the real behavior of a health facility, where it is unlikely that all appliances of the same kind are turned on at the same time. The sum of the minute-by-minute power drawn by all the appliances of the study area results in the daily load curve.

The advantage of RAMP's stochastic approach is that it overcomes the issues related to load estimation techniques that make use of load factors or simulate appliance use to be equal across all users. In fact, both methods are not fully able to characterize the real behavior of the system of users as a whole. Adopting a load factor decreases the estimated peak load, spreading the energy consumed by similar users that make use of the same appliances in slightly different moments and with different patterns. In turn, not adopting the load factor and simulating all the appliances turning on and off at same time among users overestimated the peak demand. RAMP singularly simulates turn-on and turn-off moments per every appliance per every user,

Table C1 | **Input parameters for RAMP users**

DIMENSION	DESCRIPTION	RANGE (UNIT)
Ownership	▪ Category of user that owns the appliance	User type
Number of appliances per user	▪ Number of that specific appliance owned by the user	Not applicable
Appliance power	Nominal power of the specific appliance; allows for a random variability in a defined range for thermal appliances	Watts
Number of daily functioning windows	Number of time "windows" in which the appliance is used during the day	1–3
Window start and end times	Hours of start and end of time windows in which the appliance can be used	00:00–23:59
Variability of window start and end times	Percentage of allowed random variation of the length of the usage windows	0–100%
Daily functioning time	Total amount of time that the appliance is used during one day	0–1,440 minutes
Random variability of daily functioning time	Percentage of allowed random variation of the total daily time of use	0–100%
Minimum time the appliance is kept on after switch-on event	Minimum amount of time the appliance stays on after it has been switched on	0–1,440 minutes
Percentage of occasional use	Probability that the appliance is used on a single day	0–100%
Weekend (we) or weekday (wd) use	Allows usage of the appliance to be constrained to only weekdays or weekends	we/wd/none

Source: Based on Lombardi et al. 2019.

stochastically changing them according to the inputs provided. This offers a much more realistic estimation of the load curve, with a slightly, and randomly, different result for every simulated day.

The load curve generated by RAMP represents the yearly electricity consumption that the simulated user type would consume if using appliances as inputted (Figures 2–4).

Model results consist of .csv files containing the power drawn from the entire study area for every minute of the day, accompanied by scatter plots such as the example in Figures 2–4, where the solid blue line represents the average of all the simulated days, and the yellow cloud represents all the single days.

RAMP was released as an open-source code and has a dedicated repository on the GitHub platform: https://github.com/RAMP-project/RAMP.

ENDNOTES

1. Health facilities with access to some form of electricity, with limited or no service outages in electricity supply; in other words, facilities that did not suffer from frequent outages (e.g., an outage lasting more than two hours at a time during the previous one or two weeks).
2. Health facilities that do not have any access to electricity.
3. Health facilities that have unreliable access (i.e., are prone to extensive outages) or only partial access to electricity (i.e., only for specific equipment).
4. Based on facility-level parameters and sample data (e.g., medical equipment availability and use).
5. According to Uganda MoH classification.
6. For more information about EAE, see https://www.energyaccessexplorer.org.
7. To learn more about the Clean Energy Access tool, see https://africa-knowledge-platform.ec.europa.eu/energy_tool; for the Decision Response Energy Assessment Management tool, visit The Power Partnership website, https://www.thepowerpartnership.org/.
8. M-LED is a geospatial data processing platform.
9. The increase in appliance numbers does not go beyond the recommended standard numbers for the next higher facility level.
10. RAMP is an open-source, bottom-up stochastic model for generating high-resolution multienergy load profiles. It applies in contexts where only rough information about a user's behavior is obtainable. The use of open-source tools allows the methodology to be replicated without incurring software licensing costs.
11. The term *catchment population target* is used by the MoH to categorize and design health centers by level (II, III, and IV) (refer to Table 1).
12. Based on the MoH's health facility classification.
13. Energy audits and surveys from the MoH's Energy for Rural Transformation Program and the United Nations Foundation's Powering Health Project.
14. Based on the MoH's health facility classification; energy audits and surveys from the MoH's Energy for Rural Transformation Program and the United Nations Foundation's Powering Health Project; Pakravan and Johnson (2021); and USAID et al. (2020).
15. Based on the MoH's health facility classification; energy audits and surveys from the MoH's Energy for Rural Transformation Program and the United Nations Foundation's Powering Health Project; Pakravan and Johnson (2021); USAID et al. (2020); and Falchetta et al. (2021).
16. This will provide more information to accurately size and design an energy supply solution according to the required power capacity demanded for the facility.
17. Health facilities that have unreliable access (are prone to extensive outages) or only partial access (i.e., only specific equipment) to electricity.

REFERENCES

Bondarenko, M., D. Kerr, A. Sorichetta, and A.J. Tatem. 2020. "Census/Projection-Disaggregated Gridded Population Datasets, Adjusted to Match the Corresponding UNPD 2020 Estimates, for 51 Countries across Sub-Saharan Africa Using Building Footprints." Southampton, UK: WorldPop, University of Southampton. https://doi.org/10.5258/SOTON/WP00683.

Facebook Connectivity Lab and CIESIN (Center for International Earth Science Information Network). 2016. "High Resolution Settlement Layer (HRSL)." https://www.ciesin.columbia.edu/data/hrsl/.

Falchetta, G., A.T. Hammad, and S. Shayegh. 2020. "Planning Universal Accessibility to Public Health Care in Sub-Saharan Africa." *Proceedings of the National Academy of Sciences of the United States of America* 117 (50): 31760–69. https://doi.org/10.1073/pnas.2009172117.

Falchetta, G., N. Stevanato, M. Moner-Girona, D. Mazzoni, E. Colombo, and M. Hafner. 2021. "The M-LED Platform: Advancing Electricity Demand Assessment for Communities Living in Energy Poverty." *Environmental Research Letters* 16 (7): 074038. https://doi.org/10.1088/1748-9326/ac0cab.

Korkovelos, A. 2020. *An Exploratory Geospatial Approach of Estimating Electricity Requirements for Health Facilities*. Jupyter Notebook, GitHub. https://github.com/akorkovelos/gep_health_facilities.

Lombardi, F., S. Balderrama, S. Quoilin, and E. Colombo. 2019. "Generating High-Resolution Multi-energy Load Profiles for Remote Areas with an Open-Source Stochastic Model." *Energy* 177 (June): 433–44. https://doi.org/10.1016/j.energy.2019.04.097.

Maina, J., P.O. Ouma, P.M. Macharia, V.A. Alegana, B. Mitto, I. Socé Fall, A.M. Noor, R.W. Snow, and E.A. Okiro. 2019. "A Spatial Database of Health Facilities Managed by the Public Health Sector in Sub-Saharan Africa." *Scientific Data* 6 (1): 134. https://doi.org/10.1038/s41597-019-0142-2.

Mentis, D., M. Howells, H. Rogner, A. Korkovelos, C. Arderne, E. Zepeda, S. Siyal, et al. 2017. "Lighting the World: The First Application of an Open Source, Spatial Electrification Tool (OnSSET) on Sub-Saharan Africa." *Environmental Research Letters* 12 (8): 085003. https://doi.org/10.1088/1748-9326/aa7b29.

MoH (Ministry of Health). 2012a. "Standard Drawings for Health Centre II." Kampala: MoH, Republic of Uganda.

MoH. 2012b. "Standard Drawings for Health Centre III." Kampala: MoH, Republic of Uganda.

MoH. 2012c. "Standard Drawings for Health Centre IV." Kampala: MoH, Republic of Uganda.

MoH. 2016. *Service Standards and Service Delivery Standards for the Health Sector*. Kampala: MoH, Republic of Uganda. http://library.health.go.ug/sites/default/files/resources/Health%20Sector%20Service%20Standards%20%26%20Service%20Delivery%20Standards_2016.pdf.

MoH. 2018. *Health Facility Inventory: Uganda 2018*. Kampala: MoH, Republic of Uganda. http://library.health.go.ug/health-infrastructure/health-facility-inventory/national-health-facility-master-facility-list-2018.

MoH. 2021. "Equipment List for Ugandan Health Centre II, III, IV." Kampala: MoH, Republic of Uganda.

MoH, United Nations High Commissioner for Refugees, and WRI. 2020. "Uganda Health Facility Dataset." Energy Access Explorer. https://www.energyaccessexplorer.org/tool/a/?id=5d137d39-e46d-4abc-bfc9-76254501fa09&output=eai&view=inputs&variant=raster&tab=controls&divtier=0&subdiv=0.

Moner-Girona, M., G. Kakoulaki, G. Falchetta, D.J. Weiss, and N. Taylor. 2021. "Achieving Universal Electrification of Rural Healthcare Facilities in Sub-Saharan Africa with Decentralized Renewable Energy Technologies." *Joule* 5 (10): 2687–714. https://doi.org/10.1016/j.joule.2021.09.010.

Pakravan, M.H., and A.C. Johnson. 2021. "Electrification Planning for Healthcare Facilities in Low-Income Countries, Application of a Portfolio-Level, Multi Criteria Decision-Making Approach." *ISPRS International Journal of Geo-Information* 10 (11): 750. https://doi.org/10.3390/ijgi10110750.

Sahlberg, A., B. Khavari, A. Korkovelos, and M. Howells. 2018. *Electrification Pathways for Benin: A Spatial Electrification Analysis Based on the Open Source Spatial Electrification Tool (OnSSET)*. Stockholm: Division of Energy System Analysis, KTH Royal Institute of Technology. http://www.onsset.org/uploads/1/8/5/0/18504136/electrification_pathways_for_benin.pdf.

The Power Partnership. 2020. *Decision Response Energy Assessment Management (DREAM)*. https://www.thepowerpartnership.org/.

USAID (U.S. Agency for International Development). 2011. *Powering Health: Electrification Options for Rural Health Centers*. Washington, DC: USAID. http://pdf.usaid.gov/pdf_docs/PNADJ557.pdf.

USAID, Energy Sector Management Assistance Program, HOMER Energy, and We Care Solar. 2020. *Powering Health*. HOMER Energy. https://poweringhealth.homerenergy.com/.

Weiss, D.J., A. Nelson, C.A. Vargas-Ruiz, K. Gligorić, S. Bavadekar, E. Gabrilovich, A. Bertozzi-Villa, et al. 2020. "Global Maps of Travel Time to Healthcare Facilities." *Nature Medicine* 26 (December): 1835–38. https://doi.org/10.1038/s41591-020-1059-1.

WHO (World Health Organization). 2023. "Database on Electrification of Health-Care Facilities." Global Health Observatory https://www.who.int/data/gho/data/themes/database-on-electrification-of-health-care-facilities.

WHO and World Bank. 2015. *Access to Modern Energy Services for Health Facilities in Resource-Constrained Settings: A Review of Status, Significance, Challenges and Measurement*. Geneva: WHO. https://apps.who.int/iris/handle/10665/156847.

ACKNOWLEDGMENTS

The authors thank the following peer reviewers for their insightful feedback on this technical note: Lanvin Concessao, Eric Mackres, Akansha Saklani, Jing Song, and Tinebeb Yohannes (World Resources Institute [WRI]); Alex Korkovelos (World Bank); Lily Odarno (Clean Air Task Force); Luc Severi (Sustainable Energy for All); Mark Shibuta (Uganda Electricity Distribution Company Limited); and Cyrus Sinai (University of North Carolina at Chapel Hill). We also thank Jennifer Layke, WRI's Energy Director, for overseeing this publication, and we acknowledge the support of WRI's Energy Program and Energy Access team. Special thanks to Logan Byers, Benson Ireri, Fabian Jendel, Christine Odeph, Renee Pineda, Douglas Ronoh, Rebekah Shirley, Jake Stockman, Emilia Suarez, Gregory Taff, Romain Warnault, and Davida Wood for their input during the development of this note.

This research was supported by the IKEA Foundation and Uganda Energy Sector GIS Working Group.

ABOUT THE AUTHORS

Santiago Sinclair-Lecaros is a Research Associate for EAE in WRI's Energy Program.
Contact: santiago.sinclair-lecaros@wri.org

Dimitrios Mentis is the Lead for EAE in WRI's Energy Program.
Contact: dimitrios.mentis@wri.org

Eng. Sitra Mulepo C.S. is a Senior Mechanical Engineer in the Health Infrastructure Department, Ugandan Ministry of Health.
Contact: sitraik@hotmail.com

Giacomo Falchetta is a Research Scholar at the Energy, Climate and Environment Program of IIASA, the International Institute for Applied Systems Analysis.
Contact: falchetta@iiasa.ac.at

Nicolò Stevanato is Postdoctoral Researcher at the UNESCO Chair in Energy for Sustainable Development, Department of Energy, Politecnico di Milano.
Contact: nicolo.stevanato@polimi.it

ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

ABOUT THE HEALTH INFRASTRUCTURE DEPARTMENT

The Ugandan MoH's Health Infrastructure Department (HID), under the Directorate of Strategy, Policy and Development, is responsible for health infrastructure policy formulation, design, development, and capacity-building for health infrastructure management in Uganda. HID comprises the Civil and Sanitary Engineering Division and Biomedical and Electro-Mechanical Engineering Division, and its staff provides engineering support to all local governments across the country.

ABOUT IIASA

The International Institute for Applied Systems Analysis (IIASA) is an international research institute that advances systems analysis and applies its research methods to identify policy solutions to reduce human footprints, enhance the resilience of natural and socioeconomic systems, and help achieve the Sustainable Development Goals.

ABOUT POLITECNICO DE MILANO

Politecnico di Milano is a public scientific-technological university that trains engineers, architects, and industrial designers. The university has always focused on the quality and innovation of its teaching and research, developing a fruitful relationship with business and the productive world by means of experimental research and technological transfer. Politecnico di Milano takes part in several research, site, and training projects, collaborating with the most qualified European universities. Politecnico's contribution is increasingly being extended to other countries—from North America to Southeast Asia to eastern Europe. Today, Politecnico di Milano offers several exchange and double-degree opportunities and a wide range of degree programs taught entirely in English.